Hacettepe University Graduate School of Social Sciences

Department of Economics

THREE ESSAYS ON CLEAN ENERGY

Ayşegül UÇKUN ÖZKAN

Ph.D. Dissertation

Ankara, 2023

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The jury finds that Ayşegül UÇKUN ÖZKAN has on the date of 13/11/2023 successfully passed the defense examination and approves her Ph. D. thesis titled "Three Essays on Clean Energy".

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ETİK BEYAN

Bu çalışmadaki bütün bilgi ve belgeleri akademik kurallar çerçevesinde elde ettiğimi, görsel, işitsel ve yazılı tüm bilgi ve sonuçları bilimsel ahlak kurallarına uygun olarak sunduğumu, kullandığım verilerde herhangi bir tahrifat yapmadığımı, yararlandığım kaynaklara bilimsel normlara uygun olarak atıfta bulunduğumu, tezimin kaynak gösterilen durumlar dışında özgün olduğunu, **Doç. Dr. Özge KANDEMİR KOCAASLAN** danışmanlığında tarafımdan üretildiğini ve Hacettepe Üniversitesi Sosyal Bilimler Enstitüsü Tez Yazım Yönergesine göre yazıldığını beyan ederim.

Ayşegül UÇKUN ÖZKAN

ACKNOWLEDGEMENTS

I would like to thank my Advisor, Assoc. Prof. Dr. Özge KANDEMİR KOCAASLAN, for her guidance, support, and encouragement over the years. It was a pleasure and privilege to become her PhD student, and benefit from her mentoring. Her reliable supervision, valuable comments and advice have helped me advance academically. I will always be grateful to my advisor.

I would like to express my gratitude to the members of my thesis committee, Prof. Dr. Başak DALGIÇ and Prof. Dr. Burcu FAZLIOĞLU, for devoting their time to monitor my progress and provide insightful feedback on my thesis. I am also grateful to Prof. Dr. Kıvılcım METİN ÖZCAN and Assoc. Prof. Dr. Zühal KURUL who honored me as a part of my thesis review committee, took the time to read this thesis and made valuable contributions.

Special thanks to Maria Eugenia SANIN from Paris Saclay University. I am grateful to her for carrying my thesis farther by providing diverse perspectives and making helpful suggestions.

I would like to thank my advisor in master's degree at Ankara University, Prof. Dr. Belgin AKÇAY, who not only taught me the working discipline but also became a role model for me over time.

I would like to thank Asst. Prof. Dr. Fatma Didem TUNÇEZ, Head of the Department of Energy Management at KTO Karatay University, and my colleagues Leyla BAŞTAN TÖKE and Emre GÜLER for their pleasant working environment and support. I am also grateful to my lovely friend Asst. Prof. Dr. Yasemin SAVAŞ for her close friendship, for providing me with a comfortable working atmosphere, and for bearing with me during the dissertation writing process.

I would like to express my endless love and thank you to my beautiful mother Nurten UÇKUN, my father Mustafa UÇKUN and my dear brother Rıfat UÇKUN for their unwavering support and encouragement throughout my life.

Finally, and most importantly, my lovely spouse Ahmet Ferhat ÖZKAN, who is always on my side with his love, patience, and understanding, and who is always my pathfinder and the closest soul, deserves my sincere gratitude. Also, my most precious is my son Deniz ÖZKAN. I live my life with the intention of guiding you. This thesis is dedicated to you.

ABSTRACT

UÇKUN ÖZKAN, Ayşegül. *Three Essays on Clean Energy*, Ph.D Dissertation, Ankara, 2023.

This thesis is made up of three essays that examine clean energy development from various perspectives. In the first essay, we investigate how fluctuations in oil prices affect the stock returns of clean energy and oil and gas companies by using a SVAR. Our results show that a negative oil supply shock affects the stock returns of clean energy companies in a positive way, while a positive oil-specific demand shock affects them in a negative way. The findings also reveal that an increase in oil prices owing to an oil-specific demand shock does not improve the stock returns of oil and gas companies. Consequently, the results indicate that oil and clean energy are not alternatives to each other on the global level.

The second essay pinpoints supply and demand shocks in the oil and gas markets and investigates their effects on clean energy stock returns in Europe using a SVAR. Our findings show that while a negative shock in global oil supply does not significantly affect clean energy stocks, a negative shock in the gas supply positively affects clean energy stocks. Moreover, both oil-specific and gas-specific demand shocks have a positive impact on the stock returns of European clean energy companies. The earlier findings imply that clean energy can substitute oil and gas in Europe.

The final essay focuses on the spillover between investor attention and green bond returns by utilizing the Diebold-Yilmaz connectedness approach. We find that there are positive but small spillovers between investor attention and green bond returns. Besides, connectedness between investor attention and green bond market performance is stronger in the short run than in the long run. Besides, there is a time-varying feedback effect between green bond returns and investor attention. Last but not least, compared to the pre-Covid-19 and war periods, investor attention has a greater impact on green bond returns during the Covid-19 period.

Keywords

Oil Price Shocks, Gas Price Shocks, Substitution Effect, Clean Energy Stock Returns, Oil and Gas Stock Returns, Green Bond Returns, Investor Attention

ÖZET

UÇKUN ÖZKAN, Ayşegül. *Temiz Enerji Üzerine Üç Makale*, Doktora Tezi, Ankara, 2023.

Bu tez, temiz enerji gelişimine çeşitli açılardan bakan üç bölümden oluşmaktadır. İlk bölümde, petrol fiyatlarındaki dalgalanmaların temiz enerji ile petrol ve gaz şirketlerinin hisse senedi getirilerini nasıl etkilediğini SVAR kullanarak araştırıyoruz. Sonuçlarımız, negatif bir petrol arz şokunun temiz enerji şirketlerinin hisse senedi getirilerini olumlu yönde, petrole özgü talep şokunun ise olumsuz yönde etkilediğini göstermektedir. Bulgular ayrıca, petrole özgü talep şoku nedeniyle petrol fiyatlarındaki artışın, petrol ve gaz şirketlerinin hisse senedi getirilerini iyileştirme eğiliminde olmadığını da ortaya koymaktadır. Bu doğrultuda sonuçlar, küresel düzeyde petrol ve temiz enerjinin birbirinin alternatifi olmadığını göstermektedir.

İkinci bölümde, petrol ve gaz piyasalarındaki arz ve talep şokları tespit edilmekte ve bu şokların Avrupa'daki temiz enerji hisse senedi getirileri üzerindeki etkileri SVAR kullanılarak araştırılmaktadır. Bulgularımız, küresel petrol arzındaki negatif bir şokun temiz enerji stoklarını önemli ölçüde etkilemediğini, gaz arzındaki negatif bir şokun ise temiz enerji stoklarını olumlu yönde etkilediğini göstermektedir. Ayrıca hem petrole hem de gaza özgü talep şokları, Avrupa'daki temiz enerji şirketlerinin hisse senedi getirilerini olumlu yönde etkilemektedir. Bu sonuçlar, temiz enerjinin Avrupa'da petrol ve gazın yerini alabileceğini göstermektedir.

Son bölüm ise Diebold-Yılmaz bağlantılılık yaklaşımını kullanarak yatırımcı dikkati ile yeşil tahvil getirileri arasındaki yayılma etkisine odaklanmakta ve yatırımcı dikkati ile yeşil tahvil getirileri arasında pozitif fakat küçük yayılmalar olduğu tespit edilmektedir. Ayrıca, yatırımcı dikkati ile yeşil tahvil getirisi arasındaki bağlantının, uzun vadeye göre kısa vadede daha güçlü olduğu ve yeşil tahvil getirileri ile yatırımcı dikkati arasında zamanla değişen bir geri besleme etkisinin olduğu sonucuna ulaşılmaktadır. Son olarak, Kovid-19 öncesi ve savaş dönemleriyle karşılaştırıldığında, yatırımcı dikkati Kovid-19 döneminde yeşil tahvil getirileri üzerinde daha büyük bir etkiye sahiptir.

Anahtar Sözcükler

Petrol Fiyat Şokları, Gaz Fiyat Şokları, İkame Etkisi, Temiz Enerji Hisse Senedi Getirileri, Petrol ve Gaz Hisse Senedi Getirileri, Yeşil Tahvil Getirileri, Yatırımcı Dikkati

TABLE OF CONTENTS

ABBREVIATIONS

ABS	Asset-Backed Securities
AIC	Akaike Information Criteria
Bcm	Billion Cubic Metres
BP	British Petroleum
BREXIT	The British Government’s Formal Start of the Process of Existing from the EU
BRIC	Brazil, Russia, India, China
CARs	Cumulative Abnormal Returns
CBI	Climate Bond Initiative
CBOE	Chicago Board Options Exchange
CLEAN	S&P Global ECO Index
CNNE	China’s New Energy Index
COP15	The 15th Conference of the Parties to the United Nations Framework Convention on Climate Change
CPI	Consumer Price Index
DJUSEN	Dow Jones US Oil and Gas Index
ECO	WilderHill Clean Energy Index
EPU	Economic Policy Uncertainty
ERIX	European Renewable Energy Index
ESG	Environmental, Social and Governance

ETFs	Exchange-Traded Funds
EU	European Union
FPE	Final Prediction Error
G7	Group of Seven
GAS	S&P GSCI Natural Gas Index
GBP	Green Bond Principles
GECON	Global Economic Conditions
GFEVD	Generalized Forecast Error Variance Decompositions
GMM	Generalized Method of Moments
GSVI	Google Search Volume Index
GW	Gigawatts
HCIP	Harmonized Index of Consumer Prices
IAVS	Increments of the Attention Volume for Each Stock
ICMA	International Capital Market Association
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPI	Industrial Production Index
JB	Jarque-Bera
LNG	Liqufied Natural Gas
MOVE	Merrill Lynch Option Volatility Estimates
MSCI	Morgan Stanley Capital International

NEX	WilderHill New Energy Global Innovation Index
NPSO	Net Pairwise Spillovers
NYMEX	New York Mercantile Exchange
OIL	S&P GSCI Crude Oil Index
OPEC	The Organization of the Petroleum Exporting Countries
OPEC+	OPEC with 10 Other Oil-Producing Countries
OVX	CBOE Crude Oil Volatility Index
RAC	Refiner’s Acquisition Cost of Crude Oil
SIC	Schwarz Information Criteria
SPGB	S&P Green Bond Index
SVAR	Structural Vector Autoregression
SVI	Search Volume Index
TTF	Title Transfer Facility
US	United States
VIX	CBOE Volatility
VXXLE	CBOE Energy Sector ETF Volatility
WHO	World Health Organization
WTI	West Texas Intermediate

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The transition to clean energy and initiatives to lessen dependency on fossil fuels are taking on more significance. We are in a new era where these fundamental energy sources (oil and gas) must be replaced with clean energy sources to live better in an industrialized world. In this context, this thesis is composed of three essays exploring the clean energy development in different perspectives. On the one hand, while oil and gas are the leading energy sources in global energy consumption, clean energy has a rapidly increasing market and plays an important role in combating climate change. This raises the question of whether oil, gas, and clean energy, particularly oil and clean energy, can be substituted for one another. On the other hand, due to worries about climate change and the fact that climate risk is becoming a financial risk, decarbonization is at the forefront of companies' recovery agendas. Investors have consequently sought out innovative products across several asset classes to tackle the challenges arising from climate change, leading us to the development of one of the green finance tools known as green bonds. Green bonds are only used for environmentally friendly investments, with about 32% of all green bond issuance going toward clean energy investments. That's because worries about climate change are prompting investors to search for environmentally friendly investments and bringing their attention to the financial efforts being made to combat the issue of climate change. The attention that investors are turning to renewable energy has an impact on sector advancements in that area. The present thesis is structured into three distinct chapters, each of which delves into a distinct facet pertaining to the advancement of clean energy.

First, the impact of oil price shocks on the stock returns of clean energy companies on the global level is examined. By doing this, it is being researched to see if clean energy can be replaced by oil on a global scale. The primary factor behind this phenomenon is that oil accounts for the majority of global energy use, while on the other hand, the proportion of clean energy is rising steadily. Global uncertainties, such as the Covid-19 pandemic, prompt investors in the oil market to shift their attention towards clean energy sources. The Russia-Ukraine war served as a major wake-up call for all investors. This raises the question of whether oil can be substitute for clean energy on the global level. There is no apparent consensus on the consequences of three structural oil price shocks on the stock returns of clean energy companies in the empirical literature. In addition, studies on the correlation between clean energy and oil price shocks have employed the Kilian index to calculate the aggregate demand shock. However, in the debate that arose in 2019 between Kilian (2019) and Hamilton (2019) on the measures of global real economic activity, Hamilton (2019, p. 301) stresses that the Kilian index has failed to explain the changes in global activity over the past decade and that global economic activity is more volatile than it seems. Furthermore, Baumeister and Guérin (2020, p. 3) discover that the GECON index is a more effective indicator than the Kilian index for measuring the timing and magnitude of fluctuations in the global business cycle. Consequently, the GECON index is seen better suitable for gauging global economic activity. In this aspect, this study's use of the GECON index differs from previous studies in the literature. The model is evaluated using several oil prices (RAC, Brent, WTI) and various clean energy indices (ECO, NEX), and it is determined that oil cannot be used as a substitute for clean energy on the global level. The absence of the oil-to-clean energy substitution effect can be attributed to a number of factors. First, the primary energy sources in the world's energy consumption are still fossil fuels, despite the fact that the share of renewable energy is rising. Second, oil and gas companies do not perceive a great deal of pressure to convert to renewable energy. Finally, the recent conflict between Russia and Ukraine has made it clear that delaying a nation's decision to phase out fossil fuels has a negative impact on clean energy stock returns.

Second, an investigation is conducted to determine if oil and clean energy, which cannot be replaced with each other on the global level, may be replaced with each other at the European level. At the European level, it is also being investigated whether gas and clean energy may be substituted for one another. The primary driving force behind this is that the European Commission sees gas as a complement to clean energy for European investors in July 2022. The fact that the Russia-Ukraine conflict has had a significant impact on Europe, a continent with a high reliance on foreign energy, raises the question of whether fossil fuel price shocks will push for more investment in clean energy gains importance as an alternative way for Europe to ensure security of supply while succeeding the energy transition to less polluting sources. Since gas has a local market structure, it is hard to define gas price shocks on the global level, and the previous studies on the natural gas market do not separately identify gas price shocks at the European level. It is also seen that oil price shocks are generally defined on the global level in the empirical literature. To the best of our knowledge, this is the first study of the relationship between oil price shocks and clean energy stock returns at the European level. In addition, we contribute to the literature by identifying the gas price shocks at the European level and then examine the effects of three different gas price shocks (gas supply shock, economic demand shock, and gas-specific demand shock) on clean energy stock returns. Consequently, based on the analysis, we find that even if the European Commission endorsed gas as a green course thinking to its complementarity with intermittent renewables, investors do not consider gas this way, and shocks in the market generate substitution towards clean energy. Additionally, it has been concluded that oil is a substitute for clean energy at the European level.

Anticipated escalation in oil prices is predicted to stimulate heightened investments in renewable energy and generate a substitution effect between oil and clean energy. Notwithstanding the global fall in oil prices due to the impact of Covid-19, clean energy companies experienced a rise in their stock returns while oil and gas companies saw a decline in their stock returns. As previously noted, the first part observed that elevated oil prices alone do not effectively expedite the shift towards clean energy sources on the global level. Evidence demonstrates that investors' responses can be altered in the presence of significant uncertainty, such as during the Covid-19 pandemic. It has been demonstrated that investor attitude fluctuates when there is substantial uncertainty during financial and economic crises. This study examines the impact of investor attention on the returns of green bonds, which are exclusively used for sustainable investments, in three distinct sub-periods: Pre-Covid-19, Covid-19, and the Russian invasion of Ukraine. The objective is to investigate whether investor attention fluctuates during periods of uncertainty. This study makes a valuable contribution to the existing body of research on green bonds by exploring the relationship between green bonds and investor attention. This is a significant area of investigation, as there is a limited amount of literature that examines the interplay between behavioral finance and clean energy finance. To our knowledge, there are only four studies that look at the relationship between investor attention and green bond market performance, but only two of them directly examine the connection between green bonds and investor attention: Pham and Huynh (2020) and Pham and Cepni (2022), while the other two, Piñeiro-Chousa et al. (2021) and Piñeiro-Chousa et al. (2022), directly examine the connection between green bonds and investor sentiment. The results demonstrate that the impact of investor attention on the returns of green bonds is most pronounced during the Covid-19 period. This effect diminishes during the war period. This highlights the importance of examining how green bonds behave under normal and extreme market conditions.

CHAPTER 1

THE EFFECTS OF OIL PRICE SHOCKS ON CLEAN ENERGY AND OIL AND GAS STOCK RETURNS: EVIDENCE FROM GLOBAL LEVEL

"It is oil that makes possible where we live, how we live, how we commute to work, how we travel—even where we conduct our courtships. It is the lifeblood of suburban communities. Oil (and natural gas) are the essential components in the fertilizer on which world agriculture depends; oil makes it possible to transport food to the totally non-self-sufficient megacities of the world. Oil also provides the plastics and chemicals that are the bricks and mortar of contemporary civilization, a civilization that would collapse if the world's oil wells suddenly went dry."

Yergin, D. (1991, p. 14). *The Prize: The Epic Quest for Oil, Money & Power*. Simon & Schuster.

1.1. INTRODUCTION

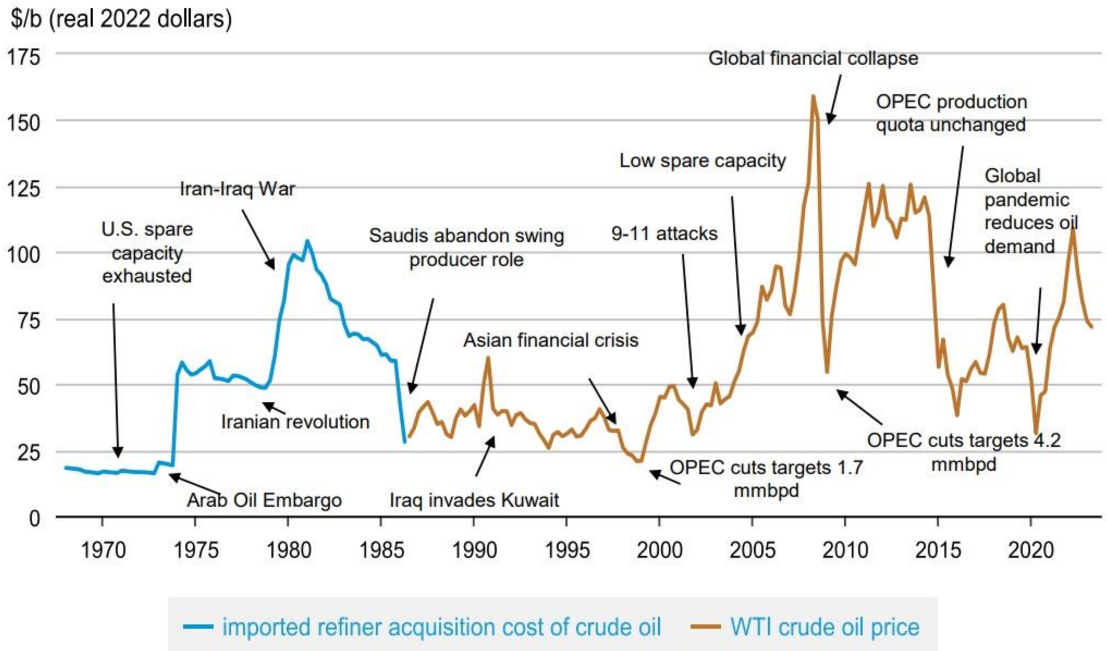
According to Yergin (1991, p. 12), oil is a symbol of human progress. Oil is unquestionably a necessary component of modern production. Furthermore, oil is seen not only as an input for production process but also as a financial asset and a barometer of global economic activity (Venditti and Veronese, 2020, p. 1). Fluctuations in oil prices have an impact on companies' investment decisions since they have a direct impact on production costs (Aziz and Bakar, 2013, p. 109). Crude oil prices have been impacted by a number of geopolitical, economic, and other developments, including war, OPEC[1] decisions, and the financial crisis. In order to understand oil price shocks, it is crucial to identify the factors that influence price fluctuations.

Oil prices are primarily driven by supply and demand. However, it would be inaccurate to claim that supply and demand are the only factors that influence it. The price of oil may also change in response to regional and geopolitical risks that increase the likelihood of terrorism, war, and oil supply shortages. In order to maintain crude oil prices at the desired level, OPEC member countries[2], which account for 35,3% of global oil production (BP, 2022, p. 15) and control around 70,1% of global oil reserves (BP, 2021, p. 16), set an upper limit, or output quota, for their members. When oil prices rise, OPEC members can drive down prices by boosting output, or in other words, by creating an oversupply (Yergin, 1991, p. 725). Fig. 1 displays how crude oil prices have changed over the past 50 years in response to various geopolitical, economic, and other events like wars, OPEC decisions, and financial crises. Events that impede the supply of oil or heighten uncertainty about future oil supplies also frequently cause prices to rise. With a ratio of 48,3%, the majority of the world's crude oil is found in Middle Eastern nations (BP, 2021, p. 16). This region has traditionally been prone to political upheavals or has been disrupted by political occurrences. Political occurrences such as the Yom Kippur War (1973–1974 Arab Oil Embargo), the Iranian Revolution in 1979, the Iran–Iraq War, and the Persian Gulf War in 1991 resulted in dramatic supply disruptions and thereby many significant oil price shocks at the same time. Weather may also have a significant impact on the supply of oil. Hurricanes in 2005, for instance, led to inadequate spare capacity. Refineries and oil and gas production were stopped as a result of hurricanes. Oil-related products' prices increased significantly as the market's supply decreased. Prices may also increase if other occurrences, such as pipeline issues or refinery outages, hinder the flow of oil and products. These factors do have a short-run effect on oil prices, though. Prices typically revert to their prior levels once everything is back to normal, that is, when the issue has been resolved (i.e., when the flow of oil and products returns to normal). During the global financial crisis of 2008, oil prices reached their all-time high of $167,39 per barrel. After the crisis, the world

[1] The Organization of Petroleum Exporting Countries.
[2] Algeria, Angola, Congo, Equatorial Guinea, Gabon, Iran, Iraq, Kuwait, Libya, Nigeria, Saudi Arabia, United Arab Emirates, Venezuela (OPEC, 2023).

economy entered a recession, and oil prices dropped to $57,77 in 2009. Oil prices, however, increased when the crisis ended, reaching $104,97 in 2010 and then $132,39 as of the second quarter of 2011. The 2011 Arab Spring also contributed to this rise in prices. The Middle East and North Africa's uncertain political climate contributed to the rise in oil prices. Oil prices started to fall after 2014 (EIA, 2023). There are primarily two reasons for this drop. First, an oversupply resulted from the US's entry into the market with its shale oil production as a new player. The second reason is the decline in demand brought on by China's economy, which is the world's greatest consumer of energy. As is clear from this, rising production of oil results in an excess of supply, which drives down prices. Conversely, falling demand also drives down prices.

Figure 1 The Global Developments Affecting Crude Oil Prices



Source: EIA (2023, p. 2).

Fossil fuels account for 83% of global energy consumption, making fossil fuels the primary energy source for modern economies (BP, 2021). Oil is one of the fossil fuels, which raises the worry that it contributes to greenhouse gas emissions. For instance, oil accounts for 46% of all US energy-related CO_2 emissions in 2021 (EIA, 2022). One of the most significant concerns facing the world today is combating climate change since carbon emissions are constantly rising. Rather than lowering energy demand, the best option to reduce CO_2 emissions is to switch to clean energy. An increasing number of countries are striving to attain net-zero emissions by 2050 was noted in the International Energy Agency (IEA)'s Net Zero Emissions by 2050 Scenarios (2021a, p. 3). Global emissions of greenhouse gases are rising as well, though. It is further noted that this gap between words and action must be closed. The transition to clean energy is heavily emphasized in this direction. Globally, the capacity of renewable energy increased by more than 260 gigawatts (GW) in 2020. Furthermore, renewable energy sources accounted for nearly 80% of the world's total new power generation capacity in 2020, showing that renewables are becoming the preferred source of new electricity generation in the world (IRENA, 2021, p. 3). As a result, the generation of renewable energy sources, including hydroelectricity, climbed by over 6% in 2020, boosting their share of the world's electricity generation mix to over 28%. Due to ongoing cost reductions in solar and wind technology as well as the aggressive and effective climate regulations adopted by the EU (European Union), US, China, India, Japan, Chile, and Australia, solar and wind energy production have been steadily increased (Enerdata, 2022). Furthermore, the IPCC (Intergovernmental Panel on Climate Change)'s scenarios (2018, p. 15) predict that by 2050, 70 to 85% of all electricity will come from renewable sources. On the other side, as of 2021, the proportion of renewable energy (including hydropower) in global primary energy consumption was 13,47% as opposed to the proportions of oil and gas consumption, which are roughly 31% and 24,5%, respectively (BP, 2022). Oil is the most widely used primary energy source in global energy consumption.

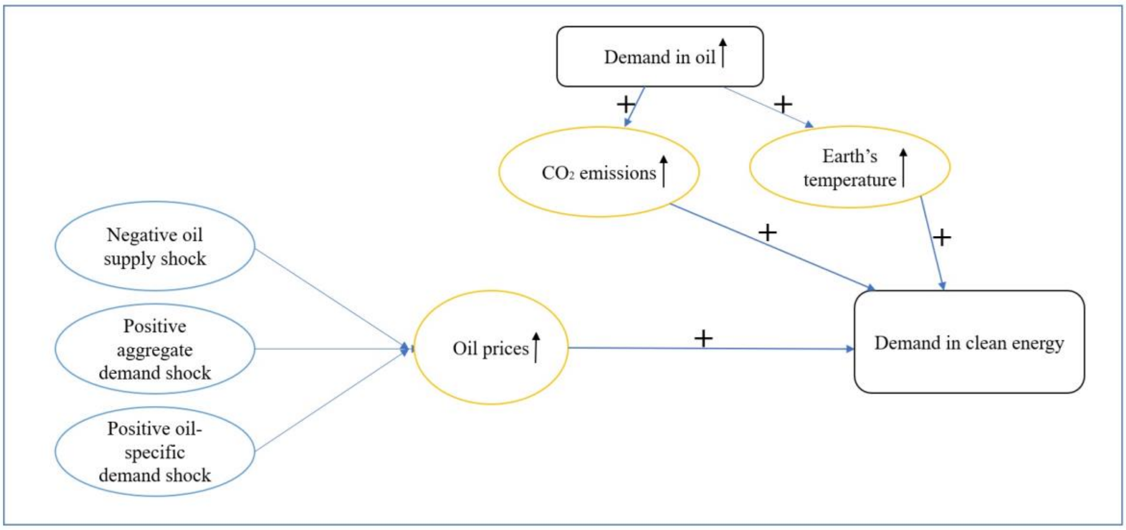
On the other hand, clean energy sources are now among the most competitive energy sources as a result of recent rapid technology advancements and falling costs. For the purpose of tracking and assessing the effectiveness of investments in the clean energy sector, projecting future returns, and determining the profitability of clean energy investments, it is essential to examine the stock returns of clean energy companies. Because stock returns are a measure of the earnings provided to shareholders by the company. Consequently, the higher the stock returns of clean energy companies, the better the financial performance of the company. This study aims to clarify two key questions in this regard. Do the clean energy stock returns respond to crude oil price shocks and are these responses depend on the driving force of the shock in the crude oil market? In this context, we first investigate how a shock to the oil supply affects the clean energy stock returns. Unpredictable changes in the global oil production are linked to shocks to the oil supply. Previous research generally finds that the consequences of oil supply shocks on financial markets are either negative or limited (see, for examples, Kilian and Park, 2009, p. 1286; Ready, 2018, p. 157; Mokni, 2020, p. 605; Demirer et al., 2020, p. 6; Zhu et al., 2021, p. 7; Kielmann et al., 2022, p. 1563). The negative impact is understandable given that a disruption in the oil supply would result in an escalation of oil prices, precipitate a decline in economic activity, and adversely affect stock returns. Because a rise in oil prices will put pressure on companies' production costs, lower households' discretionary income and spending, and boost the inflation expectations (Demirer et al., 2020, p. 6). Because of this, it is anticipated that the demand for renewable energies would rise as oil prices rise. Renewable energy sources were formerly uneconomical substitutes for fossil fuels since they were less efficient and more expensive. Yet, by offering government subsidies and incentives to both consumers and producers that choose renewable energy, renewable energy has transitioned from an uneconomical option to an economical one (Ross, 2022). As clean energy may replace oil economically, it's possible that in response to high oil prices, oil companies could move to clean energy, which will raise demand for clean energy. In this way, the market for clean energy may grow and clean energy companies' financial performance could improve.

Second, we explore how an aggregate demand shock affects the clean energy stock returns. The developments in global oil demand associated with global business cycles, such as the financial crisis, are captured by aggregate demand shock. According to the previous studies (Kilian and Park, 2009, p. 1274; Filis et al., 2011, p. 152; Ready, 2018, p. 17; Mokni, 2020, p. 605; Demirer et al., 2020, p. 6; Hasanov and Dagher, 2021, p. 18), an aggregate demand shock can have a favorable impact on financial markets due to its association with a rise in economic activity. The occurrence of a positive aggregate demand shock is expected to stimulate economic activity, leading to potential beneficial effects on the stock returns of clean energy companies. Because it is believed that a period of economic prosperity will make the switch to environmentally friendly energy easier. Economic prosperity is consequently one of the best times for the switch to renewable energy sources, and it is therefore expected that the rise in economic activity has a positive effect on the clean energy stock returns.

Last but not least, we reveal how an oil-specific demand shock affects the clean energy stock returns. Because of growing fears about future oil supply shortages, oil-specific demand shocks are connected with unpredictability in oil price fluctuations (Kilian and Park, 2009, p. 1270). Oil-specific demand shocks are intended to reflect the factors affecting oil prices after adjusting for oil supply and global demand shocks, that is due to the link between precautionary demand and future crude oil supply availability (Davig et al., 2015, p. 24). For instance, when there is growing uncertainty about future oil supply, there is a tendency for precautionary demand to surge, which causes an abrupt increase in oil prices (Alquist and Kilian, 2010, p. 539). Hence it is anticipated that oil-specific demand shocks will have a detrimental impact on the stock returns of clean energy companies. Currently, there is a notable increase in the demand for oil, with a particular emphasis on emerging market economies like China and India. This surge in demand has raised concerns regarding potential inadequacies in projected oil supply (Zhao, 2020, p. 8). Hence, it may be claimed that the current demand for oil may increase if a future decline in supply of oil is anticipated. This might also be a sign that oil producers are not transitioning to renewable energy sources. Hence, in the absence of a substitution effect resulting from this particular oil shock, it can be inferred that oil companies will have financial gains, while clean energy companies will witness a decline in their profits.

The recent advancements in technology and the declining costs of clean energy sources, along with the initiatives to lessen reliance on fossil fuels in the fight against global warming, suggest that there may be a substitution effect between clean energy and oil. Fig. 2 shows the diagram of the substitution effect between oil and clean energy. We anticipate that oil prices will rise in response to the negative shock to the oil supply and the positive shocks to the aggregate demand and oil-specific demand. Investors are anticipated to transition to clean energy as a result of escalating oil prices. Stated differently, unanticipated changes in oil prices lead to market uncertainty, which raises the need for an energy substitution between oil and clean energy (Zhao, 2020, p. 1). Moreover, in order to mitigate CO_2 emissions and prevent the rise in earth's temperature, brown (dirty) companies tend to switch to clean energy (Urom et al., 2022, p. 326). Thus, it is crucial to investigate whether shocks to the oil market and aggregate demand lead to substitution effects for clean energies.

Figure 2 Diagram of Substitution Effect between Oil and Clean Energy



Source: The diagram was developed by the author.

Previous empirical research has predominantly concentrated on examining the relationship between oil price shocks and macroeconomic aggregates (see, for example, Hamilton, 1983; Kilian and Vigfusson, 2011; Abiyev et al., 2015; Charfeddine and Barkat, 2020; Kocaarslan et al., 2020) and as well as the association between oil price shocks and stock markets (see, Park and Ratti, 2008; Cunado and Perez de Gracia, 2014; Hashmi et al., 2021; Jiang and Liu, 2021, amongst others). However, there is a limited body of research that examines the effects of different oil price shocks on the returns of clean energy stocks (Henriques and Sadorsky, 2008; Managi and Okimoto, 2013; Inchauspe et al., 2015; Pham, 2019; Zhang et al., 2020b; Zhou and Geng, 2021, amongst others).

This paper makes several contributions to the existing literature. First, we examine the effects of different oil price shocks on clean energy stock returns. It is well acknowledged that changes in oil prices play a key role in the advancement of clean energy. As oil has the ability to influence all markets in a variety of ways and maintains its leading position in global energy consumption, it is critical to determine whether changes in oil prices have an impact on clean energy, which has a rapidly growing market and plays a crucial role in combating climate change. Second, we utilize the Global Economic Conditions (GECON) indicator, which is newly established by Baumeister, Korobilis and Lee in 2020 to quantify the effects of global economic demand shocks on the financial performance of clean energy firms, in contrast to the previous studies[3]. In the debate that arose in 2019 between Kilian (2019) and Hamilton (2019) on the measures of global real economic activity, Hamilton (2019, p. 301) stresses that the Kilian index has failed to explain the changes in global activity over the past decade and that global economic activity is more volatile than it seems. Furthermore, Baumeister and Guérin (2020, p. 3) discover that the GECON index is a more successful indicator than the Kilian index for measuring the timing and magnitude of fluctuations in the global business cycle. Baumeister et al. (2020, pp. 16-19) further say that the GECON index is a more comprehensive index than previous indices since it is constructed by applying the expectation-maximization algorithm to sixteen indicators[4] and does not attempt to capture merely the cyclical component of global real economic activity. The GECON index can therefore monitor energy price volatility more reliably than other proxies of economic activity because it is associated with different indicators (Salisu et al., 2021, p. 144). In light of this, the GECON index is utilized in this study. The last contribution is that we compare the effects of oil price shocks on the stock returns of oil and gas and clean energy companies. It is clear that the transition to clean energy and efforts to reduce reliance on fossil fuels are becoming increasingly important. In order to live better in an industrialized world, we are now in a new era where these essential energy sources must be replaced with clean energy sources. To highlight the substitution effect, we evaluate how fluctuations in oil prices affect the stock returns of clean energy and oil and gas companies.

[3] Previous studies use Kilian index to measure the global economic activity.

[4] It is related to "commodity prices, economic activity, financial indicators, transportation, uncertainty and expectation measures, weather, and energy-related indicators" (Baumeister et al., 2020, pp. 16-19).

The following are the key findings. First, both models utilizing the ECO and NEX indices[5] demonstrate that a negative oil supply shock exerts a favorable impact on the returns of clean energy stocks. Second, in the model using the ECO index, increases in aggregate demand have an immediate positive impact on the returns of clean energy stocks. Third, in both models, the stock returns of clean energy are negatively affected by an oil-specific demand shock. This means that increased oil prices driven by oil-specific demand shocks do not induce investors to move to clean energy sources. Lastly, to clarify the substitution effect, when the effects of oil price shocks on clean energy and oil and gas stock returns are compared, it is observed that a spike in oil prices caused by the oil-specific demand shock does not appear to benefit oil and gas stock returns. Consequently, previous findings imply that oil and clean energy are not substitutes for one another at the global level.

The remaining sections of the first essay are as follows. In Section 1.2, a review of the research on the relationship between oil price shocks and clean energy stock returns is given. The datasets are described in Section 1.3. Both the empirical methodology and the findings are presented in Sections 1.4 and 1.5. Conclusions and policy implications are included in Section 1.6.

1.2. EMPIRICAL LITERATURE

Previous research examining the correlation between oil prices and macroeconomic aggregates has reached a consensus regarding the asymmetric reactions of macroeconomic indicators to oil price shocks: Rises and declines in oil prices have asymmetric effects on aggregate economic activity (Balke et al. 2002, p. 27; Kilian and Vigfusson, 2011, p. 419; Charfeddine and Barkat, 2020, p. 13; Kocaarslan et al., 2020, p. 5). Also, scholars studying how oil price fluctuations affect financial markets largely agree that crude oil price movements, both positive and negative, have asymmetric

[5] We evaluate the financial performance of clean energy companies using the WilderHill clean energy (ECO) index and the WilderHill New Energy Global Innovation (NEX) index. The ECO index, which is the first to track the stock prices of clean energy companies, has emerged as a benchmark index (WilderShares, 2018, p. 3). Similar to the ECO index, the NEX index consists of companies that prioritize climate change solutions and the usage of clean energy (Solactive, 2022).

effects on the price of stocks (see, Hashmi et al., 2021, p. 7; Jiang and Liu, 2021, p. 1, amongst others). Yet, few research have explored the relationship between the clean energy stock returns and oil price shocks. To comprehend the expansion of the clean energy industry, it is imperative to elucidate the correlation between oil price shocks and the returns of clean energy stocks. It has been observed that increased oil prices have improved the clean energy stock returns (Henriques and Sadorsky, 2008, p. 998).

When Henriques and Sadorsky (2008, p. 1009) examine whether the clean energy stock returns are sensitive to fluctuations in oil prices, they conclude that the influence of oil price shocks on the clean energy stock returns is minimal. Managi and Okimoto (2013, p. 8) adopt Markov-switching vector autoregressive models to construct a model that incorporates the identical variables utilized by Henriques and Sadorsky (2008). They find that oil price shocks have a favorable impact on the returns on clean energy stocks, in contradiction to Henriques and Sadorsky (2008). In their study, Inchauspe et al. (2015, p. 325) deploy a state-space multi-factor asset pricing model to examine the correlation between oil prices and stock market returns. They utilize the NEX, a clean energy index, as a point of contrast to previous studies on the subject[6]. This study suggests that the MSCI World Index and technology stock returns are both significantly correlated with NEX returns, whereas oil prices are not as strongly. Pham (2019, p. 355) examines the relationship between oil prices and clean energy stock returns, with a particular focus on sub-sectors within the clean energy stock market and demonstrates how this connection has altered dramatically over time in various sub-sectors. More recently, Zhao (2020, pp. 15-16) utilizes SVAR to discover that oil supply shocks and aggregate demand shocks have positive effects on clean energy stock returns, while policy uncertainty and oil-specific demand shocks have negative effects. He also discovers that the first seven months of an oil-specific demand shock's positive effect on oil and gas stock returns are followed by a negative effect. The study conducted by Zhang et al. (2020b, p. 1) examines the relationship between oil price shocks and the clean energy stock market. The findings reveal an asymmetric influence of oil shocks on the clean energy stock market, particularly at higher quantiles, over an extended period of time. In addition, the impact of aggregate demand shocks on clean energy stocks over

[6] Previous studies use ECO index as a proxy for the clean energy index.

the medium run is favorable at both the lower and higher quantiles. By substituting a risk shock for an oil-specific demand shock, Zhou and Geng (2021, pp. 1-6) investigate the connection between oil price shocks and emerging energy stock markets in China, Europe, and the US. They discover that the returns of all new energy stock markets are more significantly explained by oil demand shocks and risk shocks than by oil supply shocks, which have a much smaller influence. In addition, shocks to supply and demand have very little impact on the volatility of all new energy stock markets. The risk shock, on the other hand, significantly affects how volatile the new energy stock markets are in China and the US.

Maghyereh and Abdoh (2021, p. 12) extend the research of Zhang et al. (2020b) by incorporating oil and gas stock returns and applying a quantile cross-spectral technique in addition to SVAR. They discover that the oil-specific demand shock is the shock that has the most effects on stock returns for both clean energy and oil and gas. Across the higher quantiles in all horizons, aggregate demand shock has a stronger impact on oil and gas stock returns. In contrast, the aggregate demand shock influences the returns of clean energy stocks over the medium and long-run horizons. Furthermore, oil supply shock has a bigger impact on oil and gas stock returns than it does on those of clean energy stocks. In their investigation of the connection between financial stress, commodity price volatility, including oil and gas, and clean energy stock returns, Fu et al. (2022, p. 1) discover that the clean energy stock returns are highly impacted by rising financial stress indices, oil and gold prices, and both long- and short-run price movements, but natural gas only significantly impacts clean energy stocks over the long run. Kang et al.’s (2017, p. 349) study how economic policy uncertainty and oil price shocks affect the stock returns of oil and gas companies, but they do not consider how these factors affect the stock returns of clean energy companies. It has been found that the presence of a shock in oil-specific demand leads to an initial positive effect that endures for around nine months. Conversely, a shock in aggregate demand has a favorable influence on the stock returns of oil and gas companies. According to Diaz and Perez de Gracia (2017, p. 80), there is evidence to suggest that fluctuations in oil prices exert a significant and favorable influence on the stock returns of oil and gas companies within a very short period of time.

To summarize, there is no apparent consensus on the consequences of three structural oil price shocks on the stock returns of clean energy companies. As new variables are introduced and the sample period changes, we notice that the impact of shocks varies. Also, different from previous studies[7], we chose the GECON index to measure the overall economic activity.

1.3. DATA

We employ monthly data from 2001:01[8] to 2022:06, totaling 258 observations. These observations cover the recent financial crisis, the Covid-19 pandemic period, and the Russia-Ukraine war. Our data consist of global crude oil supply, the spot price of the refiner's acquisition cost of crude oil (RAC)[9], the consumer price index (CPI) for the US, and the ECO and the NEX indices to measure the stock market performance of clean energy companies and the GECON index developed by Baumeister, Korobilis and Lee (2020) to measure the global economic activity.

We will use the log differences of world crude oil production in thousand barrels per day as a measure for the percent change in global crude oil production. To obtain the real oil price, the nominal price of RAC will be deflated by the US CPI. The real oil prices are expressed in log levels. The GECON index will be used in the level. The ECO and the NEX indices are in US dollars and are designed to both identify and monitor the clean energy sector and measure the stock market performance of clean energy companies. The ECO index is a modified, equally weighted index of publicly traded companies in the US that stand to gain from a move toward decarbonization and cleaner energy (WilderShares, 2018, p. 3). We also utilize the NEX index in addition to the ECO index. The stock performance of clean energy companies is also tracked by the NEX index. The NEX index, in contrast to the ECO index, concentrates on both US and global companies. In addition, the ECO index contains 82 stocks focused on renewable

[7] Previous studies use Kilian index to measure the global economic activity.
[8] Since the clean energy index is available since 2001, the sample period starts from 2001.
[9] We also use alternative measures of oil prices as WTI (West Texas Intermadiate) and Brent spot prices. We observe that results are robust to the changes in the oil price measure. Therefore, we do not include these results here but are available in appendices.

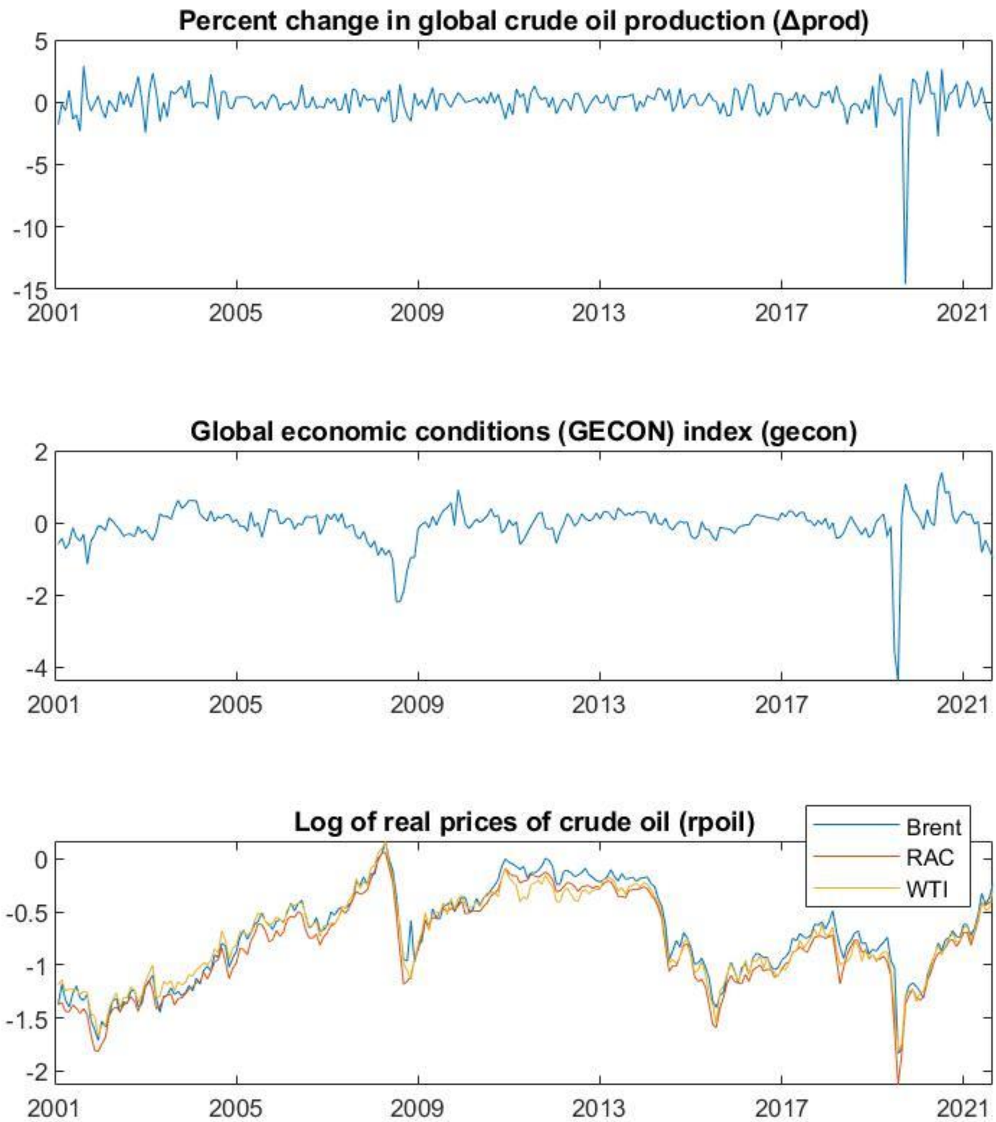
energy technologies, while the NEX index contains 130 stocks (Solactive, 2022). The ECO and the NEX indices are used in log levels. The data are obtained from DataStream (Thomson Reuters), except the GECON index from Baumeister's website.

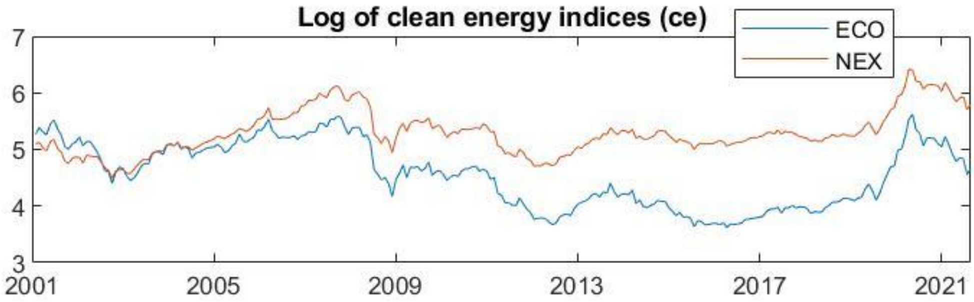
The historical development of our series across the sample period is depicted in Fig. 3. The percent change in global crude oil production remains very steady until Covid-19. The fluctuations of the global economic condition index reveal the global economic cycle. Due to the epidemic caused by the Covid-19, containment measures have resulted in a global halt in output and mobility, which has led to a considerable decline in global oil demand. The global pandemic has caused a substantial decline in oil production and oil prices, which has coincided with a sharp decline in the GECON index. Furthermore, it is evident that the sharp drops in oil prices came after crises like the 2008 global financial crisis and the Covid-19 pandemic. In 2008, there was a global financial crisis, and by the second quarter of that year, the price of oil had reached a record high of $167,39 per barrel. In the first quarter of 2009, oil prices decreased to $57,77 per barrel as a result of the post-crisis slowing of the global economy (EIA, 2023). As a result of Covid-19, oil prices have fallen due to a slowdown in industrial production and the impact of limitations on airline transportation. Hence, the most notable decline in oil prices occurred during the corresponding period[10]. One of the OPEC countries, Saudi Arabia, wanted to restrict production in order to stop prices from falling further. Russia, however, prevented this action by boosting its supply and output. Russia retaliated similarly to Saudi Arabia's increase in oil production, which sparked an oil price war[11] (Ma et al., 2021, p. 3). As a result, the oil price continued to decline[12]. From 2009 to Covid-19, the clean energy indices are relatively steady. Companies lost interest in fossil fuel projects as a result of the abrupt drops in oil prices and changes in oil supply and demand brought on by Covid-19. Companies made the decision to postpone new initiatives and permanently ended costly activities in response to the decline in oil prices. Decarbonization is now at the forefront of companies' recovery agendas thanks to technology advancements and the constantly falling cost of renewable energy. As a result, this circumstance made it easier for nations that produce oil to switch to low-

[10] Crude oil prices declined to $50,85 per barrel.
[11] The oil price war between Russia and Saudi Arabia in March-April 2020.
[12] Crude oil prices dropped to $31,47 per barrel in the second quarter of 2020.

carbon and cleaner energy policies (OECD, 2020, pp. 2-3). That explains why the clean energy indices rise following 2019. From November 2021, however, clean energy indices start to trend downhill, and the Russia-Ukraine war in 2022 only makes this tendency worse. As a result of the supply disruption and price hikes caused by Russia's invasion of Ukraine, the countries' goals of lowering their usage of fossil fuels and making a swift transition to renewable energy have shifted. Because the countries' top priority has been to find quick ways to make sure they have reliable and affordable energy. As a result, investments in sustainable energy were delayed (Birol, 2022, p. 5).

Figure 3 Historical Evolution of the Series on the Global Level





Source: Author’s calculations.

1.4. THE STRUCTURAL VAR MODEL

We estimate the SVAR model using monthly data for the vector of time series z_t = ($\Delta prod_t$, $gecon_t$, $rpoil_t$, ce_t), where $\Delta prod_t$ is the percent change in global crude oil production, $gecon_t$ is the global economic conditions index as a measure for global real economic activity, $rpoil_t$ is log of the real price of oil, and ce_t denotes log of the clean energy index measuring the stock returns of the clean energy companies.

The SVAR representation is

$$A_0 z_t = \alpha + \sum_{i=1}^{24} A_i z_{t-i} + \varepsilon_t \tag{1}$$

where, ε_t denotes the vector of serially and mutually uncorrelated structural innovations, $\varepsilon_t = (\varepsilon_t^{\Delta prod}, \varepsilon_t^{gecon}, \varepsilon_t^{rpoil}, \varepsilon_t^{ce})'$. A_0 and A_i indicate the contemporaneous and lagged coefficient matrices, respectively. Assuming that e_t is the reduced-form error of the corresponding VAR innovations decomposing according to $e_t = A_0^{-1}\varepsilon_t$, where A_0^{-1} has a recursive structure.

The structural model of the form is

$$e_t \equiv \begin{pmatrix} e_{1t}^{\Delta global\ oil\ production} \\ e_{2t}^{global\ real\ activity} \\ e_{3t}^{real\ price\ of\ oil} \\ e_{4t}^{clean\ energy\ return} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} \varepsilon_{1t}^{oil\ supply\ shock} \\ \varepsilon_{2t}^{aggregate\ demand\ shock} \\ \varepsilon_{3t}^{oil-specific\ demand\ shock} \\ \varepsilon_{4t}^{clean\ energy\ stock\ shocks} \end{pmatrix} \tag{2}$$

Assumptions

- Crude oil prices are treated as endogenous,
- The model consists of two blocks: The global crude oil market, and the clean energy market,
- There is a vertical short-run supply curve of crude oil and a downward-sloping short-run demand curve.

Studies looking at the relationship between oil prices and macroeconomic aggregates have only looked at the impact of oil price shocks, not the nature of shocks in general. Moreover, oil price fluctuations are thought to be exogenous and are presumed to be the result of supply disruptions, which are mostly brought on by geopolitical risk factors (see Hamilton, 1983; Hamilton, 2003; Kilian, 2008a; Kilian; 2008b, among others). Recent research has demonstrated that the prevailing notion attributing oil price shocks solely to supply interruptions and demand-related factors is inadequate (Kilian and Park, 2009, p. 1269; Kilian, 2009, p. 1058; Jadidzadeh and Serletis, 2017, p. 67; Demirer et al., 2020, p. 2). It's crucial to pinpoint the cause of the oil price fluctuations in order to more thoroughly analyze how oil prices affect financial markets. Due to their dissimilar natures, oil supply and demand shocks may have divergent consequences on the economy. For instance, economic activity is adversely affected by price rises brought on by supply shocks, whereas economic activity is benefited by price rises brought on by oil demand shocks (Ready, 2018, p. 3). Assuming that crude oil prices are endogenous, we will explain changes in real oil prices in terms of three structural shocks: shocks to the global crude oil supply ("oil supply shock" denoted by ε_{1t}), shocks to the global demand ("aggregate demand shock" denoted by ε_{2t}), and shocks from changes in precautionary demand for oil ("oil-specific demand shock" denoted by ε_{3t}).

The model consists of two blocks, the global crude oil market (first block of Eq. (2)) and the clean energy stock market (second block of Eq. (2)). Fluctuations in the real price of oil in the global crude oil market block are explained by three structural shocks (ε_{1t}, ε_{2t}, ε_{3t}). There is only one structural innovation in the clean energy market block, and this innovation, which represents clean energy stock shocks as ε_{4t}, is not caused by global crude oil demand or supply shocks, and it is therefore not a true structural shock.

There is a vertical short-run supply curve of crude oil and a downward-sloping short-run demand curve. A sudden change in the real price of oil is the consequence of both shifts in the demand curve, which are brought on by either aggregate demand shocks or oil-specific demand shocks as well as unexpected shocks to the oil supply (Kilian, 2009, p. 1059).

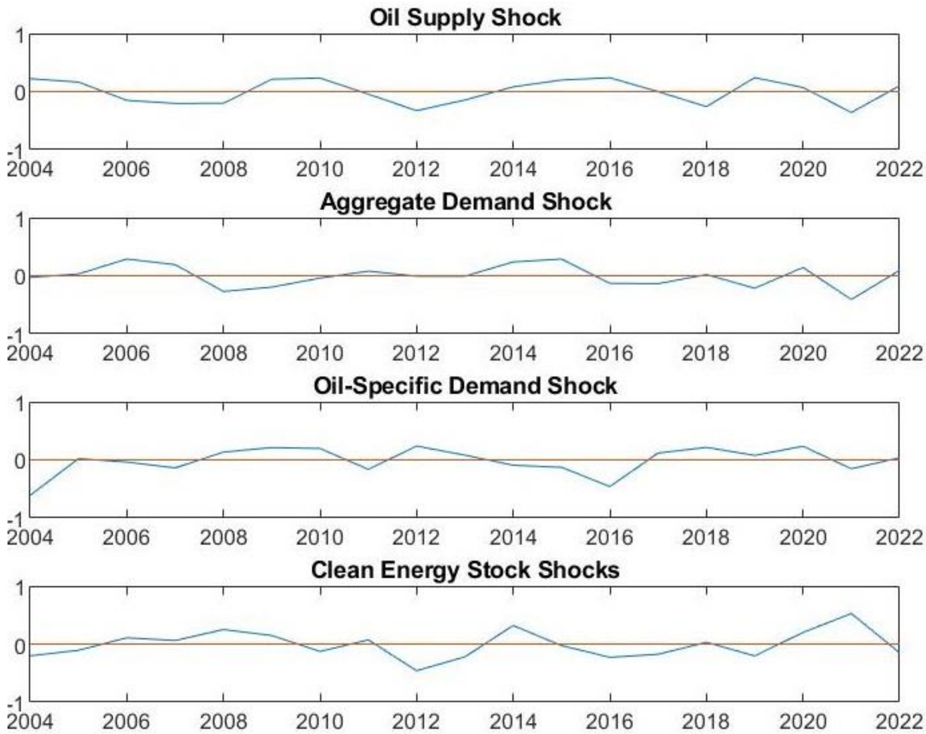
1.5. EMPIRICAL RESULTS

1.5.1. Structural VAR Estimates

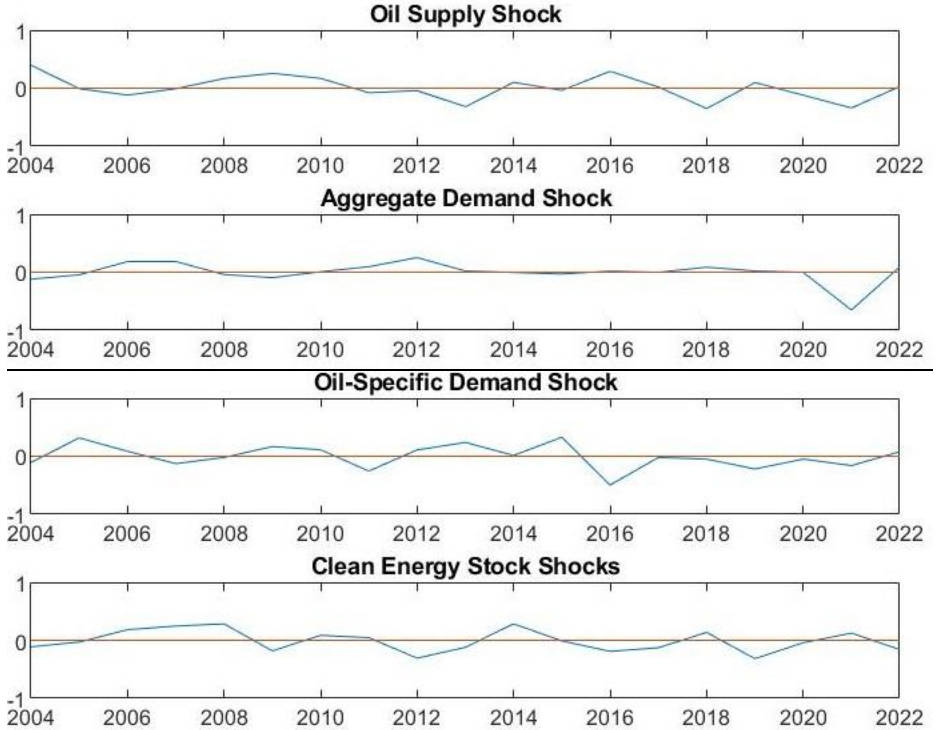
We consider dynamics with a delay of up to 24 months, following Kilian (2009, p. 1058) and Kilian and Park (2009, p. 1270). Using the least-squares method, we estimate the VAR in its reduced form. Using the obtained estimates, we then construct the SVAR representation and calculate the VAR impulse responses by Cholesky decomposition for one-standard deviation structural innovations based on a recursive design with 2,000 replications. The model is estimated using the MATLAB software.

Fig. 4 illustrates the temporal trajectory of the structural shocks as proposed by the model. We note that while the oil supply disruption in the model with the ECO index occurs between 2006 and 2008, the oil supply disruption in the model with the NEX index occurs in 2006 and ends after 2007. The negative supply shock that the model with the ECO index experienced in 2012 is experienced by the model with the NEX index in 2013. Since 2014, shale gas and oil production in the US has increased, which has led to an increase in supply (Uçkun, 2016, p. 48). The model created using the ECO index makes it easier to see the positive effect of the increase in shale oil production on oil supply. This can be attributed to the ECO index's exclusive focus on US companies, in contrast to the NEX index. In the model with the NEX index, the aggregate demand shock does not produce any reaction between the years 2013 and 2020. This may be due to the NEX index's relative stability in comparison to the ECO index during this time, as well as the stability of the GECON index over the same time (see Fig. 3). In the period between 2011 and 2014, the oil-specific demand shock and the oil supply shock are observed to move in opposite directions. In other words, the 2011 Arab Uprisings and the Eurozone financial crisis reduced oil supply, which exacerbated uncertainty and resulted in an unanticipated rise in oil-specific demand in 2012 in both models. After the global pandemic, clean energy stock shocks soar, while all other shocks unexpectedly decrease.

Figure 4 Historical Evolution of the Structural Shocks in the Oil Market with Clean Energy Stock Shocks



Historical evolution of the structural shocks with the ECO index



Historical evolution of the structural shocks with the NEX index

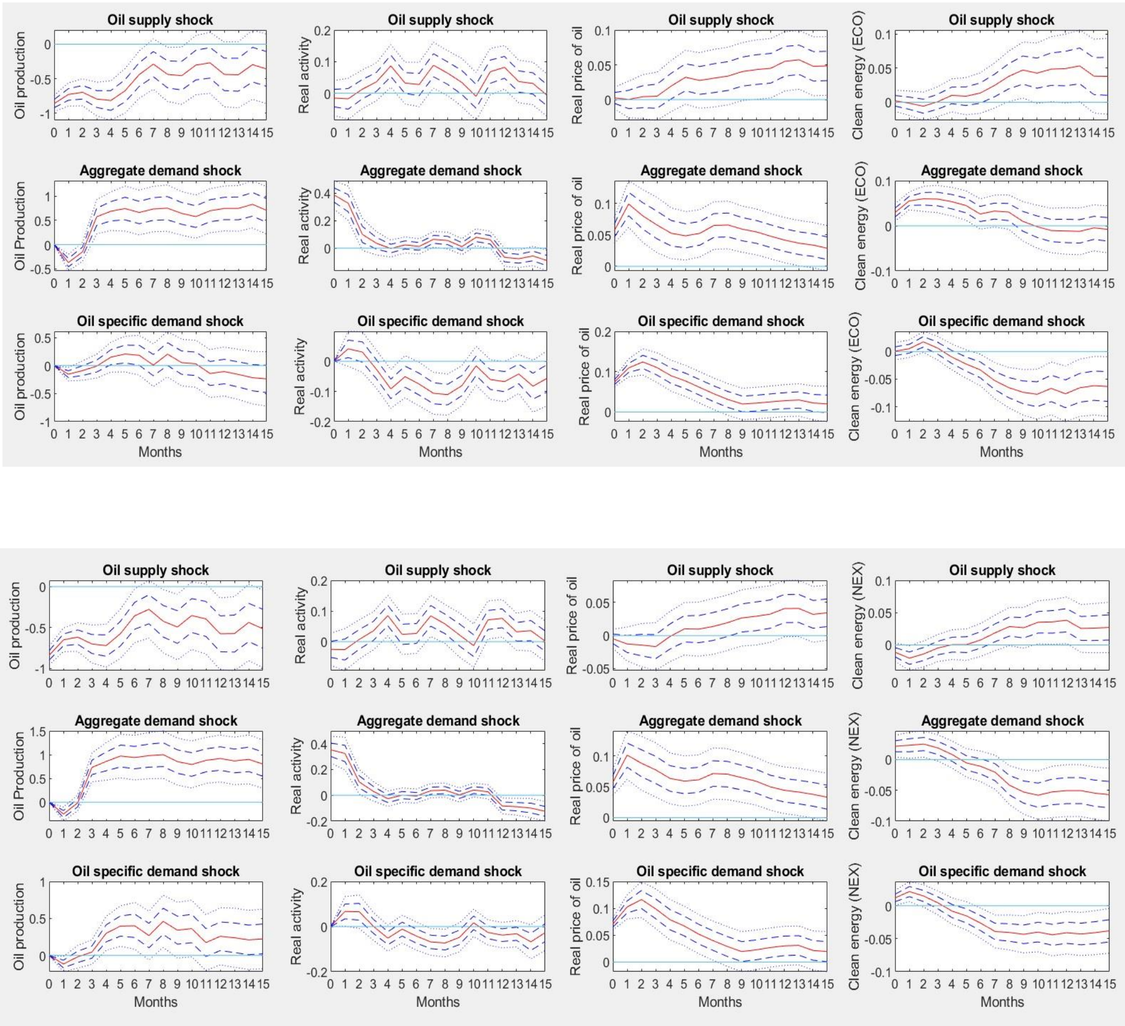
Source: Author's calculations.

Fig. 5 depicts the effects of the three structural shocks on global oil production, real economic activity, the real price of oil, and clean energy stock returns. As done by Kilian (2009, p. 1060) and Kilian and Park (2009, p. 1272), the oil supply shock is normalized to indicate a negative shock, while the aggregate demand shock and the oil-specific demand shock are normalized to indicate positive shocks, such that the real price of oil rises as a result of all three shocks.

According to one-standard error bands, a rapid decline in global oil production has a favorable and statistically significant impact on clean energy stock returns starting from the seventh month in both models. In the first eight months of the model using the ECO index, aggregate demand expansions have a statistically significant positive immediate effect on the clean energy stock returns.

In addition, after the third month in both models, an unexpected increase in precautionary demand for oil has a statistically significant negative impact on the clean energy stock returns. These outcomes are consistent with Zhao (2020, p. 9), who shows that while oil-specific demand shock has negative effects on clean energy companies' stock returns, oil supply shock has positive effects on those returns. The fact that the positive oil-specific demand shock has a negative impact on the stock returns of clean energy companies further supports the conclusion that clean energy cannot be used as a substitute for oil. As crude oil production is a long-run production project and capital intensive, Wang et al. (2014, p. 27) underline the oil supply's low short-run price elasticity. Thus, the oil supply will not respond in the short run to changes in aggregate demand, price, or clean energy stock return. Because supply is currently reliant on the output of a small number of major producers, a supply shock will not result in significant changes in overall oil production. Hence, in the short run, investments in clean energy would not be stimulated by a decrease in oil supplies and consequent price increases. Based on these findings, it is possible to draw the conclusion that clean energy and oil are not alternatives to one another. This is corroborated by Desilver (2020), who argues that, despite the growing percentage of renewable energy in global energy consumption, fossil fuels continue to dominate in the US. This is due to the pressure that fossil fuel firms are ostensibly under to switch to renewable energy. Likewise, there are companies that have established a net zero emissions target and altered their names and branding (for instance, BP (British Petroleum) changed their name from “British Petroleum” to “Beyond Petroleum” to demonstrate that it is serious about the energy transition). Yet, the truth is that even though fossil fuel-based energy is currently more affordable to produce than renewable energy, the proportion of fossil fuels in global energy consumption has essentially remained constant over the past ten years. As also stated by Hareesh Kumar (2021), oil and gas companies do not actually feel much pressure to switch to clean energy, and the majority of companies tend to put off their obligations to reduce emissions as long as possible.

Figure 5 Responses to the Three Structural Shocks on the Global Level



Notes: Dashed and dotted lines denote one-standard error and two-standard error bands, respectively.
Source: Author's calculations.

The three structural shocks' impact on the returns for clean energy stocks is quantified by the forecast error variance decomposition given in Table 1. In the models with the ECO and NEX indices, the aggregate demand shock has the greatest explanatory power for the short-run variation in clean energy stock returns, with 10,25% and 7,63%, respectively. In the model with the ECO index, the oil-specific demand shock has the most explanatory power in the long run, whereas the aggregate demand shock has the most explanatory power in the model with the NEX index. In more specific terms, according to the model employing the ECO index, around 10% of the overall long-term variation in clean energy stock returns may be ascribed to oil supply shocks, whereas oil demand shocks account for approximately 41% of the observed variation. In contrast, it is shown that oil demand shocks provide a substantial contribution of approximately 49% to the overall long-term variation in clean energy stock returns, as per the model employing the NEX index. Conversely, oil supply shocks account for a comparatively smaller proportion of approximately 7%.

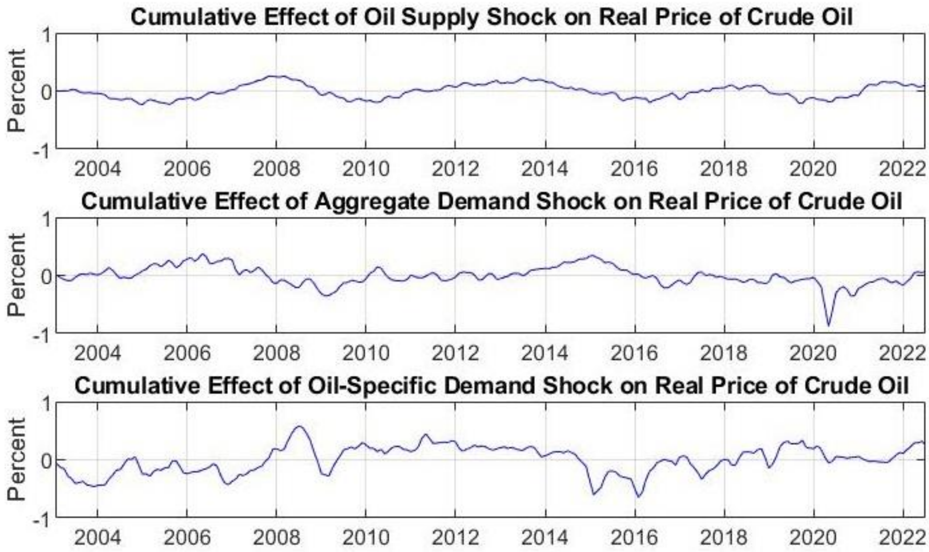
Table 1 Percent Contribution of Three Structural Shocks in the Crude Oil Market to the Overall Variability of Clean Energy Stock Returns

Horizon	Oil supply shock	Aggregate demand shock	Oil-specific demand shock	Other shocks
1	0,05 (2,12)*	10,25 (7,63)	0,00 (2,30)	89,68 (87,93)
2	0,04 (4,46)	25,04 (8,05)	0,16 (4,87)	74,74 (82,60)
12	6,30 (6,21)	13,39 (15,84)	17,81 (12,45)	62,49 (65,49)
∞	9,77 (6,75)	10,15 (35,56)	30,54 (13,32)	49,52 (44,35)

Notes: Based on variance decomposition of the SVAR(1).
* The results of the model with the NEX index are in parentheses.
Source: Author’s calculations.

The cumulative contribution of three structural shocks that drive the crude oil market to the real price of crude oil is represented in Fig. 6. Fig. 6 implies that the oil supply and aggregate demand shocks contribute similarly to the real price of oil, and that these contributions are less than the contribution of the oil-specific demand shock. In accordance with the studies by Kilian and Park (2009, pp. 1272-1274), Kilian (2009, p. 1062), and Jadidzadeh and Serletis (2017, p. 70), we find that oil-specific demand shocks are the most important contributor to the abrupt spikes and drops in the real price of oil. The reason for this is that changes in precautionary demand are brought on by anticipation of future oil supply shortages, and the market responds to these expectations very quickly (Kilian, 2009, p. 1062).

Figure 6 Cumulative Effect of Oil Price Shocks on the Price of Crude Oil on the Global Level: Historical Decomposition



Source: Author’s calculations.

1.5.2. Clarifying the Substitution Effect

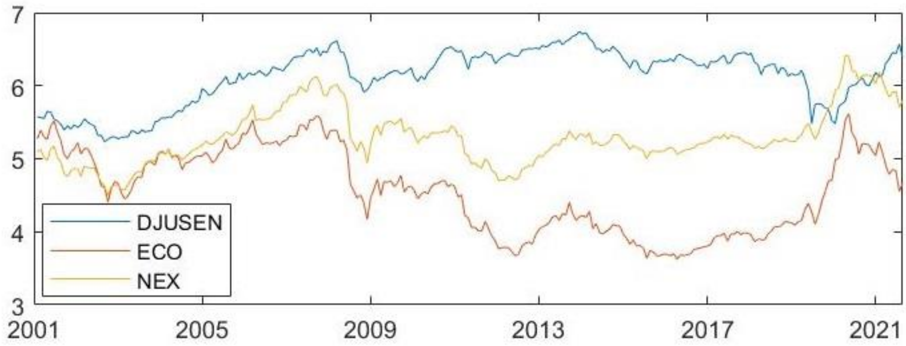
IEA (2021b, p. 3) places a strong emphasis on the significance of making the switch to clean energy in order to terminate the world’s reliance on fossil fuels and achieve net zero emissions. This makes it crucial to investigate if clean energy has a substitutive effect for fossil fuels, particularly oil, which accounts for the biggest portion of global energy consumption. Using monthly data for the vector of time series z_t = ($\Delta prod_t$, $gecon_t$, $rpoil_t$, $oilgas_t$), we will estimate the SVAR model to highlight the substitution impact. $oilgas_t$ stands for the Dow Jones U.S. Oil and Gas Index (DJUSEN), which tracks the stock performance of US companies in the oil and gas industry. Datastream is used to extract the Oil and Gas Index, which is then calculated using log levels.

Before to the global financial crisis of 2008, all indices are heading in much the same direction; however, after the crisis, the ECO and NEX indices have a sharp decrease, and the differences between the indices, particularly between the ECO and DJUSEN indices, begin to widen (see Fig. 7). The NEX index oscillates between the DJUSEN and ECO indices. As a result of the severe economic recession that the 2008 global financial crisis caused, the ECO index keeps going down. When COP15[13] met in 2009, public concerns about climate change were the main topic of discussion. Most nations, particularly those in Europe and the US, have launched stimulus packages in this manner (IEA, 2020). Temporary stimulus packages, however, have harmed the renewable energy industry rather than helped it. Because the renewable energy sector is dependent on government support, it is particularly vulnerable to cutbacks during times of financial difficulty brought on by the current economic crisis. After the global financial crisis, subsidies were reduced in the EU member states. For instance, the German government reduced its support for solar energy in 2010 and 2011 (Victor and Yanosek, 2011, p. 115). To sum up, as a result of inconsistent government support for the clean energy sector, global investments in renewable energy and the ECO index have both fallen.

Moreover, the Oil and Gas Index starts to fall as the ECO index soars quickly with Covid-19. The rate of growth of the ECO index, however, is significantly greater than the rate of decline of the Oil and Gas index. In addition, the NEX index has surpassed the DJUSEN index and is at its highest point ever. This is supported by a recent study by Wan et al. (2021, pp. 1-2), which find that as governments implement green recovery plans in response to the pandemic, clean energy stock returns increase. This attracts investors' attention to clean energy investments and lead to a rise in their stock prices. The positive effect of the pandemic on clean energy stock returns is also discovered by Ghabri et al. (2021, p. 4962). The DJUSEN index has begun to rise as of 2021, despite declines in the ECO and NEX indices. The importance of energy security, which encompasses the accessibility and affordability of energy resources, has been highlighted by the Russia-Ukraine war as of February 2022. As a result of the impossibility of a rapid transition to clean energy in the near future, countries relying on Russian oil and gas have opted to obtain oil and natural gas from other countries, and countries planning to close their coal and nuclear power plants and to speed their transition to clean energy have decided to defer their plans for the time being (Pfeifer, 2022).

[13] The 15th Conference of the Parties to the United Nations Framework Convention on Climate Change.

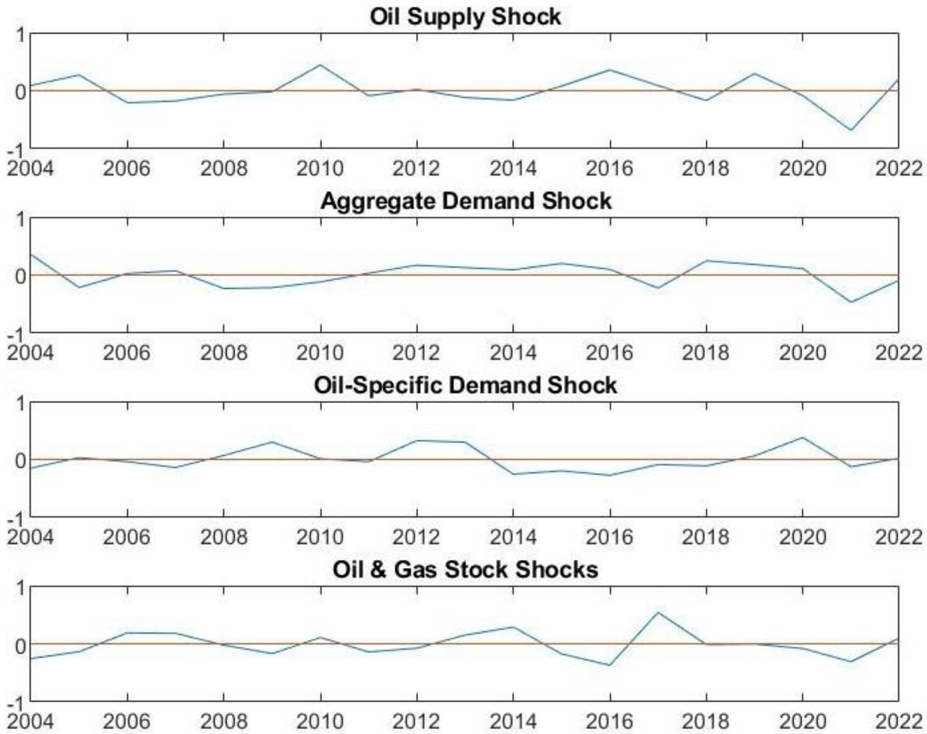
Figure 7 Historical Evolution of the DJUSEN, ECO and NEX Indices (in log levels): 2001:01-2022:06



Source: Author’s calculations.

Fig. 8 shows that the increase in oil supply in the 2010s can be attributed to a major crude oil surplus that began in 2014-2015 and escalated in 2016. An oversupply resulted from the US’s entry into the market as a new player (with shale oil production). As a result, oil prices started to drop after 2014. Both the oversupply brought on by American shale gas production and the decline in demand as a result of the downturn in China’s economy, the world’s largest energy consumer (Wong, 2015), are contributing factors to the drop in oil prices. Also, we observe that oil and gas companies’ stock returns have declined over this time period. Besides, all shocks unexpectedly decline following the global epidemic (however, clean energy stocks have increased since the onset of the global pandemic, see Fig. 4). According to Gollakota and Shu (2023), Covid-19 has a significant detrimental impact on the financial performance of dirty energy companies. In comparison to other industries, the energy sector has a greater fixed asset ratio and financial leverage, which results in higher fixed and operational costs. As a result, throughout the Covid-19 period, the stock values of big energy companies like Royal Dutch Shell and BP declined significantly. Also, this process has given rise to the notion that switching to renewable energy is vital in order to decarbonize the world economy. Moreover, the decreasing cost of renewable energy sources has inspired many governments to establish increasingly ambitious goals for the switch to renewable energy.

Figure 8 Historical Evolution of the Structural Shocks in the Oil Market with Oil and Gas Stock Shocks



Source: Author’s calculations.

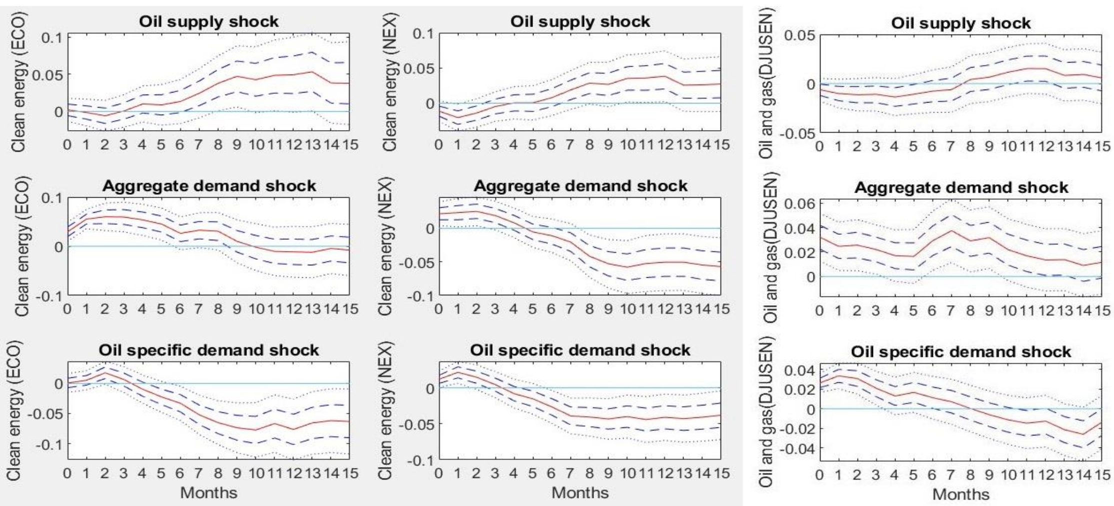
For a very brief period of time (between the first and fourth months), an oil supply shock has a negative and significant impact on the returns for oil and gas stocks (see Fig. 9). The findings of Kang et al. (2017, pp. 349–350) indicating a negative oil supply shock has a temporally statistically significant negative impact on the stock returns of oil and gas companies are consistent with this finding. The positive effect of a negative oil supply shock on the clean energy stock returns claims that a rise in oil prices brought on by oil supply shocks causes investors to switch from oil to renewable energy sources, demonstrating the substitution effect between oil and clean energy. The outcome of the negative effect of the oil supply shock on oil and gas stock returns in this study does not, however, support the substitution effect that is produced by the positive effect of the oil supply shock on clean energy stock returns. Simply put, investors are anticipated to transfer from oil to clean energy as a result of rising oil prices brought on by a negative oil supply shock, which will result in higher stock returns for clean energy companies and lower stock returns for oil and gas companies.

It is evident that the aggregate demand shock exerts a persistent and substantial influence on the returns of oil and gas stocks. However, the impact of the aggregate demand shock on the returns of oil and gas company stocks gradually decreases over time, with the exception of a brief period between the fifth and seventh months. In a similar vein, Zhao (2020, p. 11) finds that the beneficial impact of the aggregate demand shock on oil and gas stock returns in the first twenty months typically rises but declines in the final five months of his analysis using the Kilian index. According to Maghyereh and Abdoh (2021, p. 8), who also used the Kilian index, aggregate demand shock increases oil and gas company stock returns across the short-, medium-, and long-term. A positive impact of aggregate demand shock on oil and gas company stock returns is also discovered by Kang et al. (2017, p. 349), but this positive impact on stock returns increases over time.

The oil-specific demand shock affects the stock return of oil and gas companies in the first six months with statistically significant positive effects, but this effect is waning over time. This result is compatible with the findings of Kang et al. (2017, p. 349) and Zhao (2020, p. 11). Fig. 9 shows that the stock returns of both oil and gas and clean energy companies fall in response to a shock in the oil-specific demand. In other words, stock returns of both clean energy and oil and gas companies begin to fall when the price of oil increases due to an unanticipated surge in precautionary oil demand. With regard to clean energy stock returns in particular, worries are growing about predicted oil supply shortfalls as a result of the ongoing turbulence in the oil market caused by Covid-19 and the quickly rising oil demand in emerging market nations like China and India. Hence, it may be claimed that the current demand for oil may increase if a future decline in supply of oil is anticipated. In other words, if the present oil demand grows, this can be a sign that oil producers do not convert to renewable energy. On the other hand, Gupta (2016, pp. 145–149) notes that the sensitivity of the stock returns of oil and gas companies to an increase in oil prices is substantially lower than a decline in oil prices, concentrating on 2136 active and dead/delisted stocks of oil and gas companies from 70 nations from 1983 to 2014. Additionally, he discovers that lower oil and gas stock returns are a result of the rise in global uncertainty. Maghyereh and Abdoh (2021, p. 9)'s observation that an oil-specific demand shock has a greater impact on oil and gas company stock returns in a normal economic condition confirms this result. Our time period encompasses the 2008 global financial crisis, the 2011 Arab Uprisings and Eurozone debt crisis, the global pandemic, and the Russia-Ukraine war, all of which contribute to global uncertainty. We can thus conclude that these uncertainties cause the stock returns of oil and gas companies to decline.

In summary, it is generally observed that a rise in oil prices resulting from oil-specific demand shock does not normally lead to a corresponding increase in the stock returns of oil and gas companies. This is primarily due to the fact that the stock returns of these companies exhibit a higher sensitivity to declines in oil prices and are more susceptible to oil-specific demand shocks in normal economic conditions. The absence of a substitution effect between oil and clean energy is evident due to the impact of oil-specific demand shocks, which lower the stock returns for both clean energy and oil and gas companies.

Figure 9 Responses of the Stock Returns of Oil and Gas and Clean Energy Companies to the Structural Shocks



Notes: Dashed and dotted lines denote one-standard error and two-standard error bands, respectively.
Source: Author’s calculations.

In the long run, aggregate demand shock accounts for over 21% of the variation in oil and gas stock returns, oil-specific demand shock accounts for 13%, and oil supply shock almost entirely accounts for 9,5%. The variability of oil and gas stock returns is best explained by the aggregate demand shock.

Table 2 Percent Contribution of Demand and Supply Shock to the Overall Variability of Oil and Gas Stock Returns

Horizon	Oil supply shock	Aggregate demand shock	Oil-specific demand shock	Other shocks
1	0,72	19,32	12,94	66,99
2	1,41	16,39	18,11	64,08
12	2,50	16,99	8,68	71,81
∞	9,48	20,73	13,08	56,69

Notes: Based on variance decomposition of the structural VAR model (1).
Source: Author’s calculations.

1.6. CONCLUSIONS AND POLICY IMPLICATIONS

Using a SVAR, this study attempts to answer the question of how different oil price shocks affect the stock prices of clean energy and oil and gas companies. The analysis is motivated by the large swings in oil prices between 2001 and 2022 and how they affect the performance of the oil and gas and the clean energy stock returns. We take into account the global economic conditions (GECON) index, which pinpoints shocks to aggregate demand.

The followings are the key conclusions. First, both models utilizing the ECO and NEX indices demonstrate that a negative oil supply shock yields a favorable effect on the returns of clean energy stocks. Second, in the model using the ECO index, increases in aggregate demand have an immediate positive impact on the returns of clean energy stocks. Third, in both models, the stock returns of clean energy are negatively impacted by the oil-specific demand shock. This indicates that increased oil prices as a result of an oil-specific demand shock do not motivate investors to switch to clean energy. Last, in order to further explain the substitution effect, it is also noted that when comparing the effects of oil price shocks on the stock returns of both clean energy and oil and gas, it is found that the spike in oil prices brought on by the oil-specific demand shock does not, in general, improve the stock returns of oil and gas companies. This is due to the fact that the stock returns of oil and gas companies exhibit a higher sensitivity to declines in oil prices and are more susceptible to oil-specific demand shocks in normal economic conditions. Consequently, the prior findings imply that oil and clean energy are not substitutes for one another on the global level.

The absence of the oil-to-clean energy substitution effect can be attributed to a number of factors. First, the primary energy sources in the world's energy consumption are still fossil fuels, despite the fact that the share of renewable energy is rising. Second, oil and gas companies do not perceive a great deal of pressure to convert to renewable energy. Finally, the recent conflict between Russia and Ukraine has made it clear that delaying a nation's decision to phase out fossil fuels has a negative impact on clean energy stock returns.

Rising oil prices are likely to spur an increase in investments in clean energy and provide a substitution effect between oil and clean energy. High oil prices, however, are not sufficient to accelerate the transition to clean energy sources. This transition should be facilitated by government action, as investments in clean energy are more inclined to grow when stable government subsidies are adopted in clean energy and the costs of renewable energy technology decrease. Yet, this situation can alter when there is a great deal of ambiguity, like with Covid-19. We saw a surge in the stock returns of clean energy companies and a fall in the stock returns of oil and gas companies despite the fact that oil prices fell with Covid-19. This demonstrates that investor sentiment changes when there is a significant level of uncertainty during financial and economic crises, and that the renewable energy industry has the ability to successfully compete with oil even while oil prices have been fluctuating at recent lows. Consequently, it is left to future studies to study the substitution effect between oil and clean energy by integrating government intervention and investor sentiment in the model.

CHAPTER 2

THE EFFECTS OF OIL AND GAS PRICE SHOCKS ON CLEAN ENERGY STOCK RETURNS: EVIDENCE FROM EUROPEAN LEVEL

2.1. INTRODUCTION

The European market is strongly affected by changes in oil and gas prices due to its high level of foreign dependency on fossil fuels and high rate of fossil fuel use in overall energy consumption. In 2021, oil and petroleum products made up 34,1% of the EU's energy mix, followed by natural gas at 23,3%, renewable energy at 17,2%, nuclear energy at 12,7%, and solid fossil fuels at 11,1% (Eurostat, 2023a). Considering that the EU imported 55,6% of the energy used in 2021, only 44,4% of its energy needs were satisfied by domestic production and stock changes. Moreover, 92% of the EU's consumption of oil and petroleum products, as well as 83,3% of its consumption of natural gas, is imported (Eurostat, 2023b). 59,4% of the EU's final energy consumption comes from fossil sources (gas, oil, and solid fossil fuels) and the share of renewables and biofuels in the final energy consumption is 11,7% (Eurostat, 2023c). In the context of rising oil and gas prices, the question of whether fossil fuel price shocks will push for more investment in clean energy gains importance as an alternative way for Europe to ensure security of supply while succeeding the energy transition to less polluting sources. In this paper, we contribute to answering this question by using a SVAR methodology to study how clean energy stocks in Europe react to shocks, on the one hand, in the oil market and, on the other hand, in the gas market.

Some studies at the European level have focused on the dynamics of oil price shocks at the industrial level (Scholtens and Yurtsever, 2012), and on the relationship between oil price shocks and the stock market (Degiannakis et al. 2014; Krokida et al. 2020). To the best of our knowledge, only Zhou and Geng (2021) have included the EU in their study of the impact of oil market shocks on clean energy stock returns. Using China's new energy index (CNNE), the European renewable energy index (ERIX), and the ECO index for the US, Zhou and Geng (2021) compare the response of clean energy stock indices to three structural oil price shocks: Supply shock, demand shock, and risk shock. Unlike our paper, they use the World Integrated Oil and Gas Producer Index to represent the global oil industry, the 1-month returns on the second nearest maturity NYMEX (New York Mercantile Exchange) Crude-Light Sweet Oil contract to indicate the changes in crude oil prices and the VIX (Chicago Board Options Exchange (CBOE) Volatility) index to identify the risk shock. Zhou and Geng (2021, p. 9) find that the oil demand and risk shocks have significant explanatory power on the returns of all new energy markets, while the oil supply shock has a minor effect. Aside from the methodological difference with Zhou and Geng (2021) and from the fact of studying also the gas market, herein we focus for the first time specifically on the EU region. Our results are generally in accordance with theirs even if we are able to disentangle the different impact of supply, aggregate demand and oil-specific demand in more detail.

Regarding the interaction between the gas market and clean energy stocks in Europe, we are the first to use the SVAR methodology to study this. Previous literature has found a weak impact for Europe. Concretely, Reboredo and Ugolini (2018, p. 151), Liu and Hamori (2020, p. 24) and Umar et al. (2022, p. 11) have found that changes in gas prices have a small impact on the stock returns of clean energy companies. Similarly, Xia et al. (2019, p. 1) find that changes in gas prices have no significant impact on the stock returns of clean energy companies. Only Fu et al. (2022, p. 7) find that changes in gas prices have a positive impact on the stock returns of clean energy companies, but they do not study the European context. Our results are therefore at odds with this literature since we find a significant impact of gas shocks on clean energy stocks in Europe.

Our study contributes to the existing literature in three ways. First, while the literature generally focuses on crude oil price shocks, we extend this literature by describing the impact of shocks in the market of another fossil fuel: Natural gas. In this regard, following the three structural shocks in the oil market described in the literature, we use the same method to identify gas price shocks in the European market. Knowing that the gas market is mostly regional, even after the introduction of the North American shale gas, we provide a complete representation of these shocks in Europe. Second, current literature mostly focuses on the relationship between oil price shocks and clean energy stock returns at the global level. We extend the existing literature by focusing on the relationship between oil price shocks and clean energy stock returns at the European level. Third, especially due to the recent developments in the natural gas markets, herein we study the impact of changes in gas prices in terms of attractiveness in clean energy technologies. The European Commission's endorsement of gas as a transition fuel in July 2022 due to its capacity to serve as backup for intermittent renewables has raised the question of whether gas is viewed by investors as complementary to clean energy in European financial markets. Europe's high dependence on Russian gas and the increased risk of gas shortages due to the conflict in Ukraine further emphasized the importance of understanding the impact of changes in gas prices. Herein we contribute to the literature by identifying the gas price shocks at the European level and then examine the effects of three different gas price shocks (gas supply shock, economic demand shock, and gas-specific demand shock) on clean energy stock returns.

Our main findings are as follows. First, a negative gas supply shock boosts clean energy stock returns, implying that clean energy is a viable alternative to gas for European investors. Instead, a negative global oil supply shock has no substantial impact on clean energy stocks. This means that rising oil prices due to the oil supply shock in the global market do not encourage investors to switch to clean energy at the European level. Second, the oil price model outperforms the gas price model in terms of how long the positive effects of economic demand shocks on clean energy stock returns last. Third, both the oil-specific and the gas-specific demand shock boost the stock returns of clean energy companies. The previous results suggest that there is a substitution effect between oil, gas, and clean energy stocks. This last result shows that, in terms of investment, gas cannot really be considered as a complement to intermittent technologies as the recent considerations of the European Commission could suggest.

The rest of the second essay is structured as follows. The prior literature is summarized in Section 2.2. The data is described in Section 2.3. Section 2.4 gives the findings and outlines the empirical methodology. Section 2.5 concludes.

2.2. EMPIRICAL LITERATURE

There are numerous studies examining the effects of oil price shocks on different dynamics, from macroeconomic aggregates to specific sectors like industry or agriculture. The relationship between oil price shocks and macroeconomic aggregates has been examined for the first time for the US in the 80s (Hamilton, 1983). Studies focusing on the effects of oil price shocks on macroeconomic aggregates such as production or employment rates have proliferated since then (see, Kilian, 2009; Kilian and Vigfusson, 2011; Herrera et al., 2019; Wen et al. 2021, amongst others). Other related studies have focused on the impact of oil price shocks in the industrial sector (Scholtens and Yurtsever, 2012; Herrera, 2018), or in monetary policy (Natal, 2012; Kim et al., 2017). The relationship between oil price shocks and financial markets has been a hot topic for many years (Kilian and Park, 2009; Degiannakis et al., 2014; Ready, 2018; Krokida et al., 2020; Demirer et al., 2020; Kielmann et al., 2022) as well as the impact of oil price shocks on agricultural commodity pricing (Wang et al., 2014; Umar et al., 2021).

There is also a vast literature that investigates the relationship between natural gas and crude oil prices (Pindyck, 2004; Brown and Yücel, 2008; Zamani, 2016; Jadidzadeh and Serletis, 2017). Besides, numerous studies have been conducted to understand the behavior of the natural gas market, particularly what drives natural gas prices (Nick and Thoenes, 2014; Hou and Nguyen, 2018; Ji et al., 2018; Hailemariam and Smyth, 2019; Rubaszek et al., 2021).

In what follows we concentrate on papers that study the impact of fossil fuel prices on clean energy stock returns: Sub-section 2.2.1 focuses on the relationship between changes in oil prices and clean energy stock returns, and sub-section 2.2.2 focuses on the relationship between changes in gas prices and clean energy stock returns.

2.2.1. Changes in Oil Prices and Clean Energy Stock Returns

Many studies have examined the connection between the oil prices and the clean energy stock markets, particularly on the global level, but their findings have not produced a consensus. The results can be put forward as follows. First, an increase in oil prices is found to enhance clean energy stock returns (Kumar et al., 2012, p. 215; Managi and Okimoto, 2013, p. 8). Second, an increase in oil prices is observed to have a negligible impact on clean energy stock returns (Henriques and Sadorsky, 2008, p. 998; Inchauspe et al., 2015, p. 325). Third, an increase in oil prices owing to oil-specific demand shock is shown to increase clean energy stock returns (Maghyereh and Abdoh, 2021, p. 3), decreases clean energy stock returns (Zhao, 2020, p. 15), or has an asymmetric effect (Zhang et al., 2020b, p. 6). Fourth, in studies focusing on the effects of risk shocks rather than oil-specific demand shocks (Zhou and Geng, 2021, p. 9), risk shocks have a major impact on the returns of clean energy stocks in China, Europe, and the US (see Table 3 for detail).

Methodologically, our paper is closest to Henriques and Sadorsky (2008), Zhao (2020), Maghyereh and Abdoh (2021)[14] and Zhou and Geng (2021), since they also study the effects of oil price shocks on clean energy stock returns using a SVAR. From these papers only Zhou and Geng (2021) include the European clean energy stocks in their analysis.

Table 3 A Summary of Previous Studies on Changes in Oil Prices and Clean Energy Stock Returns

Author, Year	Method	Region	Results
Henriques and Sadorsky, 2008	SVAR	Global	The returns on clean energy stocks are not statistically significantly affected by rising oil prices.
Kumar et al., 2012	VAR	Global	An increase in oil prices boosts the returns on clean energy stocks.
Managi and Okimoto, 2013	Markov-switching VAR	Global	An increase in oil prices boosts the returns on clean energy stocks.
Inchauspe et	A state-space	Global	In comparison to the MSCI World index and the

[14] Maghyereh and Abdoh (2021) and Zhou and Geng (2021) apply different models in addition to SVAR.

al., 2015	multi-factor asset pricing model		PSE, the influence of oil prices on clean energy stock returns is quite minimal.
Pham, 2019	Multivariate GARCH models	Global	The relationship between oil prices and clean energy stocks varies significantly between subsectors of clean energy stocks.
Zhao, 2020	SVAR	Global	Oil price spikes owing to oil supply and aggregate demand shocks boost clean energy stock returns. Oil price increases due to oil-specific demand shock reduce clean energy stock returns.
Zhang et al., 2020b	Wavelet-based quantile-on-quantile	Global	An increase in oil prices due to oil supply and aggregate demand shock enhances clean energy stock returns at higher quantiles, whereas the impact of an increase in oil prices caused by oil-specific demand shock is asymmetric.
Maghyereh and Abdoh, 2021	SVAR, novel quantile cross-spectral dependence approach	Global	In general, there is a stronger correlation between clean energy and oil-specific demand shocks than there is between aggregate demand shocks and clean energy. A spike in oil prices due to an oil-specific demand shock boosts clean energy stock returns.
Zhou and Geng, 2021	SVAR, the decomposition methods, the rolling window method	China, Europe, US	Oil supply shock has a little impact on the returns of all new energy stock markets, whereas oil demand shock and risk shock have significant impact.

2.2.2. Changes in Gas Prices and Clean Energy Stock Returns

Existing literature does not focus on the relationship between gas price shocks and stock returns of clean energy companies as we do herein. Indeed, none of the papers cited used a SVAR approach. Instead, there are few studies identifying gas price shocks. For example, Ghabri et al. (2021, p. 4970) investigate how oil and natural gas price shocks affect clean energy stock markets, especially due to post-pandemic oil price shocks by applying a time-varying VAR model. They do not, however, recognize oil and gas price shocks the way we do herein. That is to say, they use the WTI as a benchmark for crude oil to reflect shocks in the price of oil and the NYMEX as a benchmark for natural gas to represent shocks in the price of gas. They find that the oil price shock has a greater impact on ECO returns than on ERIX returns and that clean energy stock prices have increased in response to the dramatic drop in oil prices. Moreover, renewable energy is unresponsive to the natural gas shocks after the oil price shocks. Without focusing on the stock returns of clean energy, Hou and Nguyen (2018, p. 52), who concentrate on the US natural gas market and examine how the market responds to structural shocks in different regimes, identify gas price shocks for the US as supply shock (represented by gas production), demand shock (represented by the US industrial production index (IPI)), and gas-specific demand shock (represented by gas price). Using a Markov switching VAR, they find that the price of gas is mainly driven by gas-specific demand shocks.

Wang et al. (2022, p. 12), on the other hand, estimate the volatility of clean energy stock returns and natural gas prices and use five uncertainty indices and seven global economic conditions. They detect that global economic conditions have more power than uncertainty indices to predict the volatility of natural gas and clean energy exchange-traded funds (ETFs).

The existing studies that have looked at the effects of changes in gas prices on clean energy stock returns have found a weak relationship between gas prices and clean energy stock returns. Results can be summarized with the following three statements. First, changes in gas prices have a small impact on the stock returns of clean energy companies (Reboredo and Ugolini, 2018, p. 151; Liu and Hamori, 2020, p. 24). Second, changes in gas prices have no impact on the stock returns of clean energy companies (Xia et al., 2019, p. 1; Ghabri et al., 2021, p. 4970). Third, changes in gas prices have a positive impact on the stock returns of clean energy companies (Fu et al., 2022, p. 7) (see Table 4 for detail).

Table 4 A Summary of Previous Studies on Changes in Gas Prices and the Stock Returns of Clean Energy Companies

Author, Year	Method	Data	Region	Result(s)
Hou and Nguyen, 2018	A Markov switching VAR	The wellhead price and natural gas import prices, US natural gas gross withdrawals, US IPI, RAC	US	The impact of gas demand and price shocks on gas production is negligible.
Reboredo and Ugolini, 2018	Multivariate vine copula	Brent, WTI, UK gas futures, NYMEX, ARA, NYMEX Clearport Central Appalachian Coal Futures, Phelix index, NYMEX PJM Electricity futures, ERIX, ECO, S&P 500, STOXX 50	US, Europe	Gas prices have a small impact on the stock returns of clean energy companies.

Xia et al., 2019	Connectedness network	ERIX, the Brent futures prices, UK natural gas futures prices, Phelix electricity index, coal future prices, EUA carbon futures settle prices	Europe	Strong substitution relation between electricity, oil, and coal and renewable energy.
Liu and Hamori, 2020	Connectedness network	WTI, Henry Hub gas futures, UK NBP gas futures, US government bond, UK government bond, S&P 500, STOXX 50, CBOE VIX, EURO VIX, ECO, ERIX, Brent	US, Europe	Both crude oil and natural gas returns have a modest amount of spillover effects on renewable energy stocks, with crude oil having a bigger impact than natural gas.
Ghabri et al., 2021	TVP-VAR	WTI, NYMEX, ECO, ERIX	Global	ECO returns are more affected by oil price shock than ERIX returns. After the crude oil shocks, renewable energies did not respond to the natural gas shocks.
Wang et al., 2022	Shrinkage method, volatility forecasting	Natural gas futures, Invesco WilderHill clean energy ETF, Invesco global clean energy ETF, iShares global clean energy ETF, VanEck vectors low carbon energy ETF, US equity market volatility, global EPU, geopolitical risk index, monetary policy uncertainty, US EPU, World industrial production, global steel production, Kilian index, real commodity price factor, GECON, global weakness index, global intensity index	Global	Global economic conditions have more power than uncertainty indices to predict the volatility of natural gas and clean energy exchange-traded funds (ETFs).
Fu et al., 2022	QARDL	S&P global ECO index (CLEAN), global financial stress index, WTI, gold prices, global natural gas prices	Global	Changes in natural gas prices have a beneficial effect on clean energy stocks only in the long run, while they have no effect in the short run.
Umar et al., 2022	Frequency-domain approach	CLEAN, Bloomberg WTI Crude Oil subindex, Bloomberg Natural Gas Subindex, Bloomberg GasOil subindex, Bloomberg FuelOil subindex	Global	The prices of oil and clean energy stocks are highly correlated. There are limited relationships between clean energy stocks and the natural gas and oil markets.

2.3. DATA

We use monthly data over the period 2008:01 to 2021:12, including the Eurozone debt crisis, the pandemic period, and the OPEC+[15] agreement. The data is collected mainly from DataStream and the Bloomberg terminal. The period has been determined according to the availability of data.

Regarding the model that considers oil price shocks, our data consist of global crude oil production, Brent spot prices[16], the EU IPI, and ERIX. In order to detect the oil supply shock, we will use the percent change in the global crude oil production by taking the log difference of world crude oil production in thousand barrels per day, instead of just the oil production in Europe. Since the EU relies on net imports for 92% of consumed crude oil and petroleum products, oil production in the EU alone will not have a significant impact. To obtain the real oil price, the nominal price of Brent is deflated by the harmonized index of consumer prices (HICP). The real oil prices are expressed in log levels. To capture the EU's economic activity, we use the EU monthly industrial production index, take the first difference of the natural logarithm, and convert the index into a growth rate. We use EU IPI as we are looking at a local market. Regarding the stock returns of clean energy companies, we use ERIX to represent renewable energy development. ERIX is Europe's most representative renewable energy market index, comprising the ten largest and most liquid stocks in biofuels, geothermal, marine, solar, water, and wind (Societe Generale, 2022). The ERIX index is used in log levels.

Regarding the model that considers gas price shocks, our data consist of natural gas production, Dutch TTF (Title Transfer Facility) gas prices, the EU IPI, and ERIX. To define gas supply shock, we use natural gas production in terajoules[17]. There are basically two sources of gas supply in the EU which are production and gas storage capacity (Stern and Rogers, 2014, pp. 23-24) since the EU is a net importer of gas. Since imports are determined by the equilibrium of demand from the EU and supply

[15] OPEC inked an agreement with 10 other oil-producing countries to form OPEC+.
[16] The main benchmark for oil pricing in Europe is Brent spot prices.
[17] Since gas production data for Russia is obtained in million cubic meters, it is converted to terajoules.

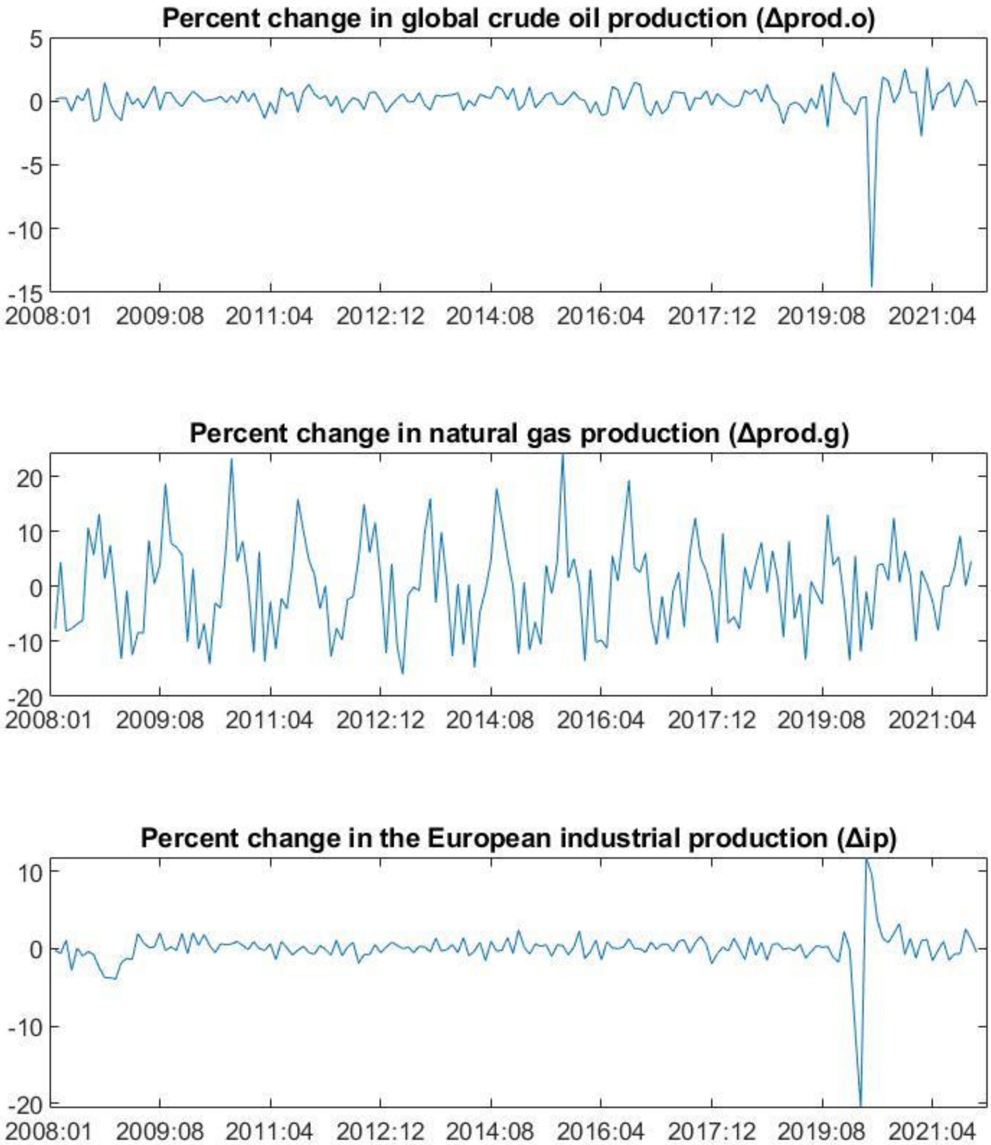
from exporting countries, to consider an exogenous supply shock we consider total production (and not just imports) from the countries that serve the EU region. The total supply for Europe is then constructed summing its own production plus imports from its suppliers: Russia, Norway, and Algeria, and only to a lesser extent Qatar[18]. Natural gas production enters the model as the percent change by taking the first difference of the natural logarithm. Then, the nominal price of TTF is deflated by HICP to obtain the real price of gas and expressed in log levels. We consider the Dutch TTF gas price because it is the leading European benchmark price. Finally, we express the EU IPI as the percentual change and ERIX is in log levels.

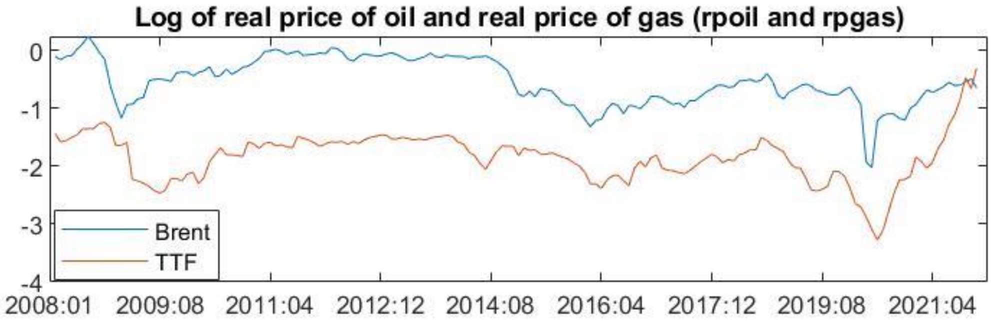
Fig. 10 shows the historical development of all the data used over the sampling period for both the oil and gas models. The percent change in global crude oil production remains relatively stable until Covid-19. However, we observe that the percent change in natural gas production fluctuates a lot. Weather events are an important factor in the demand for gas. One reason is that a difference between a cold and warm winter in Europe can easily increase gas demand by 20-30 bcm (billion cubic metres) (Honoré, 2020, p. 11). Covid-19 causes a slowdown in industrial production and mobility due to containment measures, as we can also observe. The real prices of oil and gas react to various developments in the markets. For example, both prices start to decrease after 2008, 2014, and 2019 in conjunction with the 2008 financial crisis, an increase in shale gas and oil production, and the global pandemic, respectively. After Covid-19, the rate of increase in gas price is higher than the rate of increase in oil price. This is partially the case because after the pandemic, storage was not sufficiently full and, when the economic activity regained dynamism, gas prices increased more than proportionally. ERIX experiences a rapid decline after the 2008 financial crisis. One of the most important reasons for this is the temporary stimulus packages implemented to promote clean energy before the crisis. However, some governments decided to cut subsidies, and so cuts in subsidies due to unregulated government support made the clean energy sector more fragile in the years following the financial crisis. For example, Germany cut solar subsidies in 2010, while Italy limited subsidies for solar power that same year due

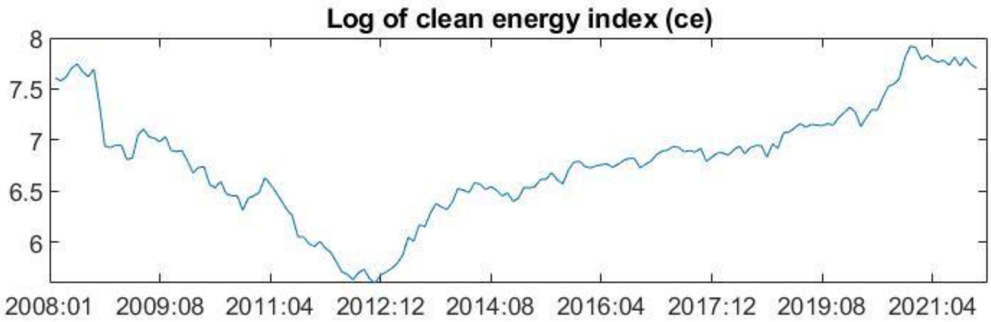
[18] Algeria and Qatar are not included in the empirical analysis due to data unavailability on monthly gas production.

to the crisis (Victor and Yanosek, 2011, p. 115). Moreover, the Czech Republic and Spain reduced tariffs on solar energy in 2010 (Tirado and Bloom, 2013). It is only in 2012 that ERIX starts to increase.

Figure 10 Historical Evolution of the Series at the European Level







Source: Author's calculations.

2.4. EMPIRICAL MODEL

This study investigates how shocks in the oil and gas markets affect the stock returns of clean energy companies in Europe. Assuming that the natural gas market is regional and fragmented, and the price of oil is dictated by worldwide markets, we begin by analyzing the effects of oil price shocks. Hence, it is crucial to show how ERIX, which stands for renewable energy development in Europe, reacts to shocks in the global oil market before showing how it reacts to shocks in the regional gas market. The model is estimated using the MATLAB software.

2.4.1. Model for the Relation between Oil Price Shocks and European Clean Energy Stocks

Following the global crude oil model proposed by Kilian (2009), we add a fourth dimension and estimate a SVAR model using monthly data of the variables described in the previous section. Precisely we estimate the SVAR for the vector of time series z_t = ($\Delta prod.o_t$, Δip_t, $rpoil_t$, ce_t), where $\Delta prod.o_t$ is the percent change in global crude oil production, Δip_t is the percent change in the EU IPI, $rpoil_t$ is the real price of oil, and ce_t is the clean energy index. In order to capture changes in crude oil demand, we utilize the EU IPI rather than Kilian's (2009) index because we are interested in researching the European market.

The reduced-form VAR model is

$$A_0 z_t = \alpha + \sum_{i=1}^{p} A_i z_{t-i} + \varepsilon_t \tag{3}$$

where ε_t denotes the vector of serially and mutually uncorrelated structural innovations, $\varepsilon_t = (\varepsilon_t^{\Delta prod.o} \varepsilon_t^{\Delta ip}{}_t, \varepsilon_t^{rpoil}, \varepsilon_t^{ce})'$. We explain fluctuations in the real oil prices in terms of three structural shocks: shocks to the global crude oil production ("oil supply shock" denoted by ε_{1t}), shocks to the demand driven by EU economic activity ("economic demand shock" denoted by ε_{2t}), and shocks from changes in precautionary demand for oil ("oil-specific demand shock" denoted by ε_{3t}).

The structural model is of the form

$$e_t \equiv \begin{pmatrix} e_{1t}^{\Delta prod.o,t} \\ e_{2t}^{\Delta ip,t} \\ e_{3t}^{rpoil,t} \\ e_{4t}^{ce,t} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} \varepsilon_{1t}^{oil\ supply\ shock} \\ \varepsilon_{2t}^{economic\ demand\ shock} \\ \varepsilon_{3t}^{oil-specific\ demand\ shock} \\ \varepsilon_{4t}^{clean\ energy\ stock\ shocks} \end{pmatrix} \tag{4}$$

Our model (4) consists of two blocks, the first of which contains the first three equations and describes the global market for crude oil, and the second of which has just the last equation and describes the market for clean energy. This is the case since our primary purpose is to explore the effects of structural shocks in the crude oil market on clean energy stock prices in Europe. Using the Cholesky decomposition method[19], the order of the variables is important because it affects the results (Wang et al., 2014, p. 26). Therefore, the Cholesky identification strategy (Eq. (4)) implicitly presupposes that

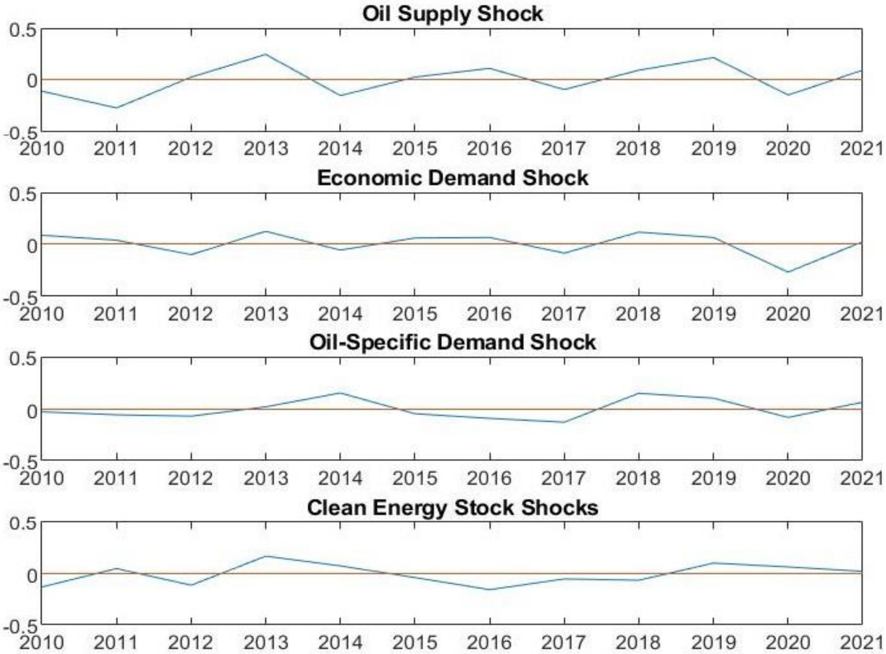
[19] Cholesky decomposition is utilized in the model to derive impulse response functions and variance decompositions.

economic activity, real price of oil and clean energy stock returns do not have a contemporaneous effect on supply of oil, but with a delay of at least one month. This is indeed the case and has been verified in recent times where rising prices did not result in oil supply increases: only exogenous events, like decisions on OPEC production quotas, can affect oil production since it implies huge investments that take time to become operative. Moreover, supply of oil does not contemporaneously react to economic activity, to the real price of oil and to changes in clean energy returns. This is what the restrictions $a_{12}=a_{13}=a_{14}=0$ imply. Also, the Cholesky decomposition assumes that economic activity is only affected by supply shock and economic demand shocks, whereas oil-specific demand shock and clean energy stock shocks do not have a contemporaneous effect on economic activity, according to $a_{23}=a_{24}=0$. In the same line, this methodology assumes that real price of oil changes instantaneously in response to oil supply shock, economic demand shock and oil-specific demand shock, but that real price of oil does not contemporaneously react to clean energy stock shocks ($a_{34}=0$). Finally, clean energy stock returns are affected by oil supply shock, economic demand shock, and oil-specific demand shock contemporaneously.

2.4.2. Structural VAR Estimates for Oil Price Shocks in Europe

Fig. 11 shows the time path of the structural shocks in the global oil market. After the Arab Uprising and the European debt crisis in 2011, there are disruptions in the oil supply. Besides, from 2014, a rise in oil supply is shown along with an increase in shale oil and gas production (Liu and Li, 2018, p. 1). After the pandemic, all shocks decrease except for the clean energy stock shock, which remains unchanged. By the rising investment in clean energy, this may indicate the start of the decoupling between fossil fuel energy sources and economic activity.

Figure 11 Historical Evolution of the Structural Shocks in the Oil Market



Source: Author's calculations.

Fig. 12 represents the responses of global oil production, economic activity, the real price of oil, and clean energy stock returns to the three structural shocks in the global oil market. We observe that the oil supply shock has no stable impact on oil production[20]. Similarly, the impact of an oil supply shock on real activity is not significant throughout the whole period. Moreover, a negative shock in global oil supply has a statistically insignificant effect on clean energy stock returns in the first six months, followed by a statistically significant negative effect on clean energy stock returns. This means that rising oil prices due to the oil supply shock in the global market do not encourage investors to switch to clean energy in the European market. Instead, oil-specific demand shocks inside the European region positively affect the clean energy stock returns after the twelve-months horizon[21]. This supports the hypothesis of substitutability between

[20] In the first five months, there is an increase in oil production from -0.5 to 0. Then, in the sixth month, the standard error bands cross the zero axis, which means that oil supply shock has no significant effect on oil production. In the seventh month, a negative oil supply shock reduces oil production, then in the eighth month, the standard error bands cross the zero axis again. After that, oil production increases for two months, then falls again. At twelve months, it again has a statistically insignificant effect.

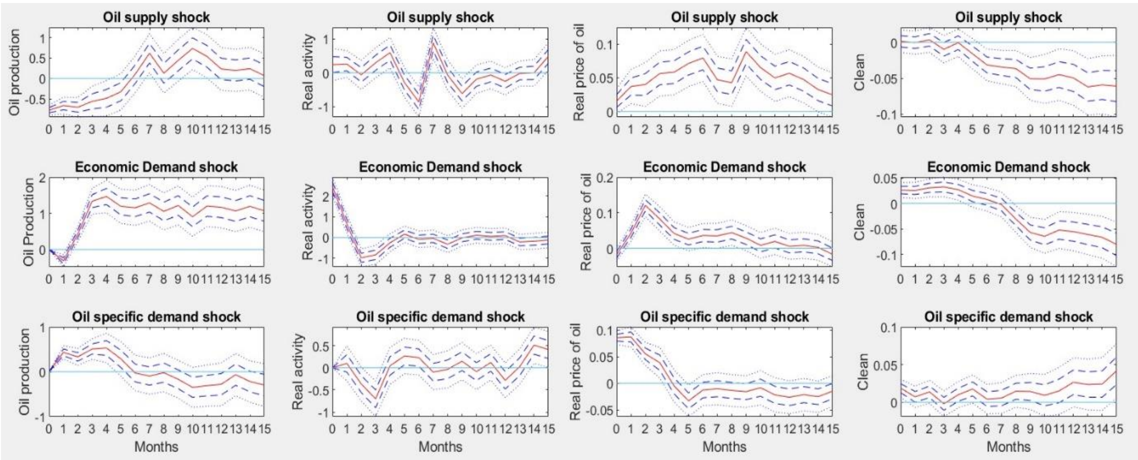
[21] Early on, clean energy stock returns' response to the oil-specific demand shock is statistically insignificant. The reason for this is that, despite the rise in oil prices after 2009, the oil-specific demand shock could not be absorbed since ERIX prices continue to fall.

oil and clean energy in the region. The explanation of this result lies in the fact that oil-specific demand shocks capture the factors that affect oil prices because of the relationship between precautionary demand and the availability of future crude oil supply (Davig et al., 2015, p. 17). In more detail, oil-specific demands are a reflection of the demand for just oil, driving the substitution effect (Maghyereh and Abdoh, 2021, p. 8).

Oil-specific demand shock initially has a strong positive impact on oil prices, but during the first five-months horizons, that impact shifts to a downward trend. One possible explanation is the decline in oil demand in the EU since 2000 (Eurostat, 2023d) as a result of many developments, such as the development of environmentally friendly vehicles, advancements in vehicle efficiency, the blending of biofuels, and the worldwide economic crisis (Cai et al., 2022, p. 1). Second explanation is that following the global financial crisis of 2008, both the price of oil and the rate of consumer price inflation as measured by HCIP, as well as the price of ERIX, all plummets. There are significant developments that contributed to the decline in the oil price during the time when the oil-specific demand shock has a declining impact on the price of oil and even when the effect turns negative: Global pandemic in 2019, shale gas and oil production boom in 2014, and 2008 global economic crisis. Both oil prices and inflation rise following these periods. According to Henriques and Sadorsky (2008, p. 1002), increased oil prices are frequently connected with inflationary pressures. Moreover, according to Kilian (2009, p. 1067), positive precautionary demand shocks increase consumer prices. Recently, rising oil prices with the Russia-Ukraine war contributes more than three percent to consumer price inflation in most countries in Europe, and even more than five percentage points in some countries such as Belgium, Netherlands, and Romania (Ari et al., 2022, p. 6).

We find that an unexpected increase in economic demand in Europe results in an immediate increase in the real price of oil and gas (see Fig. 12 and Fig. 14), which is similar to the findings of Jadidzadeh and Serletis (2017) on the global level. We also find that the positive effect of the increase in economic activity on the stock returns of clean energy lasts for eight months and turns into a negative effect afterward. The positive effect can be explained by the fact that when there is a positive aggregate demand shock, oil demand will increase, and this will cause an increase in oil prices. The effects of rising oil prices on oil-importing countries will positively affect renewable energy investment in the EU (Karacan et al., 2021, p. 2). After the second month, an economic demand shock results in a decline in the real price of oil as well as a decline in the returns on clean energy stocks.

Figure 12 Responses to the Structural Shocks in the Oil Market



Note: Dashed and dotted lines denote one-standard error and two-standard error bands, respectively.
Source: Author's calculations.

2.4.3. Model for the Relation between Gas Price Shocks and European Clean Energy Stocks

We estimate a SVAR model using monthly data for the vector of time series z_t = (Δprod.g_t, Δip_t, $rpgas_t$, ce_t), where Δprod.g_t is the percent change in gas production, Δip_t the percent change in the EU IPI, $rpgas_t$ is the real price of gas, and ce_t denotes the stock returns of the clean energy companies.

The SVAR representation is the same as in Eq. (3) but considering gas shocks. This means that, in this case, ε_t denotes the vector of serially and mutually uncorrelated structural innovations, $\varepsilon_t = (\varepsilon_t^{\Delta prod.g)}, \varepsilon_t^{\Delta ip}{}_t, \varepsilon_t^{rpgas}, \varepsilon_t^{ce})'$.

$$A_0 z_t = \alpha + \sum_{i=1}^{24} A_i z_{t-i} + \varepsilon_t \tag{5}$$

Again, similarly to the oil price shock model, here we explain fluctuations in the real gas prices in terms of three structural shocks: Shocks to the gas production ("gas supply shock" denoted by ε_{1t}), shocks to the demand driven by EU economic activity ("economic demand shock" denoted by ε_{2t}), and shocks from changes in precautionary demand for gas ("gas-specific demand shock" denoted by ε_{3t}).

The structural model is therefore

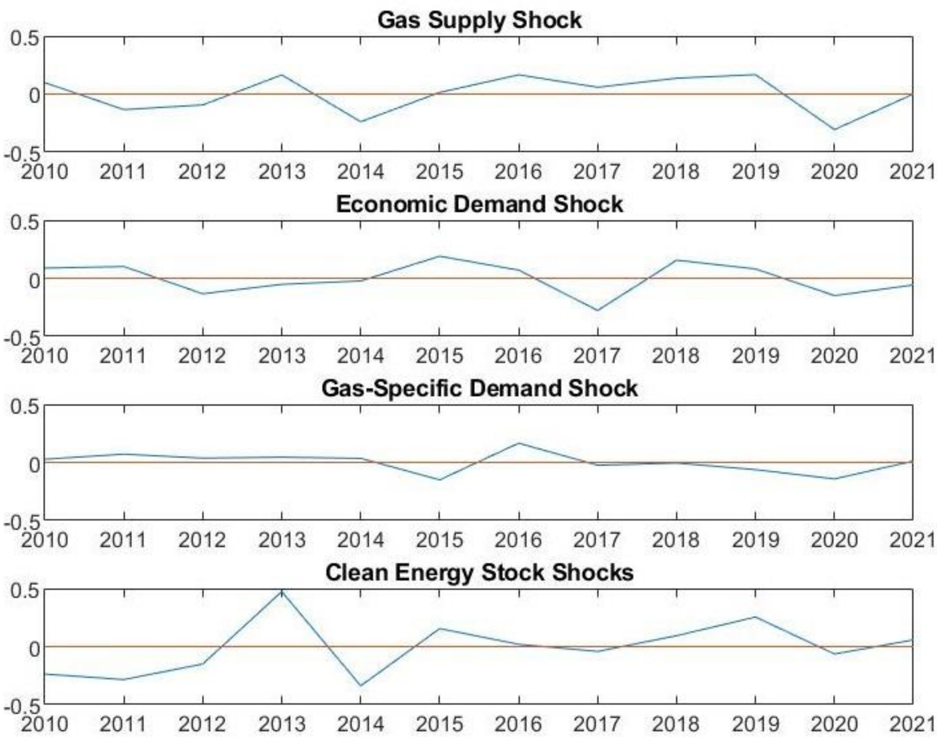
$$e_t \equiv \begin{pmatrix} e_{1t}^{\Delta prod.g,t)} \\ e_{2t}^{\Delta \mathrm{ip,t}} \\ e_{3t}^{rpgas,t} \\ e_{4t}^{ce,t} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{pmatrix} \varepsilon_{1t}^{gas\ supply\ shock} \\ \varepsilon_{2t}^{economic\ demand\ shock} \\ \varepsilon_{3t}^{gas-specific\ demand\ shock} \\ \varepsilon_{4t}^{clean\ energy\ stock\ shocks} \end{pmatrix} \tag{6}$$

Eq. (6) assumes that economic activity, real price of gas and clean energy stock returns do not have a simultaneous effect on supply of gas, but with a delay of at least one month. This is because only exogenous events can affect gas production, i.e., weather events affect gas production, as implied by the restrictions $a_{12}=a_{13}=a_{14}=0$. Also, it assumes that economic activity is only affected by supply shocks and economic demand shocks, whereas gas-specific demand shock and clean energy stock shocks do not have a contemporaneous effect on economic activity, i.e., $a_{23}=a_{24}=0$. Accordingly, real price of gas changes instantaneously in response to gas supply shock, economic demand shock and gas-specific demand shock, but that real price of gas does not contemporaneously react to clean energy stock shocks ($a_{34}=0$). Finally, clean energy stock returns are affected by gas supply shock, economic demand shock, and gas-specific demand shock contemporaneously. The previous assumptions seem plausible given that, as it is the case for oil markets, gas supply is usually decided before short-run fluctuations in the market and it is mostly affected by economic activity but not the reverse.

2.4.4. Structural VAR Estimates for Gas Price Shocks in Europe

Fig. 13 shows the time path of the structural shocks in the local gas market. Following the Arab Uprising and the Eurozone debt crisis in 2011, the supply of gas falls, just as oil supply. Clean energy stock returns have declined since that time. This can be explained by the fact that whereas oil is a global commodity, the gas market has a significant local component. Moreover, when compared to the model with oil price shocks, clean energy stock returns clearly increase in 2013 in the model with gas price shocks, suggesting that gas price shocks indicate an increase in the attractiveness of clean energy. The prices of oil and gas have decreased as shale gas and oil production increased in 2014. After the pandemic, a decrease is observed in all shocks.

Figure 13 Historical Evolution of the Structural Shocks in the Gas Market

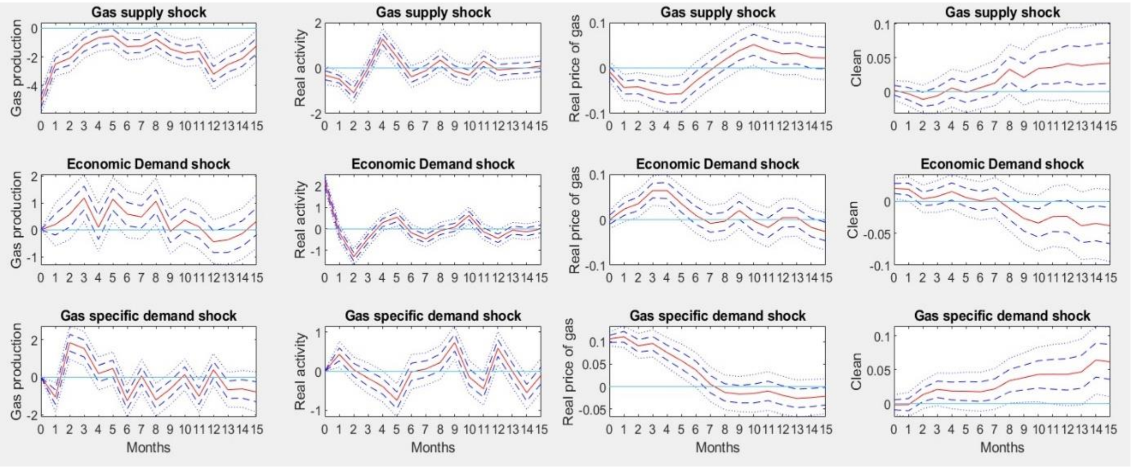


Source: Author's calculations.

Fig. 14 shows the responses of natural gas production, economic activity, the real price of gas, and clean energy stock returns to the three structural shocks in the regional gas market. The real price of gas initially decreases in response to an unexpected fall in gas production before rising. Economic demand shock affects the real price of gas at a time horizon between one and five months with a statistically significant positive impact. The real price of gas is positively impacted by the gas-specific demand shock, but this impact fades over time. One possible explanation is the decline in gas demand in Europe in the period between 2008-2015[22]. In Europe, the gas pricing formula underwent a change as of 2008. Hubs replaced oil-linked gas pricing as the predominant method of establishing gas prices between 2008 and 2014 in northwest Europe and central Europe. The main factors influencing European hub pricing are gas supply and demand. Besides, the supply of LNG (liquified natural gas) and Russian price/volume policy are two of the key factors that affect hub prices (Stern and Rogers, 2014, pp. 23-24). Several global events that could have an impact on gas prices happened during this time: 2009 Russia-Ukraine gas disputes, 2011 Libya civil war and the withheld Russian gas (Nick and Thoenes, 2014, p. 517). Knowing that the natural gas market is regional and segmented, due to the EU's heavy reliance on foreign gas, problems in the countries it imports have an impact on regional gas prices. For instance, the gas dispute that began between Russia and Ukraine in 2009 and persisted in various forms until 2014 has had an impact on the EU. Gas prices in the EU fell at this time despite the possibility of a gas supply interruption as a result of the gas dispute. This is due to three key factors. First, Russia's gas does not only transit via Ukraine on its route to Europe. Second, Europe's gas demand decreased because to the mild winter. Third, on a global scale, it was projected that natural gas liquefaction capacity would significantly grow (Desbois, 2015). Fig. 15 shows the cumulative effect of gas price shocks on the real price of gas in the EU. Keeping with Hou and Nguyen (2018), the dramatic spikes and drops in the real price of gas are mostly the result of gas-specific demand shocks. Moreover, Brown and Yücel (2008, p. 13), Nick and Thoenes (2014, p. 521) and Jadidzadeh and Serletis (2017, p. 70) emphasize that gas prices are mainly driven by other shocks in the real price of gas, such as weather, seasonality, storage, and other fuel prices, rather than the three structural shocks on the gas market.

[22] Gas demand in the EU has decreased from 418,7 bcm in 2008 to 346,7 bcm in 2015 (BP, 2021).

Figure 14 Responses to the Structural Shocks in the Gas Market

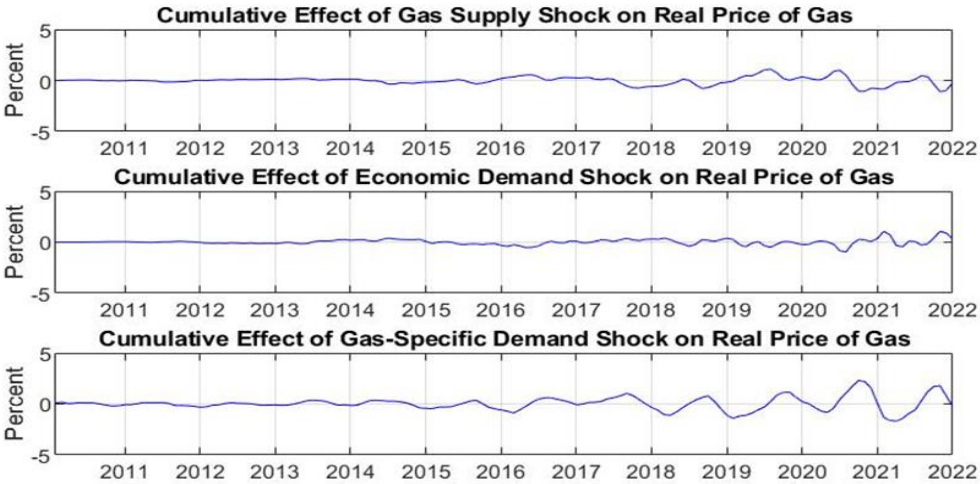


Note: Dashed and dotted lines denote one-standard error and two-standard error bands, respectively.
Source: Author's calculations.

Fig. 14 also displays that the positive effect of the economic demand shock on the stock returns of clean energy lasts for seven months but this positive effect is statistically insignificant after the first month and turns into a negative after the eighth month (and statistically significant based on a one-standard error band). An unexpected decrease in gas production has a positive and statistically significant effect on clean energy stock returns according to one standard error band after the tenth month. This is probably explained by the fact that rising gas prices encourage investors to switch to clean energy. This substitution effect can also be observed in the positive effect of a gas-specific demand shock on clean energy stock returns. If the current demand for gas decreases, this may indicate that gas producers are switching to renewable energy.

In Europe, gas is used for both heating and electricity generation. Also, in some countries, such as France, gas is used as a transition fuel meaning that its usage is coupled with renewables. Instead, in countries like Germany, gas is used to generate electricity as a baseload. Therefore, Europe, which is dependent on gas imports for both heating and electricity generation, is greatly affected by the changes in natural gas prices. One of the best ways to get out of this situation is seen as the transition to renewable energy. The record high gas prices, especially after Covid-19, brought this transition to the fore. However, the transition to renewable energy did not go as expected. One of the reasons for this is that gas is used for heating. Even if gas prices rise drastically, the switch to renewable heat, such as heat pumps, is not easily encouraged to replace gas used for heating. Most homeowners need to change their heating source, but this is very difficult, so sudden changes in prices are not enough to encourage the transition to renewable heat (Keating, 2022). On the other hand, the share of fossil sources in electricity generation in the EU has decreased from 39% in 2019 to 37% in 2021. The largest portion of this fall is due to the decline in coal, as Europe's concentration prior to Covid-19 was on coal and not natural gas. In other words, coal was being replaced by renewable energy prior to Covid-19. However, the situation altered after Covid-19, and the gas crisis resulting from the Russia-Ukraine war served as a major wake-up call for all investors. Although gas prices soared to extremely high levels in Europe as a result of the global pandemic, the prices of renewable energy fell to extremely low levels. But instead of spurring a significant expansion in renewable energy, this led to the replacement of gas by renewable energy. Over the previous two years, the amount of renewable electricity has increased by an average of 44 terawatt-hours annually, with half of this new wind and solar power replacing gas plants (Keating, 2022; Moore, 2022). Ghabri et al. (2021, p. 4970) reveal that the announcement of Covid-19 affected the ERIX index more than the ECO index because Covid-19 created more uncertainty in Europe than in the US, especially in the early days of its spread. They also find that gas prices and the ERIX index are moving in the same direction. In the impulse response function above, a demand shock decreases both the real price of gas and clean energy stock returns after the third month.

Figure 15 Cumulative Effects of Gas Price Shocks on the Real Price of Gas



Source: Author's calculations.

2.5. CONCLUSIONS AND POLICY IMPLICATIONS

This study tackles the question of how different oil and gas price shocks affect clean energy stock returns in Europe by using a SVAR. To the best of our knowledge, this is the first study of the relationship between oil price shocks and clean energy stock returns at the European level. In addition, previous studies on the natural gas market do not separately identify gas price shocks at the European level.

Our main findings are as follows. First, a negative gas supply shock has a beneficial impact on clean energy stock returns, implying that clean energy is a viable alternative to gas for European investors, contrary to what we could expect given the labeling of gas as green by the European Commission in July 2022. Instead, a negative shock to global oil supply has no statistically significant effect on clean energy stock returns throughout the period studied. This means that rising oil prices due to the oil supply shock in the global market do not encourage investors to switch to clean energy in the European market. This may be showing a lack of credibility in the European agenda on green transportation. Second, we reasonably find that both the oil-specific and the gas-specific demand shocks have a positive effect on the stock returns of clean energy companies, meaning that there is a king-of-scale effect in demand that extends to all energy sources. Finally, we find that the oil price model outperforms the gas price model in terms of how long the positive effects of economic demand shocks on clean energy stock returns last.

The previous results show there is a substitution effect operating in Europe, where a shock that decreases competitivity of fossil sources positively affects clean energy stocks. Zhao (2020, p. 15) and Maghyereh and Abdoh (2021, p. 8) find that in understanding the variability in clean energy stock returns, oil-specific demand shocks are far greater in significance than oil supply and aggregate demand shocks. This is due to the fact that a negative supply shock is a brief decrease in production brought on by a supply disruption in the short run. This may be due to a shock such as an unexpected military intervention in an oil-exporting country. We do not expect this kind of event to produce an immediate substitution in oil-importing countries. Indeed, Wang et al. (2014, p. 27) emphasize that crude oil production consists of long-run investments that are capital-intensive.

The previous results are important to draw the lines for future energy policy. Firstly, they show that, even if the European Commission endorsed gas as a green course thinking to its complementarity with intermittent renewables, investors do not consider gas this way, and shocks in the market generate substitution towards clean energy. Secondly, in the actual context of rising fossil fuel prices due to the Ukrainian conflict, we are likely to observe a strong substitution of those sources with clean energy, good news for European energy sovereignty as well as for the transition to a net-zero economy.

CHAPTER 3

THE IMPACT OF INVESTOR ATTENTION ON THE GREEN BOND MARKET

"Growth is stopped by rising pollution. [….] The economic impetus such resource availability provides must be accompanied by curbs on pollution if a collapse of the world system is to be avoided."

Meadows, D.H., Meadows, D.L., Randers, J., Behrens III, W.W. (Club of Rome) (1972, p. 133). *The Limits to Growth.* New York: Universe Books.

3.1. INTRODUCTION

This study examines the role of investor attention in the development of green bond market. Climate change is an indisputable reality and a significant concern that occupies a prominent position on the international agenda. Environmental shocks will undoubtedly become more severe and frequent. Furthermore, it is noteworthy that climate risk is increasingly emerging as a significant financial concern. Investors have so made efforts to identify innovative solutions across many asset classes that successfully address the difficulties coming from climate change (Jack Morton Auditorium, 2018). The imperative for collaboration between financial professionals and environmental advocates has led to the emergence of green bonds as a prominent instrument within the realm of sustainable finance. Green bonds have facilitated the financing of emission reductions, sustainable development, and other investments in cleaner production, so aiding in the achievement of the 2°C temperature target set forth in the Paris Agreement. Since that green bonds are only used to ecologically favorable projects, they are crucial in the efforts to combat climate change. Earlier finance research has demonstrated that efforts in environmental protection rarely generate economic returns for companies. However, as the economy has recovered, this viewpoint has shifted, and current data demonstrates that adopting green practices may unquestionably increase profits for companies (Baulkaran, 2019, p. 332; Tang and Zhang, 2020, p. 17; Flammer, 2021, p. 514). Consequently, there has been an increased utilization of green bonds as a means to fund initiatives aimed at reducing emissions and promoting sustainable development, so making a significant contribution towards achieving the 2°C temperature target outlined in the Paris Agreement.

The first green bond, known as the Climate Awareness Bond, was issued by the European Investment Bank in 2007 and was valued 600 million euros (European Investment Bank, 2021). The proceeds from this bond offering were used to provide financial support to renewable energy projects. The World Bank issued its first green bond at $300 million in 2008, following the European Investment Bank (OECD, 2015a, p. 14). The World Bank developed a model for how green bonds should be constructed when it issued the first one. The Green Bond Guidelines were developed using this model as its foundation. Also, a number of banks were involved in the creation of these market-wide voluntary guidelines, which later evolved into recommendations for independent reviews and the establishment of some transparency rules. For investors to comprehend the climate risk exposure of their investments, transparency is essential (Jack Morton Auditorium, 2018). Because transparency guarantees that investors obtain accurate information to support the funding of green projects. Transparency also enables issuers to accurately manage the proceeds from their green bonds and to gauge the actual effect of their green initiatives. Besides, the expansion of the high-quality market is hampered by a lack of transparent, comparative, and verifiable impact data and transaction costs (IDB, 2019, p. 4).

The market for green bonds expanded from $0,8 billion in 2007 to $2,313 trillion as of April 2023 (CBI, 2023a). Yet, given that the size of the global bond market is $123,8 trillion as of August 2020 (ICMA, 2023), this just represents a minor portion of the total bond market. Furthermore, following its initial emergence in 2007, the phenomenon of the green bond boom materialized in 2013, characterized by a substantial increase in the issuing of green bonds. The primary cause of this phenomenon can be attributed to the emergence of corporations and financial institutions in the market throughout the year

2013. The publication of the Green Bond Principles[23] by the International Capital Markets Association (ICMA) in 2014 marked a turning point, which increased the market from $37 billion in 2014 to $85 billion in 2016 and $158,5 billion in 2017 (CBI, 2023b). The entry of Chinese issuers into the market is one among the factors contributing to this increase in 2016.

Investor attention in the green bond market is anticipated to rise in the future for a number of reasons. First, recent studies (Zhou and Cui, 2019, p. 22; Baulkaran, 2019, p. 332; Kuchin et al., 2019, p. 17; Jormalainen, 2020, p. 68; Tang and Zhang, 2020, pp. 17-18; Flammer, 2021, p. 514) demonstrate that issuing green bonds boosts a company's ESG[24] score, contributes to the improvement of the environment, raises the company's value as a result of a favorable market response, and increases ownership of the company as stock prices rise in response to the green bond. All of these results indicate that the green bond will provide diversification benefits to investors and garner their attention (Pham and Huynh, 2020, p. 1). Second, IEA (2021a, p. 3) states that the number of companies setting a zero-emission target is increasing. Thus, worries about climate change are drawing investors' attention to the financial effects of climate change and motivating them to seek environmentally friendly investments (Pham and Huynh, 2020, p. 1; Piñeiro-Chousa et al., 2021, p. 5; Pham and Cepni, 2022, p. 200). Third, according to the Climate Bond Initiative (CBI) (2018, p. 20), the growth and success of the green bond market will be contingent upon the attention of retail investors. Retail investors' interest in sustainable investing has been rising significantly in recent years. Retail investors may also play a significant role in encouraging institutional investors to properly handle the risks associated with climate change and allocating cash toward green projects. These factors also serve as the motivation for this study, which looks at how investor attention affects the green bond market. Besides, Tang and Zhang (2020, p. 2) attempt to disclose how the stock prices and stock liquidity of listed companies would change as a result of the issuance of green bonds via three

[23] Green Bond Principles (GBP) are voluntary guidelines published by the ICMA, that can be seen as a secretariat of CBI, for the issue of green bonds.
[24] Environmental, Social and Governance: The three main determinants that enable investors to gauge the sustainability and social impact of an investment in a company.

mechanisms[25]. The "investor attention" channel is one of these mechanisms. According to the "investor attention" mechanism, issuing a green bond for the first time by a publicly traded company is equivalent to labeling the company as "green". This will improve media visibility and draw the attention of investors. This will significantly boost the company's visibility and extend its investor base by drawing the attention of bond and stock investors. They disclose that stock turnover increases considerably in conjunction with green bond issuance and that Google search volume spikes on the days of the event as well. They come to the conclusion that the market is certainly keeping track of a company's progress with green bonds. Based on the findings of Tang and Zhang (2020)'s study and in light of the growing influence of media on financial markets (Da et al., 2011, p. 1462; Gan et al., 2020, p. 2), it is imperative to examine the impact of investor attention on the green bond market. The primary research question of this chapter is whether the global Covid-19 pandemic and the ensuing energy security issues brought on by the Russia-Ukraine war have an impact on investor attention in green bonds. By doing this, we will also look into how uncertainties in the stock, bond, and energy markets, as well as the investment performances of the clean energy, oil, and gas markets affect the connectedness between green bonds and investor attention.

This study makes a valuable contribution to the existing body of research on green bonds by exploring the relationship between green bonds and investor attention. This is a significant area of investigation, as there is a limited amount of literature that examines the interplay between behavioral finance and clean energy finance. To our knowledge, there are only four studies that look at the relationship between investor attention and green bond market performance, but only two of them directly examine the connection between green bonds and investor attention: Pham and Huynh (2020) and Pham and Cepni (2022), while the other two, Piñeiro-Chousa et al. (2021) and Piñeiro-Chousa et al. (2022), directly examine the connection between green bonds and investor sentiment[26]. Our paper differs from Pham and Huynh (2020) and Pham and

[25] Three mechanisms are the "financing cost", "investor attention", and "firm fundamental" (Tang and Zhang, 2020, p. 2).

[26] Investment sentiment and investor attention are two distinct behavioral concepts. Investor sentiment is the process by which investors form their beliefs (Barberis et al., 1998, p. 308). Besides, investor sentiment is characterized as either a tendency for speculating or as optimism or the pessimism toward stocks in general (Baker and Wurgler, 2006, pp. 1648-1649). However, investor attention is a scarce

Cepni (2022) in several aspects. First, our data includes the impact of Russia's declaration of war on Ukraine. We examine the effects by splitting them into three sub-periods (pre-Covid-19, Covid-19, and Russian invasion of Ukraine) in addition to the overall effect. Second, we also examine the effect of market uncertainty in the stock, bond, and energy, and the investment performances of the clean energy, oil, and gas markets, on the link between green bonds and investor attention. While Pham and Huynh (2020) examine only general market conditions including the bond, stock, and energy commodity markets on the relationship between green bonds and investor attention, Pham and Cepni (2022) examine the volatility of the stock, bond, and energy markets similar to us. However, they do not concentrate on how investment performances of the clean energy, oil, and gas markets affect this relationship.

Following is a summary of the main findings. First, connectedness between investor attention and the success of the green bond market is stronger in the short term compared to the long term. Second, there is positive but small spillovers between investor attention and green bond returns. The impact of investor attention on the returns of green bonds is most pronounced during the Covid-19 period. This effect diminishes during the war period. Third, it can be observed that the influence of investor attention on other series is more pronounced in the short-term as opposed to the long-term. Fourth, there is a feedback channel between green bond returns and investor attention. This feedback channel exists due to the fact that green bond returns that are a net receiver of shocks from investor attention are likely to be followed by green bond returns that are a net transmitter of shocks. Fifth, during periods of Covid-19, all market volatilities have a higher impact on investor attention and green bond returns. Finally, VIX, CLEAN (S&P Global ECO Index) and OVX (CBOE crude oil volatility index) are the shock transmitters in the network, but OVX affects the system less than other shock transmitters.

The subsequent sections of the third essay are structured in the following manner. Section 3.2 contains information on green bonds, their market, and investor attention, as

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cognitive resource, hence investors are unable to closely monitor every market development (Kahneman, 1973, p. 2). However, despite conceptual differences between investor sentiment and investor attention, both behavioral concepts' predictions are similar (Prapan and Vagenas-Nanos, 2022, p. 4).

well as highlighting earlier literature on green bonds and investor attention. The data used and summary statistics are given in Section 3.3. The empirical strategy is presented in Section 3.4. The empirical results are discussed in Section 3.5, while Section 3.6 provides the concluding remarks.

3.2. EMPIRICAL LITERATURE

3.2.1. Overview of Green Bond Market

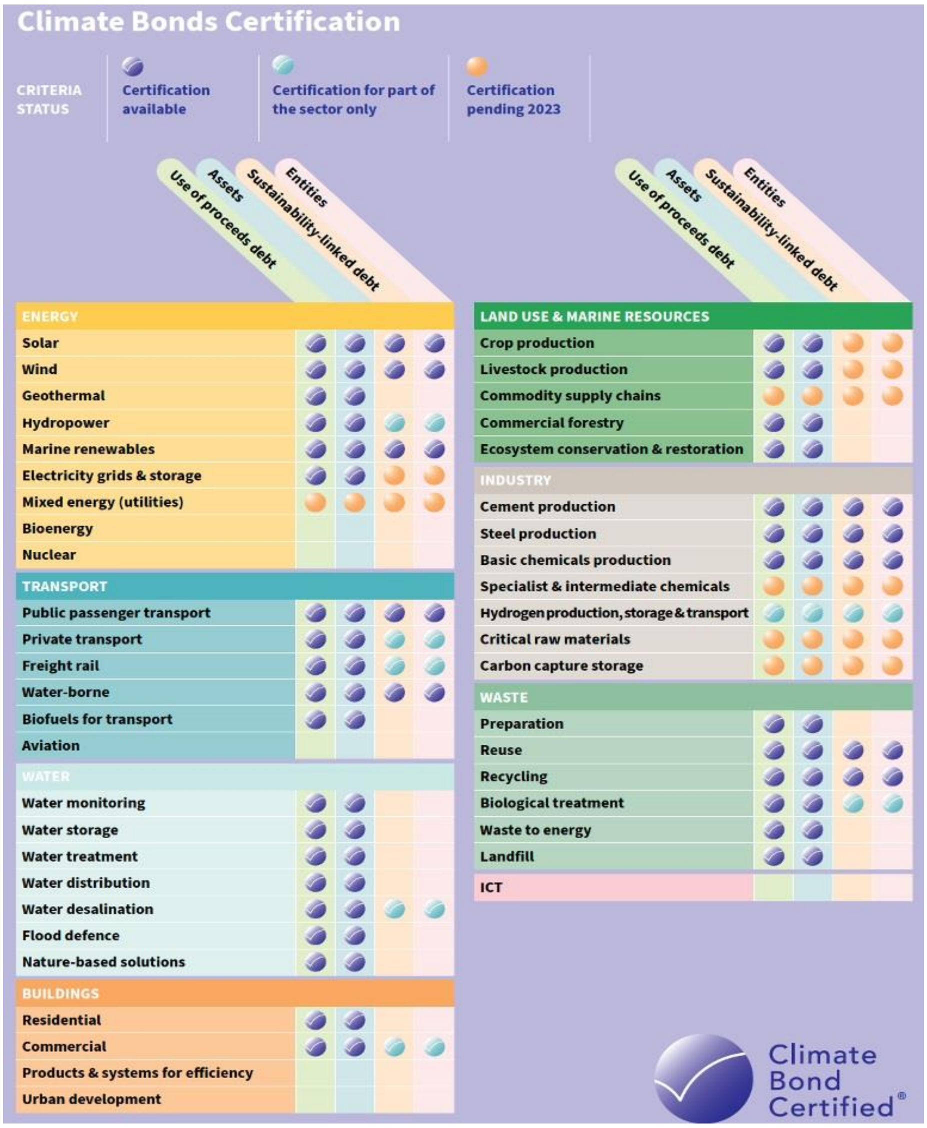
Green Bond Principles define green bonds as “any type of bond instrument where the proceeds or an equivalent amount will be exclusively applied to finance or re-finance, in part or in full, new and/or existing eligible green projects and which are aligned with the four core components[27] of the GBP” (ICMA, 2021, p. 3).

Green bonds have comparable characteristics to traditional corporate bonds with fixed income (Baulkaran, 2019, p. 331; Reboredo and Ugolini, 2020, p. 25; Ferrer et al., 2021, p. 1). The concept entails the bond issuer acquiring a predetermined sum of capital from investors for a specified duration referred to as “maturity”. Upon the bond reaching maturity, the issuer returns the “principal” amount to the investors. Additionally, the issuer disburses a predetermined interest amount, known as “coupons”, at regular intervals throughout the bond’s lifespan (OECD, 2015a, p. 5). The only difference from a regular bond is that green bonds are labeled to indicate that they will be used for environmentally friendly projects (renewable energy, energy efficiency, pollution prevention and control (such as greenhouse gas control, waste prevention), environmental sustainable management of living natural resources and land use (such as environmentally sustainable agriculture, animal husbandry, forestry), conservation of terrestrial and aquatic biodiversity, clean transportation, sustainable water and wastewater management, adaptation to climate change, eco-efficient and/or circular economy adapted products, production technologies and processes, and green buildings)

[27] Green bonds ought to be in line with the four components of GBP which are use of proceeds, process for project evaluation and selection, management of proceeds, and reporting. Use of proceeds is a fundamental aspect of a green bond issuance, as it necessitates the allocation of funds exclusively towards qualifying green projects (ICMA, 2021, p. 7).

(Fatica and Panzica, 2020, p. 5; ICMA, 2021, pp. 4-5). Fig. 16 shows the Climate Bonds Taxonomy prepared by CBI. The Climate Bonds Taxonomy serves as a roadmap for initiatives and assets that are climate-aligned. It is a tool to assist issuers, investors, governments, and municipalities in understanding the crucial investments that will bring about a low-carbon economy. This is prominent since there is not a methodology that is universally accepted for determining whether projects are green. Issuers can look at a taxonomy that specifies the assets and projects if they want to know how to identify which projects will be regarded as green.

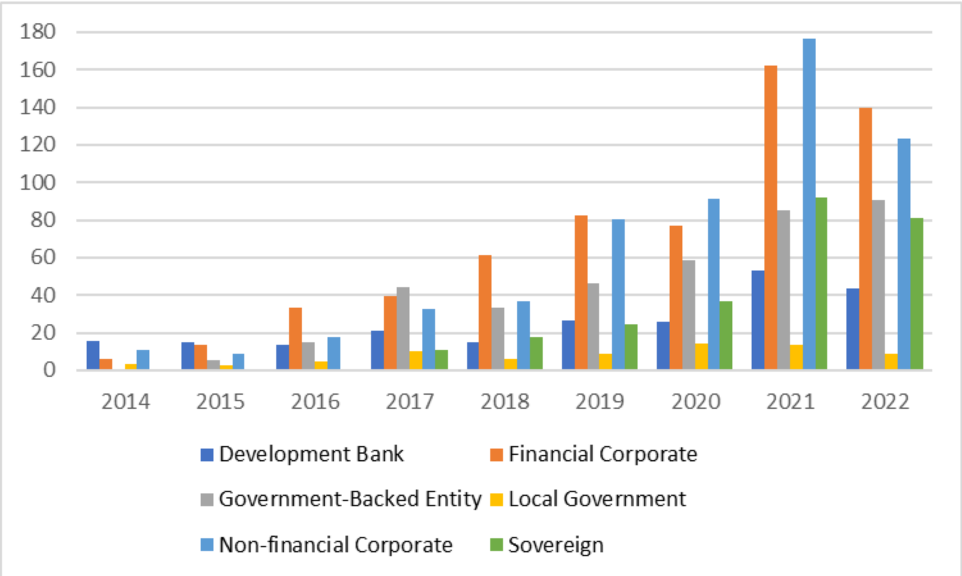
Figure 16 Climate Bonds Taxonomy



Source: CBI, 2023a.

Green bonds are issued to fund climate change solutions; the main point is that the revenue is invested in green assets. They can be printed by various types of issuers such as local governments, government-backed entity, sovereign, development bank, asset-backed securities (ABS), financial corporates and non-financial corporates (CBI, 2020, p. 6). The issuer types over time are depicted in Fig. 17. In contrast to 2014, when the development bank holds the largest portion, by 2022 it is financial corporations. As of 2022, with 28,7% of the volumes, financial corporates contribute the most, while non-financial corporates make up 25%. Nearly half of the green bonds issued in the private sector come from European corporations. The two institutions that contributed the most to the issue of private sector green bonds are the Danish multinational energy corporation Orsted and the German commercial bank Helaba (CBI, 2023b).

Figure 17 Issuer Types

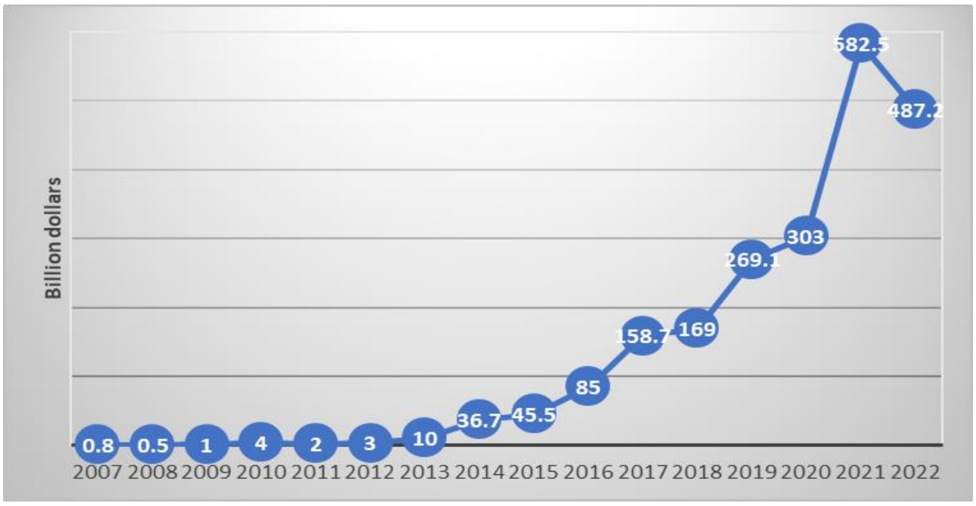


Source: CBI, 2023b.

The most important distinction in terms of green bonds is actually the difference between labeled and unlabeled green bonds. Labeling is a useful tool for identifying green bonds as a particular sub-universe of environmental (Ng and Tao, 2016, p. 514). Labeled green bonds refer to bonds being marketed as green bonds. On the other hand, unlabeled green bonds refer to bonds used for environmentally friendly projects but not marketed as green bonds. For this reason, labeling a bond as a green bond distinguishes that bond from other bonds and indicates that the funds to be obtained through the issuance will be used in environmentally friendly projects. Unlike unlabeled green bonds, labeled green bonds have gone through the issuer's adoption process of the GBP. Bonds issued by issuers who accept the GBP and meet the requirements can subsequently be referred to as "labelled green bonds".

Fig. 18 shows the historical evolution of the green bond issuance. The world's first green bond, known as the Climate Awareness Bond, was issued by the European Investment Bank in 2007 and had a value of 600 million euros. In 2008, the World Bank issued its first green bond, which was valued $300 million. Although the green bond market began in 2007, the year 2013 is known as the "green bond boom" (the year when the issuing of green bonds grew significantly). This is mostly because of the entry of corporations and financial institutions into the market in 2013. In addition, the ICMA's release of the Green Bond Principles in 2014 marked a turning point, and the entry of Chinese issuers in 2016 significantly boosted the issuance of green bonds. Green bond issuance is $487,2 billion in 2022; of that amount, developed markets accounted for 67,5%, developing markets for 23,3%, and supranational entities for 9,2% (CBI, 2023b).

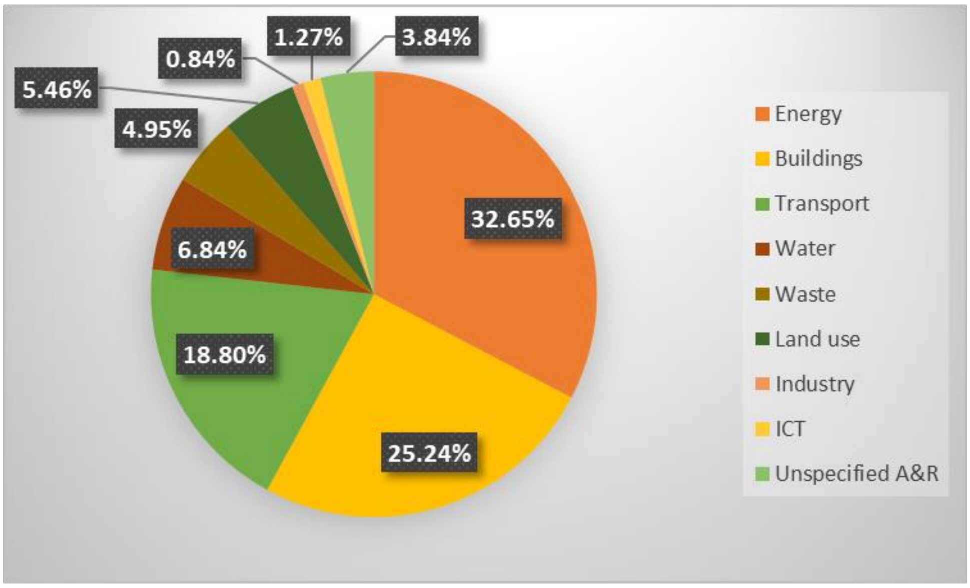
Figure 18 Growth in Green Bond Market



Source: The statistics pertaining to the years 2013 and subsequent years are gathered from the Global State of the Market reports, which are meticulously prepared by the CBI. Other data is from CBI (2023b).

The majority of green bond issuances, 77% of the overall volume of green debt, are in the sectors of Energy, Buildings, and Transportation, as depicted in Fig. 19. This is mostly due to the fact that non-financial corporates, who make up around 25% of the overall green bond issuing volume, desire to finance Energy, Buildings, and Transportation sectors. For instance, Apple issued a total of $4,7 billion green bond as of 2022 to assist the company's efforts to utilize greener materials in its products and to lower its carbon footprint (Apple, 2022). Toyota issued a $750 million green bond in February 2020 to assist fund automobiles that fulfill clean air standards such as powertrain, fuel efficiency, and emissions (Toyota Financial Services, 2020). Besides, public sector entities, such as municipalities or government-backed entities, commonly provide waste and water management services. However, their contribution to the overall volume of green bonds is relatively small compared to financial and non-financial corporations. Specifically, local governments account for 1,85% of the total volume, while government-backed entities contribute 18,6%.

Figure 19 Green Bond Proceeds for 2022



Source: CBI, 2023b.

There are several advantages of issuing green bonds. Current studies (Zhou and Cui, 2019, p. 22; Baulkaran, 2019, p. 332; Kuchin et al., 2019, p. 17; Jormalainen, 2020, p. 68; Tang and Zhang, 2020, pp. 17-18; Flammer, 2021, p. 514) show that issuing green bonds increases the company's ESG score, contributes to environmental improvement, increases the value of the company as it causes a positive market reaction, increases the ownership of the company as stock prices respond positively to the green bond, enhancing issuers' reputation as it helps in showcasing their commitment towards sustainable development, in providing extra source of environmentally friendly financing and in increasing long-run green funding through resolving maturity mismatch. Banks in many countries are unable to provide long-run green loans due to the short maturity of their liabilities and the absence of methods for hedging duration risks. Corporations that can only acquire short-run bank funding are also worry about refinancing long-run green initiatives.

On the other hand, there are also some challenges and barriers in the green bond market. The first is a lack of awareness of the benefits of green bonds because the market is still too immature (Kuchin et al., 2019, p. 5). The second is a lack of universally accepted standardization. There are Green Bond Principles published by ICMA, but this is a voluntary guideline. The third is a lack of standard definition of green bonds. This means that the definition of "green" varies by country. For example, projects such as "clean" coal and retrofitting fossil fuel power plants are deemed "green" in China, but not globally. Furthermore, about 34% of China's green bond issuance in 2016 (particularly a substantial percentage used for clean coal) did not adhere to international standards (Velloso, 2017, p. 18). The fourth is high cost of meeting green bond requirements. Second opinion or third-party assurance providers (such as accounting companies and specialist research agencies) determine whether issuers use the "green bond" for the intended purpose. A further obstacle for some small issuers in particular markets is the comparatively high cost of getting a second opinion or third-party assurance, which can range from USD 10,000 to USD 100,000. Issuers have also voiced their displeasure with the significant expenses associated with handling disclosure requirements (OECD, 2015b, p. 29). The last one is difficulties for international investors to access local green markets. Because different markets have different disclosure standards and definitions for green bonds. These variances raise transaction costs since green bonds recognized in one market must be re-labeled or re-certified in another (OECD, 2015b, p. 29).

3.2.2. Empirical Literature on Green Bond Market

Over the past five years, not only has the literature on the green bond market expanded, but so has the scope of research. Studies on the green bond market generally focus on investigating the difference between the green bond and conventional bond (greenium or green bond premium). A greenium has been proven by Karpf and Mandel (2017), Baker et al. (2018), Zerbib (2019), Nanayakkara and Colombage (2019), and Pietsch and Salakhova (2022), among others. In other words, they discover that the yield on a green bond is lower than that of a conventional bond. Larcker and Watts (2020) and Petrova (2016), however, do not discover any proof of a greenium. However, Baulkaran (2019, p. 331), Reboredo and Ugolini (2020, p. 25) and Ferrer et al. (2021, p. 1) find that green bonds have similar features in terms of the pricing and yields to conventional fixed-income corporate bonds. The only distinction is that green bonds are only utilized for eco-friendly initiatives (Fatica and Panzica, 2020, p. 12). However, Jormalainen (2020, p. 67) shows that with a premium of 0,60 to 0,84%, green bonds are more affordable than conventional bonds.

Second strand of the literature investigates the relationship between oil price and green bond dynamics. Lee et al. (2021, p. 7) point out that movements of oil price have explanatory power for green bond price dynamics. Kanamura (2020, p. 17) uses different green bond indices and looks at the link between green bonds and oil prices and finds that while there is a positive correlation between the Bloomberg Barclays MSCI, the S&P green bond index, and crude oil price returns, there is a negative correlation between the Solactive green bond index and crude oil prices. Su et al. (2023, p. 553), on the other hand, find that while the effect of oil prices on the green bond return is positive in the short run, this positive effect turns negative in the medium and long run. Besides, they also observe that the effect of the green bond return on the oil price is positive, indicating that because of the instability in the Middle East, Covid-19, and the modest scale of green bonds, green bonds are not regarded as effective ways to mitigate the oil crisis. Dutta et al. (2020, p. 4) examine whether green investments respond significantly to oil price shocks and observe that green assets are more sensitive to oil market volatility than to fluctuations in oil prices. However, Nguyen (2020, p. 57) finds that there is a negative correlation between OVX and green bond returns but this negative effect is statistically insignificant. Besides, OVX is statistically less significant when evaluated together with the uncertainty in the energy and stock markets (VXXLE (CBOE energy sector ETF volatility) and VIX, respectively). Pham and Nguyen (2022, p. 9) find that especially in low uncertainty periods, there is a small degree of connectedness between green bond returns and uncertainty indices (VIX, OVX, and EPU (economic policy uncertainty)). It means that spillover effects are smaller. Yet, in the case of high uncertainty, spillover effects are greater but less permanent. Azhgaliyeva et al. (2021, p. 10) investigate the effects of oil price shocks (supply, demand, and risk shocks) on green bond issuance and demonstrate that oil supply shocks affect green bond issuance in a positive way in the private sector.

The third strand of green bond research focuses on the impact of the issuance of green bonds on the financial performance of companies, reflecting the investor perspective. For example, Baulkaran (2019, p. 332) and Tang and Zhang (2020, p. 17) observe that stock prices increase after the green bond issuance. They also find that green bond issuance contributes to increasing corporate ownership and improving stock liquidity. Besides, issuing green bonds can provide greater media visibility and benefit existing shareholders. Like Tang and Zhang (2020), Reboredo and Ugolini (2020, p. 25) find that green bonds can help companies expand their investor base and improve their corporate social responsibility. Unlike Tang and Zhang (2020), they reveal that the green bond market is weakly linked to the stock market. Moreover, Flammer (2021, p. 514), in consistent with Tang and Zhang (2020), find that stock market is positively impacted by the issuance of green bonds, with companies improving their environmental performance and experiencing an increase in ownership.

The fourth strand investigates the relationship between green bonds, clean energy, and environmental performance. Fatica and Panzica (2020, p. 3) find a reduction in the carbon intensity of non-financial companies' assets after the green bond issuance. Conversely, Hammoudeh et al. (2020, p. 1) deduce that green bond index does not have the power to predict environmental (ECO and CO_2 emission allowances) and financial variables (the US 10-year treasury bond index). Wang et al. (2022, p. 10) take the issue in terms of signaling theory and provide evidence that the issuance of green bond supports the signaling theory, that is, it signals that companies are indeed exhibiting climate-friendly corporate behavior (not doing greenwashing) by issuing green bonds. They also find that issuing green bonds has an impact on climate risk concerns, in other words, most firms have elevated climate risk concerns after issuing green bonds. In terms of relationship between clean energy, Yan et al. (2022, p. 6479) find that there is a bi-directional causality relationship between green bonds, oil prices, gold prices and clean energy stocks, and an increase in the clean energy stock positively affects green bond market. On the contrary, Tang et al. (2023, p. 19) reveal that green bond market has not yet had much impact on the clean energy and fossil fuel markets because they find a weak negative correlation between green bond and fossil fuel and clean energy markets (see Table 5 for detail).

Table 5 A Summary of Previous Studies on Green Bond Market

Scope: The difference between the green bond and conventional bond		
Author, Year	**Method**	**Result(s)**
Karpf and Mandel, 2017	Decomposition method	A greenium has been proven.
Baker et al., 2018	General equilibrium model of Henkel, Kraus, and Zechner (2001), the taste-based framework of Fama-French (2007)	A greenium has been proven.
Zerbib, 2019	Matching method	A greenium has been proven.
Larcker and Watts, 2020	Matching method	A greenium has not been proven.
Petrova, 2016	Multi-factor benchmark model	A greenium has not been proven.
Baulkaran, 2019	Event study	Green bonds have similar features in terms of the pricing and yields to conventional fixed-income corporate bonds.
Reboredo and Ugolini, 2020	SVAR, spillover measure	Green bonds have similar features in terms of the pricing and yields to conventional fixed-income corporate bonds.
Ferrer et al., 2021	Time-frequency connectedness method of Baruník and Krehlík (2018)	Green bonds have similar features in terms of the pricing and yields to conventional fixed-income corporate bonds.
Jormalainen, 2020	Multi-factor regression, sensitivity analysis, event-study	Green bonds are more affordable than conventional bonds.
Scope: The relationship between oil price and green bond dynamics		
Author, Year	**Method**	**Result(s)**
Lee et al., 2021	Granger-causality in quantiles analysis	Movements of oil price have explanatory power for green bond dynamics.
Kanamura, 2020	A model of price correlations	While there is a positive correlation between the

	between green bonds and energy assets, a green bond premium model	Bloomberg Barclays MSCI, the S&P green bond index, and crude oil price returns, there is a negative correlation between the Solactive green bond index and crude oil prices.
Su et al., 2023	Quantile-on-quantile method	While the effect of oil prices on the green bond return is positive in the short run, this positive effect turns negative in the medium and long run.
Dutta et al., 2020	Markov regime switching	Green assets are more sensitive to oil market volatility than to fluctuations in oil prices.
Nguyen, 2020	OLS regression	There is a negative correlation between OVX and green bond returns, but this effect is statistically insignificant.
Pham and Nguyen, 2022	Markov switching dynamic regression, TVP-VAR	Spillover effects between green bond returns and uncertainty indices are smaller in low uncertainty periods but is greater in high uncertainty periods.
Azhgaliyeva et al. ,2021	The multilevel longitudinal random intercept and random coefficient models	Oil supply shocks affect green bond issuance in a positive way in the private sector.
Scope: The impact of the issuance of green bonds on the financial performance of companies		
Author, Year	**Method**	**Result(s)**
Baulkaran, 2019	Event study	Stock prices increase after the green bond issuance.
Tang and Zhang, 2020	Event study	Stock prices increase after the green bond issuance.
Reboredo and Ugolini, 2020	SVAR, spillover measure	The green bond market is weakly linked to the stock market.
Flammer, 2021	Event study	Stock prices increase after the green bond issuance.
Scope: The relationship between green bonds, clean energy, and environmental performance		
Author, Year	**Method**	**Result(s)**
Fatica and Panzica, 2020	Matching method	Carbon intensity of non-financial companies' assets decreases after the green bond issuance.
Hammoudeh et al., 2020	Time-varying causality	The green bond index does not have the power to predict environmental and financial variables.
Wang et al., 2022	Shrinkage method	Issuing green bonds has an impact on climate risk concerns.
Yan et al., 2022	QARDL	An increase in the clean energy stock positively affects green bond market.
Tang et al., 2023	Bayesian DCC-MGARCH, frequency connectedness	Green bond market has not yet had much impact on the clean energy.

3.2.3. Overview of Investor Attention

Behavioral finance was developed to explain numerous unexplained modern financial abnormalities, including the Monday effect, the equity premium puzzle, and the media effect. Behavioral finance theory contends that investors' behavioral decision-making processes are complex and that their decisions are not always rational; nonetheless, it contends that even if investors are rational, their rationality is limited. The simplest way to determine if investors are acting irrationally is to look at how they behave in actual market situations (Su and Wang, 2022, p. 4).

Emphasizing that the concept of attention began to be a central issue in an emergent cognitive psychology in the late 1950s, Kahneman (1973, p. 2) defines attention as limited cognitive resources and emphasizes that attention is required for the processing of information and decision making. Investors' attention is limited; therefore, they cannot monitor all market developments closely. To put it another way, most investors struggle to get timely and accurate market information.

A major obstacle in research on the role of investor attention is choosing an accurate measure of investor attention. We summarize which measure is used to determine investor attention in studies conducted in different fields in Table 6. Investor attention was not directly reflected prior to Da et al. (2011) and excess returns, trading volume, and turnover, which solely display the transaction characteristics of the financial market, were frequently utilized in the early research as proxies for variables representing investor attention. Direct indicators of investors' attention have been developed to forecast stock market movement, including the search volume index (SVI), social networks (Twitter feeds, blogs, forums, Wikipedia, etc.), news, etc. (Yang et al., 2017, p.1). The first study to employ Google Search Volume Index (GSVI) to gauge investor attention was done by Da et al. (2011). Da et al. (2011, p. 1497) investigate the relationship between investor attention and asset prices and find that the increase in the GSVI causes positive stock returns in the next two weeks, followed by negative returns. There are other approaches for assessing investor attention, but due to the widespread usage of the Google search engine, the GSVI has become a generally recognized indicator in financial market research to represent investor attention (Xiao and Wang, 2021, p. 2). It is significant to highlight that metrics of investor attention based on data from social media platforms and Google search activity mostly capture the attention of retail investors (Da et al., 2011, p. 1497; Pham and Cepni, 2022, p. 187) because SVI serves as an indicator of individual attention.

GSVI is the most often utilized proxy in the literature that examines the relationship between investor attention and asset prices and financial markets (Da et al., 2011; Nafar, 2015; Han et al., 2018; Piñeiro-Chousa et al., 2020; Duan, 2022; Halousková et al., 2022). However, Jiang et al. (2022, p. 568) analyze the relationship between investor attention and asset price anomalies in China using the Baidu index as a reflection of investor attention because Baidu index is China's most popular search engine and includes all Chinese common stocks listed on the Shanghai and Shenzhen stock exchanges, as well as subforums for each firm. As a result, coverage based on the East Money Stock Forum is more extensive in the Baidu index than in the GSVI. Yang et al. (2017, p. 9) employ the increments of the attention volume for each stock (IAVS), which differs from GSVI and Baidu index. While examining the impact of investor attention on stock market volatility, several researchers (Andrei and Hasler, 2015; Said and Slim, 2022) also employ GSVI. On the other hand, Ballinari et al. (2022, pp. 5-6) gauge retail investors' attention in a firm by tallying the number of messages sent on social media platforms about it on a daily basis via StockTwits. StockTwits is a social media network similar to Twitter, but it differs from Twitter in that it is primarily built for the exchange of thoughts, information, and ideas between investors. Deng et al. (2022) and Wan et al. (2021) use the Baidu index as a proxy for investor attention to examine the relationship between investor attention and environmentally friendly investments, while Song et al. (2019) use the GSVI. Amin and Ahmad (2013) and Xiao and Wang (2021) also use GSVI in order to investigate the interaction between investor attention and firm's financial performance.

In the studies examining the green bond-investor attention relationship, Pham and Huynh (2020), Pham and Cepni (2022), and Tang and Zhang (2020) employ GSVI to measure investor attention. However, Broadstock and Cheng (2019) rely on news articles relating to "green bonds" obtained from the Dow-Jones Factiva database to measure investor attention, whereas Gao et al. (2021) adopt the Baidu index as the proxy variable of investor attention for China.

Table 6 A Summary of Selected Measures to Determine Investor Attention

Scope	Researchers	Measure
The relationship between investor attention and asset prices and financial markets	Da et al., 2011; Nafar, 2015; Han et al., 2018; Piñeiro-Chousa et al., 2020; Duan, 2022; Halousková et al., 2022	GSVI
	Jiang et al., 2022	Baidu index
	Yang et al., 2017	IAVS
The relationship between investor attention and stock market volatility	Andrei and Hasler, 2015; Said and Slim, 2022	GSVI
	Ballinari et al., 2022	The number of messages sent on social media platforms about it on a daily basis via StockTwits
The relationship between investor attention and environmentally friendly investments	Deng et al. 2022; Wan et al. 2021	Baidu index
	Song et al., 2019	GSVI
The relationship between investor attention and firm's financial performance.	Amin and Ahmad, 2013; Xiao and Wang, 2021	GSVI
The relationship between green bond and investor attention	Pham and Huynh, 2020; Pham and Cepni, 2022; Tang and Zhang, 2020	GSVI
	Broadstock and Cheng, 2019	News articles relating to "green bonds" obtained from the Dow-Jones Factiva database
	Gao et al., 2021	Baidu index

3.2.4. Empirical Literature on Investor Attention

The relationship between investor attention and asset pricing is one of the most researched topics in behavioral finance literature. When looking into how investor attention affects asset price dynamics, Peng (2005, p. 324) discovers that capacity constraints lead to delayed consuming behavior and have an impact on how quickly information is factored into asset pricing. Barber and Odean (2008, p. 785), Da et al. (2011, p. 1461) and Andrei and Hasler (2015, p. 33) find that investor attention has a substantial effect on determining asset prices. Da et al. (2011, p. 1461) also discover that a rise in the search volume index, which measures investor attention, foretells higher stock prices in the coming two weeks and a potential price reversal later on in the year. Nafar (2015, p. 4) shows that security prices are influenced by the level of investor attention. More recently, Halousková et al. (2022, pp. 8-9) examine how the volatility of asset prices in particular nations are influenced by investors' attention to the war between Russia and Ukraine by developing Google search-based military conflict attention and a general stock market attention. They recover that whereas the impact of the conflict attention measure is negligible before the invasion, it considerably affects volatility during the period of increasing war risks. In addition, they discover that the impact of attention is stronger in nations that are closer to and more open to Russia. Jiang et al. (2022, p. 583) investigate how investor attention and asset pricing anomalies interact and discover a positive correlation between investor attention and subsequent anomaly returns. They attribute this positive correlation to three causes: Underreaction due to limited attention, bias amplification, and coordinated arbitrage. They (2022, p. 563) also discover that anomaly returns typically increase after days with high levels of attention.

Some researchers (Yang et al., 2017; Piñeiro-Chousa et al., 2020; Liu et al., 2021, amongst others) look into the connection between investor attention and stock markets, while others (Long et al., 2016; Ballinari et al., 2022; Said and Slim, 2022) have widened their research by including stock market volatility into the associated relationship. Yang et al. (2017, p. 9) employ the IAVS and discover that the impact of the IAVS on stock market movement is more consistent and significant when compared to Baidu index. Additionally, they discover that the IAVS may have a forecasting effect on stock market movement on the same trading day. Piñeiro-Chousa et al. (2020, p. 7) investigate the effect of investor attention on the water companies' stock returns and find that stock returns of water companies are negatively correlated with investor attention because investors' increased sensitivity to environmental issues has encouraged them to conserve water, which has resulted in a decline in the stock returns of water companies. Focusing on the China's A-share listed new energy companies and polluting companies, Liu et al. (2021, p. 8) examine the relationship between air pollution, investor attention and stock prices and discover that the general state of the stock market affects how the link between air pollution, investor attention, and stock prices fluctuate. To put it another way, while the market is in a bullish period, investors are optimistic, and air pollution as bad information negatively affects investors' expectations, prompting investors to show less attention in the stock market. However, when the stock market is performing poorly, investors will be more cautious, and air pollution will cause investors to start focusing more and more on the stocks of new energy and polluting industries. To gauge investor attention in a specific industry, Long et al. (2016, p. 61) create two distinct indexes, a positive and a negative one, and reveal that the positive index has a substantial adverse effect on stock index volatility but no discernible impact on stock index return. The return and volatility of the stock index are both significantly influenced by the negative index, though. More recently, on their study of the impact of institutional and retail investor attention on stock market volatility, Ballinari et al. (2022, p. 16) discover that both have the opposite effect on stock return volatility: While institutional investor attention lowers volatility, retail investor attention increases it on days after news releases. Said and Slim (2022, p. 21) document that investor attention in the short run has a beneficial effect on future volatility. However, the impact of investor attention is projected to reverse in the long run.

Numerous research has examined the connection between investor attention/investor sentiment and environmentally friendly investments in light of the current climate change concerns. For example, Reboredo and Ugolini (2018, p. 153) conclude that Twitter sentiment has no significant impact on returns, volatility, or trading volumes, whereas Song et al. (2019, p. 1) indicate that investor sentiment, measured by GSVI, toward renewable energy can partially explain the return and volatility of renewable energy stock. According to López-Cabarcos et al. (2019, p. 8), social network sentiment affects the returns of sustainable companies but has no bearing on those of unsustainable ones. Wang et al. (2021, p. 11) discover a significant negative link between media environmental attention and the stock returns of green industry companies. Wan et al. (2021, p. 4) look at the effect of investor attention on investments in clean energy and fossil fuels during the Covid-19 period in China and discover that the performance of clean energy companies rises during the pandemic (the period of attention shift in investor behavior during the unexpected crisis), but that of fossil fuel companies does not. Similar to Wan et al. (2021), Deng (2022, p. 7) finds in their study for China that the occurrence of environmental events will dramatically alter investor attention and ultimately boost pro-environmental investment.

The effects of investor attention have also been studied in different fields. For instance, Amin and Ahmad (2013, p. 111) investigate the impact of investor attention on the firm's financial performance and discover that profitability, liquidity, and volatility are all partially influenced by investor attention. Besides, they find that investor attention has a greater impact on a company's liquidity than on its profitability or volatility. Xiao and Wang (2021, p. 10) investigate whether the adjustment of EPU in G7[28] and BRIC[29] countries alter the link between investor attention and oil market volatility. The initial finding of this study reveals that shifts in investor attention can exert a favorable influence on total oil market volatility. Then, when the total volatility is divided into the good volatility and the bad volatility, it is discovered that the bad volatility is more affected by changes in investor attention than the good volatility. In addition, they note that EPU strengthens the favorable relationship between investor attention and bad volatility; this relationship, however, is only impacted by EPU in the US and Canada. Andrei et al. (2023, p.33) investigate the connection between economic uncertainty and investor attention on earnings announcements at the firm level and find that investor attention to firm-level data is increasing as economic uncertainty rises (see Table 7 for detail).

Table 7 A Summary of Previous Studies on Investor Attention

Scope: The relationship between investor attention and asset pricing		
Author, Year	**Method**	**Result(s)**
Peng, 2005	Continuous-time equilibrium model	Capacity constraints have an impact on how quickly information is factored into asset pricing.
Barber and Odean, 2008	Sort method	Investor attention has a substantial effect on determining asset prices.
Da et al., 2011	VAR, Fama-MacBeth (1973) cross-sectional regressions	Investor attention has a substantial effect on determining asset prices.
Andrei and	Equilibrium model	Investor attention has a substantial effect on

[28] Group of Seven: Canada, France, Germany, Italy, Japan, the United Kingdom, and the US.
[29] Brazil, Russia, India, China.

Hasler, 2015		determining asset prices.
Nafar, 2015	Fama-Macbeth (1973) regression for panel data	Security prices are influenced by the level of investor attention.
Halousková et al., 2022	HAR-RV model	The conflict attention measure considerably affects volatility during the period of increasing war risks.
Jiang et al., 2022	Dynamic logit model	There is a positive correlation between investor attention and asset price anomalies.
Scope: The relationship between investor attention and stock markets		
Author, Year	**Method**	**Result(s)**
Yang et al., 2017	Single-variable regression analysis in time series	IAVS has a forecasting effect on stock market movement on the same trading day.
Piñeiro -Chousa et al., 2020	Generalized method of moments (GMM)	The stock returns of water companies are negatively correlated with investor attention.
Liu et al., 2021	The mediating effect model proposed by Zhao et al. (2010) and MacKinnon et al. (2000)	The general state of the stock market affects how the link between air pollution, investor attention and stock prices fluctuate.
Long et al., 2016	Fama-French three-factor model	The positive index has a substantial adverse effect on stock index volatility but no discernible impact on stock index return. The negative index exerts a substantial impact on both the return and volatility of the stock index.
Ballinari et al., 2022	Fixed effects panel predictive regression model	Institutional and retail investor attention have the opposite effect on stock return volatility.
Said and Slim, 2022	Empirical similarity model, heterogenous autoregressive model	Investor attention has a beneficial effect on future volatility in the short run, while this impact turns to reverse in the long run.
Scope: The relationship between investor attention/investor sentiment and environmentally friendly investments		
Author, Year	**Method**	**Result(s)**
Reboredo and Ugolini, 2018	SVAR, spillover measure	Twitter sentiment has no significant impact on returns, volatility, or trading volumes.
Song et al., 2019	Diebold-Yilmaz (2014) spillover method	Investor sentiment toward renewable energy can partially explain the return and volatility of renewable energy stock.
López-Cabarcos et al., 2019	GARCH, logit and probit	Social network sentiment affects the returns of sustainable companies.
Wang et al., 2021	SVAR, mediating effect model	There is a negative link between media environmental attention and the stock returns of green industry companies.
Wan et al., 2021	Regression modelling	When there is a shift in investor behavior during the unexpected crisis in China, the performance of clean energy companies rises.
Deng, 2022	Multi-quantile VAR Granger causality	When there is a shift in investor behavior during the unexpected crisis in China, the performance of clean energy companies rises.
Scope: The relationship between investor attention and firm's financial performance		
Author, Year	**Method**	**Result(s)**
Amin and Ahmad, 2013	ARDL	Profitability, liquidity, and volatility are all partially influenced by investor attention.
Scope: The relationship between investor attention and oil market volatility		
Author, Year	**Method**	**Result(s)**
Xiao and Wang, 2021	Regression model	Shifts in investor attention can exert a favorable influence on total oil market volatility.
Scope: The relationship between investor attention and economic uncertainty		
Author, Year	**Method**	**Result(s)**

Andrei et al., 2023	Multi-firm equilibrium model	Investor attention to firm-level data is increasing as economic uncertainty rises.

3.2.5. Empirical Literature on the Relation between Investor Attention and Green Bond Market

Investor attention, a well-recognized predictor of financial market performance in the field of behavioral finance, has not been thoroughly investigated in previous research on green bonds. There are just two scholarly articles, namely Pham and Huynh (2020) and Pham and Cepni (2022), that specifically investigate the correlation between green bonds and investor attention. By using the Diebold-Yilmaz (2012) connectedness model, Pham and Huynh (2020, pp. 4-7) evaluate how investor attention, as measured by GSVI, affects the performance of the green bond market. Additionally, they assess the importance of the bond, stock, and energy commodity markets in the relationship between green bonds and investor attention. They reach the conclusion that green bond returns and volatility can be influenced by investor attention, but the connection varies over time. More specifically, the relationship between investor attention and green bond market performance exhibits a significant short-term interdependence; however, the relationship fades in the long run. Additionally, it is found that the influence of investor attention on the volatility of green bonds is rather minor compared to other factors. By constructing a quantile connectedness network and using two alternative measures of investor attention which are retail investor attention as measured by GSVI and institutional investor attention as measured by Bloomberg Terminal news, Pham and Cepni (2022) investigate the impact of investor attention on the performance of green bonds. Furthermore, the researchers examine the impact of several macroeconomic variables on the relationship between investor attention and the financial performance of green bonds. According to their findings (2022, p. 200), a reciprocal relationship (feedback effect) exists between investor attention and green bond returns. This relationship is particularly obvious in the context of the Covid-19 pandemic, which has exacerbated instability in financial markets. This discovery suggests that the performance of green bonds is greatly impacted by the level of attention received from investors. Moreover, the correlation between green bonds and investor attention is significantly impacted by market volatility, as indicated by the VIX, OVX, EPU, and MOVE (Merrill Lynch Option Volatility Estimate) indices.

However, only two papers, Piñeiro-Chousa et al. (2021) and Piñeiro-Chousa et al. (2022), directly examine the relationship between green bonds and investor sentiment. Piñeiro-Chousa et al. (2021, p. 5) use the generalized method of moments (GMM) to analyze the impact of investor sentiment on the green bond performance. Additionally, they look into how investor sentiment and green bond returns are related to the S&P 500 index, VIX, and the S&P GSCI Natural Gas Index (GAS), which are each proxy for the stock market, market volatility, and investment performance of the natural gas market, respectively. They derive investor sentiment from the messages posted on Twitter and find a significant influence of investor sentiment on green bond performance. More specifically, if sentiment toward green bonds rises on Twitter, so will the returns of green bond indices, and vice versa. They also discover that the returns on green bonds are found to be unaffected by VIX, but to have a negative relation with returns on the S&P 500 and GAS indices. Using Wang's (2015) panel smooth transition regression model, Piñeiro-Chousa et al. (2022, p. 525) investigate whether the S&P 500, VIX, and the MSCI World index would affect investor sentiment and consequently on the return of green bonds. Their findings demonstrate that variations in the S&P 500 and VIX indices do not affect the relationship between investor sentiment and returns on green bond indices (i.e., do not support the switching behavior), but that the MSCI World index, to some extent, leads this relationship to deviate from the linear one (see Table 8 for detail).

Table 8 A Summary of Empirical Literature on the Relation between Investor Attention/Sentiment and Green Bond

Related literature in the link between investor attention and green bond market			
Author(s), year	**Method**	**Index**	**Result(s)**
Pham and Huynh, 2020	Diebold-Yilmaz (2012) connectedness model	GSVI	Investor attention and green bond market performance have a considerable short-run influence on each other, but the relationship fades in the long term.

Pham and Cepni, 2022	A quantile connectedness network	Retail investor attention as measured by GSVI, Institutional investor attention as measured by Bloomberg Terminal news	The performance of green bonds is significantly influenced by investor attention.
Related literature in the link between investor sentiment and green bond market			
Author(s), year	**Method**	**Index**	**Result(s)**
Piñeiro-Chousa et al., 2021	GMM	Investor sentiment from the messages posted on Twitter	A significant influence of investor sentiment on green bond performance.
Piñeiro-Chousa et al., 2022	Wang's (2015) panel smooth transition regression model	Investor sentiment from the messages posted on Twitter	Variations in the S&P 500 and VIX index do not affect the relationship between investor sentiment and returns on green bond indices.

Numerous studies indirectly examine the relationship between green bonds and investor attention. For example, Broadstock and Cheng (2019, p. 20) calculate the green bond market sentiment by employing 5300 news articles relating to green bonds and provide evidence that the relationship between green and black bonds is sensitive to a variety of factors, including positive and negative news-based sentiment towards green bonds. Tang and Zhang (2020, p. 2) investigate whether green bond issuance benefits shareholders by concentrating on investor attention as well. They demonstrate that with the issuance of green bonds, stock turnover and Google search volume both considerably increase around the event days. This shows that the market is actually keeping track of a firm’s progress with green bonds. In other words, investors pay attention to the firm’s environmentally friendly initiatives. However, investors will pay attention when a firm announces the issuing of its first green bond. Because the firms have already been exposed to the public, the media exposure effect will disappear following the initial issue, which is the investor attention theory. Wang (2020) finds no results supporting the theory of investor attention. According to investor attention theory, CARs (cumulative abnormal returns) will be zero since subsequent green bond issuances will not attract investors’ attention. However, Wang (2020, p. 297) finds that the CARs induced by the first and subsequent issuances of green bonds are not equal to zero and are negative, indicating that changes in the cumulative excess returns of listed firms are not caused by changes in investor attention. Gao et al. (2021, p. 20) investigate the influence of investor attention on green security markets, including the green bonds and green stocks in China and show that green stocks and investor attention are more interdependent than green bonds. Chen et al. (2022, p. 11) investigate the general investor reaction to green bond announcements in the stock markets of Mainland China and Hong Kong and discover that both stock markets react positively to green bond announcements, indicating that investor reaction is favorable.

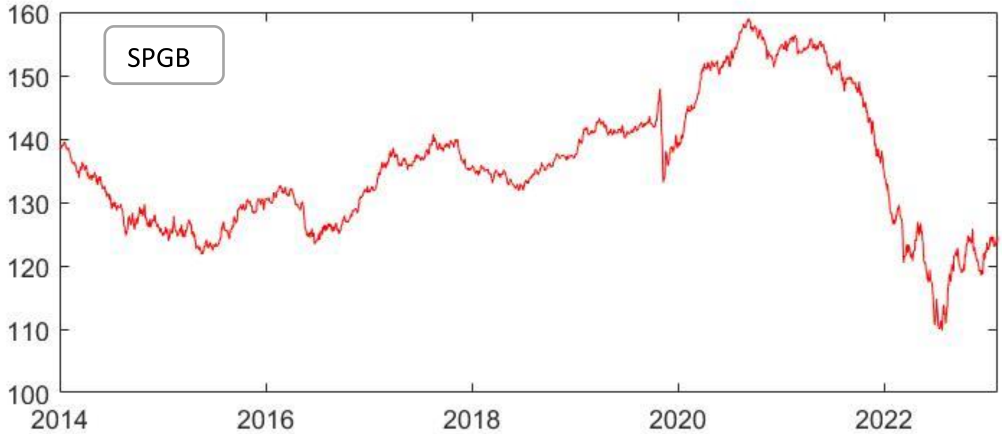
3.3. DATA AND SUMMARY STATISTICS

This study employs the S&P green bond index (SPGB) to monitor the performance of the green bond market. This index tracks the performance of green-labelled bonds that are issued globally, weighted by market value (S&P Global, 2023a, p. 3). In further detail, this index is a worldwide index that comprises green bonds that have been labelled by CBI and are issued from any country in any currency (S&P Global, 2023a, p. 5). Next, the study adopts the Google Search Volume Index (GSVI) as a proxy for investor attention since it is widely used in the body of behavioral finance literature. Using GSVI, we incorporate the keyword "Green bond" to provide an attention index for the green bond market. Our attention measures are retrieved from Google Trends. Since the launch date of the SPGB is July 31, 2014, our data set ranges from July 31, 2014 to April 28, 2023, with a total of 2275 daily observations. Fig. 20 depicts the daily values of GSVI[30] and SPGB indices. There is an upward trend in the GSVI over time. Investor attention and green bond returns have grown, particularly since 2016. One possible explanation can be the entry of Chinese issuers into the green bond market. It has been noted that once Covid-19 has been designated as a pandemic by the WHO (World Health Organization) (i.e. after March 11, 2020), investor attention as well as green bond returns surge. Both indices continue their upward trend but begin to fall after February 24, 2022 (when Russia started its invasion of Ukraine). One possible explanation is that when the war was first declared, nations, particularly those in the EU, began to explore for alternatives to Russian gas and focused on guaranteeing

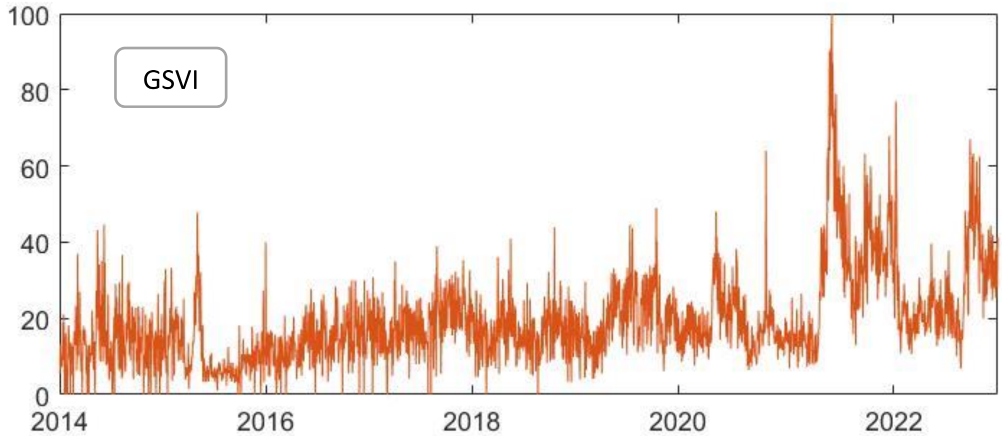
[30] Google calculates the relative search volume for a keyword with an indexed value between 0 and 100. For a given keyword, 0 denotes the lowest relative search interest and 100, the highest relative search interest. For extended periods of time, Google provides monthly statistics rather than daily data. Due to this, daily data for each month is multiplied by the corresponding month's search interest weight in order to properly compare periods in long-run data. This ensures that the processed daily data and monthly data follow roughly the same paths. In accordance with Pham and Cepni (2022), we add 1 to this index before log-transforming because the GSVI index has a minimum value of 0.

energy security; as a result, the use of coal-fired power plants was prioritized during this time, followed by a truly doubled transition to clean energy (Tollefson, 2022, p. 233).

Figure 20 Daily Values of SPGB and GSVI Indices



Source: S&P Global (2023b).



Source: Google trends (2023).

Along with these factors, we also include control variables to account for market volatility in the stock, bond, and energy markets, which are represented by VIX, MOVE, and OVX, respectively, as well as the investment performance of the oil, gas, and clean energy sectors, which are represented by the S&P GSCI crude oil index, the S&P GSCI natural gas index, and the S&P Global ECO index, respectively. All series is non-stationary at levels but stationary in its first difference. Therefore, all series are used in log-differenced in the subsequent analyses, depending on the outcomes of the unit root tests. The following are the reasons why we chose these control variables:

- The VIX index can serve as a valuable instrument for investors in evaluating the level of risk, fear, or market stress before to making investment decisions, since it provides insights into the overall movement of the stock market (Kuepper, 2023). An increase in the VIX index frequently indicates an escalation in market volatility, potentially impacting the green bond market. The VIX serves as a representative measure for stock market volatility within the model.
- The fixed-income markets that include treasury, corporate debt, and high-yield corporate debt are intricately linked to the green bond market, and developments in those markets have an impact on the green bond market (Reboredo and Ugolini, 2020, p. 34). The MOVE index, also referred to as the bond market volatility index, is used to gauge the volatility of the fixed-income market.
- Dutta et al. (2020, p. 4) reveal that green assets exhibit a higher degree of sensitivity to oil market volatility compared to swings in oil prices. They also discover that crude oil volatility has a major impact on the returns on environmental investments, which in turn influences investor attention in these markets (Pham and Cepni, 2022, p. 198). OVX is used as a proxy for energy market volatility in the model.
- Based on the fact that green bonds are exclusively employed for investments that promote environmental sustainability and taking into account that approximately 32% of green bond issuance is allocated towards clean energy investments (CBI, 2023b), it is expected that there will be a significant correlation between the returns of green bonds and the performance of the clean energy market. The S&P Global ECO index (CLEAN) is employed as a proxy for assessing the investment performance of the clean energy market.
- Naeem et al. (2021, p. 10) and Piñeiro-Chousa et al. (2021, p. 5) discover a substantial negative correlation between natural gas returns and green bond returns. It implies that green bond returns rise following a fall in the natural gas market, and vice versa. It demonstrates the hedging feature of green bonds in decreasing portfolio risk for investors in the gas market,

therefore, influencing investors' attention to green investments. Therefore, S&P GSCI natural gas index (GAS) is used as a proxy for investment performance of the natural gas market.

- The decline in oil prices has a negative impact on the attractiveness of green assets for investors, while simultaneously increasing the attraction of oil investments. Consequently, this shift in preference towards oil investments significantly influences the level of attention that investors allocate to green investments. Besides, Khamis and Aassouli (2023, p. 23) observe green bonds as an effective diversifier in a portfolio of natural gas and crude oil, indicating that investors in the oil and gas market are turning to green bonds to reduce portfolio risk, suggesting that green bonds can provide effective diversification benefits to fluctuations in oil and gas returns. S&P GSCI crude oil index (OIL) is used as a proxy for investment performance of the oil market.

Table 9 demonstrates the descriptive statistics of the log-differenced series. Unconditional variance of SPGB and CLEAN is the lowest, followed by that of OIL, GAS, MOVE, OVX, VIX and GSVI. This suggests that SPGB and CLEAN have the lowest volatility, while GSVI has the highest. Moreover, GSVI, OVX, VIX and MOVE are positively skewed, whereas SPGB, CLEAN, OIL and GAS are negatively skewed. In addition, Jarque-Bera (JB) test statistics show that all series are not normally distributed. According to ERS unit root test, all log-differenced series are stationary[31].

[31] The stationarity of all series is also supported by the KPSS unit root test. The results of KPSS unit root tests are in Appendix 9.

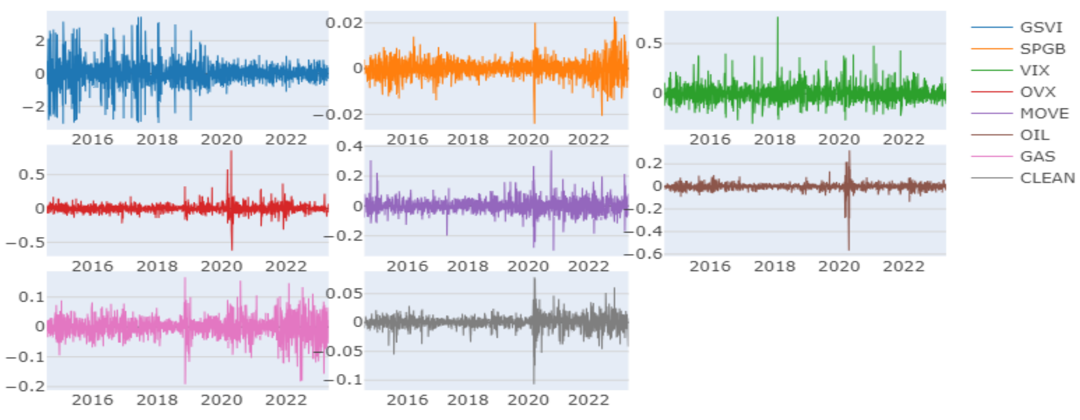
Table 9 Descriptive Statistics of the Log-Differenced Series

	GSVI	SPGB	OVX	VIX	MOVE	CLEAN	OIL	GAS
Mean	0.001	0	0	0	0	0	0	0
Variance	0.399	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Skewness	0.07	-0.2***	1.5***	1.2***	0.5***	-0.6***	-2.6***	-0.2***
Excess Kurtosis	7.04***	4.6***	29.6***	7.3***	8.3***	11.6***	64.0***	3.2***
JB	4709.8*** (0.000)	2056.4*** (0.000)	83999.2*** (0.000)	5769.9*** (0.000)	6674.0*** (0.000)	13086.9*** (0.000)	391612.6*** (0.000)	998.2*** (0.000)
ERS	-4.2*** (0.000)	-7.9*** (0.000)	-13.5*** (0.000)	-22.8*** (0.000)	-4.8*** (0.000)	-9.1*** (0.000)	-20.1*** (0.000)	-16.2*** (0.000)

Note: *p < 0.1; **p <0.005; ***p<0.01. ( ) denotes standard errors. JB (Jarque-Bera test statistics) is the test for normality, and ERS unit root test is the test for stationary. Individual abbreviations represent respectively: investor attention (GSVI), green bond returns (SPGB), energy market volatility (OVX), stock market volatility (VIX), bond market volatility (MOVE), investment performance of the clean energy market (CLEAN), investment performance of the crude oil market (OIL), investment performance of the natural gas market (GAS).

Fig. 21 demonstrates that SPGB, OVX, VIX, MOVE, CLEAN, OIL and GAS indices display dramatic responses during the global pandemic period. GAS has experienced the most volatility since Russia's invasion of Ukraine, followed by SPGB, CLEAN and MOVE.

Figure 21 Historical Evolution of the Series



Source: OVX, VIX, and MOVE indices are retrieved from investing.com. CLEAN, OIL, GAS and SPGB indices are retrieved from S&P Global. GSVI is retrieved from Google Trends.

The optimal lag length must be determined for the subsequent analysis. Because the data in this study is daily, the maximum lag length is set to 12 lags. According to the Final Prediction Error (FPE) and the Akaike Information Criterion (AIC), an 8-lag order is an optimal lag for VAR analysis, as shown in Table 10. However, 1-lag order appears to be another optimal VAR length for the Schwarz Information Criteria (SIC). Because the lag length is found to be 8 by both FPE and AIC, the optimal lag length is determined to be 8[32].

Table 10 Determining Optimal Lag Selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	2335.414	NA	1.77e-11	-2.056928	-2.036692	-2.049544
1	34724.06	64519.67	6.92e-24	-30.62489	-30.44276*	-30.55843
2	34902.26	353.7201	6.25e-24	-30.72581	-30.38179	-30.60028*
3	35024.67	242.1154	5.94e-24	-30.77744	-30.27152	-30.59283
4	35138.64	224.6214	5.68e-24	-30.82160	-30.15379	-30.57792
5	35253.58	225.7148	5.43e-24	-30.86662	-30.03692	-30.56387
6	35325.08	139.8971	5.40e-24	-30.87325	-29.88165	-30.51142
7	35390.69	127.9263	5.39e-24	-30.87467	-29.72118	-30.45378
8	35454.78	124.4828	5.39e-24*	-30.87475*	-29.55936	-30.39478
9	35498.88	85.27172	5.49e-24	-30.85717	-29.37989	-30.31813
10	35558.34	114.6497	5.51e-24	-30.85315	-29.21398	-30.25503
11	35611.42	101.9982	5.56e-24	-30.84350	-29.04244	-30.18632
12	35567.33	107.0108*	5.60e-24	-30.83635	-28.87339	-30.12009

* It determines the optimal lag length according to the criteria.

The requirement for cointegration is that the series of variables to be employed in the analysis are not stationary at their level values and become stationary after obtaining the first differences. The Johansen cointegration test was performed in this study to determine whether there is a long-run relationship between the variables in the model. Table 11 shows the results of the Johansen cointegration test, which is used to determine if the variables move together in the long run once the lag length is calculated. The null hypothesis (H_0: r = 0) indicates that there is no cointegrating vector in the system. The null hypothesis, H_0, is rejected since the trace statistic is greater than the critical value. The trace statistic suggests that there are at least four cointegrating vectors in the system. Besides, the maximum-eigenvalue test also reveals that the

[32] Since there is no autocorrelation with an 8-lag length, 8 is endorsed as the optimum lag length (see Table 12).

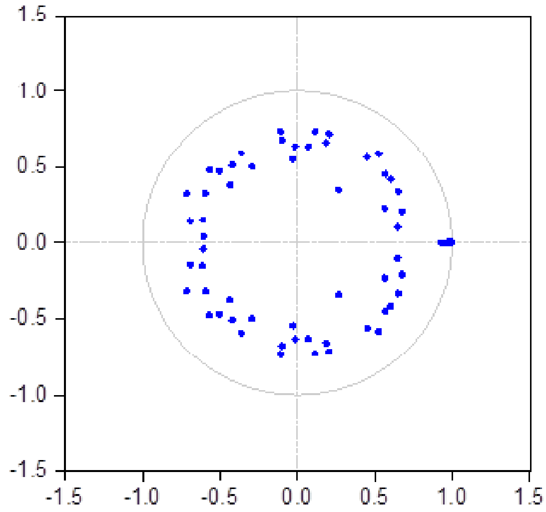
equation contains at least two cointegrating vectors. As a result, the long run cointegration relationship between series is found using Johansen's cointegration method.

Table 11 Johansen Cointegration Test Results

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized No. Of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None*	0.038502	273.7931	169.5991	0.0000
At most 1*	0.028007	184.8230	134.6780	0.0000
At most 2*	0.017563	120.4532	103.8473	0.0026
At most 3*	0.012147	80.30190	76.97277	0.0272
At most 4	0.010826	52.60733	54.07904	0.0673
At most 5	0.006288	27.94250	35.19275	0.2439
At most 6	0.004569	13.64826	20.26184	0.3143
At most 7	0.001443	3.271398	9.164546	0.5312
Trace test indicates 4 cointegrating eqn(s) at the 0.05 level, * denotes rejection of null hypothesis at the 0.05 level.				
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None*	0.038502	88.97009	53.18784	0.0000
At most 1*	0.028007	64.36981	47.07897	0.0003
At most 2	0.017563	40.15131	40.95680	0.0614
At most 3	0.012147	27.69457	34.80587	0.2747
At most 4	0.010826	24.66484	28.58808	0.1465
At most 5	0.006288	14.29424	22.29962	0.4354
At most 6	0.004569	10.37686	15.89210	0.3013
At most 7	0.001443	3.271398	9.164546	0.5312
Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level, * denotes rejection of null hypothesis at the 0.05 level.				

The inverse roots of the AR characteristic polynomial are given in Fig. 22 to test whether the constructed VAR model has a stable structure. Fig. 22 shows that the estimated VAR model's inverse roots of the AR characteristic polynomial are not beyond the reference range (-1 to +1). The fact that no AR root is located outside of the unit circle demonstrates that the established VAR model is stable.

Figure 22 Inverse Roots of AR Characteristic Polynomial



The VAR residual serial correlation LM test is used to determine whether the estimated model has autocorrelation. Because the p-value is greater than 0.05, the results of the LM test demonstrate that there is no autocorrelation at lags 1, 4, and 8. Because there is no autocorrelation at lag 8 and is long enough to capture daily data dynamics, 8-lag is endorsed as the optimum lag length.

Table 12 Serial Autocorrelation Test Results for the VAR Model

Lags	LM-Stat	df	p-value
1	81.512	64	0.0690
2	97.600	64	0.0043
3	94.287	64	0.0082
4	77.275	64	0.1232
5	133.698	64	0.0000
6	106.474	64	0.0007
7	128.504	64	0.0000
8	80.763	64	0.0768
9	99.813	64	0.0028

3.4. METHODOLOGY

We investigate the relationship between green bonds and investor attention using Diebold and Yilmaz's (2012) connectedness framework. Considering a covariance stationary N-variable VAR(p) is:

$$x_t = \sum_{i=1}^{p} \Theta_i x_{t-i} + \varepsilon_t \tag{7}$$

where x_t is a vector of n endogenous variables including the green bond index, the GSVI and other control variables. Θ_i are parameter matrices and ε_t ~ (0, $\sum$) is the residual vector.

The moving average representation is:

$$x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i} \tag{8}$$

where the NxN coefficient matrices A_i obey the recursion A_i = $\sum \Theta_j A_{i-j}$, $j = 1, \ldots, p$, with A_0 being an NxN identity matrix and with A_i = 0 for i < 0.

H-step-ahead GFEVD (generalized forecast error variance decomposition) is the variance decompositions that are independent of the order of the variables. Due to the non-orthogonalization of the shocks to each variable, the sum of the contributions to the variance of the forecast error does not equal to one (Diebold and Yilmaz, 2012, p. 58). H-step-ahead GFEVD is:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_j)} \tag{9}$$

where σ_{jj} is the standard deviation of the error term for the j-th equation, $\sum$ is the variance matrix for the error vector ε, and e_i is a vector with values 1 for the i-th element and 0 otherwise. Therefore, θ_{ij}^{g} (H) represents the effect of variable j on i in terms of the margin of error variance estimation, which is characterized as bidirectional connectedness from j to i. In this case, each predictive error variance decomposition can be normalized as follows:

$$\tilde{\theta}_{ij}^{g}(\mathrm{H}) = \frac{\theta_{ij}^{g}(\mathrm{H})}{\sum_{j=1}^{N} \theta_{ij}^{g}(\mathrm{H})} \tag{10}$$

In accordance with the aforementioned definitions, Diebold and Yilmaz (2012, pp. 58-59) defined total, directional, and net spillovers. Following is a representation of the total spillover index, which shows the average effect of a shock on one series on the others. The higher this value, the higher will be the interconnectedness of the network and thus the market risk because the shock in one variable will spread easily and quickly to the others (Akyıldırım et al., 2022, p. 353).

$$S^{g}(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} 100 = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} 100 \tag{11}$$

In order to comprehend the direction of spillovers throughout the series, it is necessary to compute directional spillovers, as the generalized impulse responses and variance decompositions remain unaffected by the order of the variables. The directional spillover to series i from all series (TO_{ij}) is indicated as follows:

$$S_{i*}^{g}(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} 100 = \frac{\sum_{\substack{j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} 100 \tag{12}$$

The directional spillover to other series from series i ($FROM_{ij}$) is indicated as follows:

$$S_{*i}^{g}(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \tilde{\theta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ji}^{g}(H)} 100 = \frac{\sum_{\substack{j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ji}^{g}(H)}{N} 100 \tag{13}$$

Net spillover is the difference between gross volatility shocks transmitted to all other markets and shocks received from all other markets. In other words, the NET equation shows the difference between the effect of other variables on variable i and the effect of i on others. If $NET_{ij} > 0$ ($NET_{ij} < 0$), series i has a greater (smaller) impact on all other series than any other series has on it. Thus, series i is a net transmitter (net receiver) of shocks and directs the network (directed by the network). Net spillover from market i to all other markets j (NET_{ij}):

$$S_i^g(H) = S_{*i}^g(H) - S_{i*}^g(H) \tag{14}$$

Net pairwise spillover ($NPSO_{ij}$) between series i and j is the difference between the gross shocks that are transmitted from series i to series j and those that are transmitted from j to i and if $NPSO_{ij} > 0$ ($NPSO_{ij} < 0$), then series i affects series j more (less) than series j affects series i. $NPSO_{ij}$ is shown as follows:

$$S_{ij}^g(H) = \left(\frac{\tilde{\theta}_{ji}^g(H)}{\sum_{i,k=1}^{N} \tilde{\theta}_{ik}^g(H)} - \frac{\tilde{\theta}_{ij}^g(H)}{\sum_{j,k=1}^{N} \tilde{\theta}_{jk}^g(H)}\right) 100 = \left(\frac{\tilde{\theta}_{ji}^g(H) - \tilde{\theta}_{ij}^g(H)}{N}\right) 100 \tag{15}$$

3.5. EMPIRICAL RESULTS

The Diebold and Yilmaz (2012) connectedness approach is utilized in this study to evaluate the interconnectedness among a network of variables. This approach offers a framework for examining the impact of an individual variable as well as the influence of the entire network. The estimation of the forecast error variance decompositions that result from a VAR model forms the basis for the subsequent measures. The ability to distinguish between net transmitter and net receiver of a shock further aids in understanding the underlying dynamics and makes it easier to formulate policy implications when results for total, directional, and net interdependence are obtained. Finally, an investigation of interdependence is conducted using a rolling window strategy. The right window size and forecast horizon should be chosen for this (Antonakakis et al., 2020, p. 2). We follow Diebold and Yilmaz (2012) in using a 200-

day rolling window and a 10-step forecast horizon. The model is estimated using the R software.

We will examine the interdependence between the rapidly expanding green bond market and the investor attention. Specifically, it will be examined how volatility in stock, bond and energy markets and investment performances of clean energy, oil and gas markets affect investors’ attention to green bonds. The static connectedness between variables is presented first, followed by the dynamic connectedness. The static model encompasses the entire sample data, enabling it to capture the long-term dynamics between the variables. In contrast, the dynamic model focuses on the short-term dynamics between the variables (Pham and Huynh, 2020, p. 5). Connectedness table gives the average values of the series over time. We can see in Table 13 that the shocks within its own system have the biggest impact on investor attention with 98,91%, followed by the investments in the gas market with 95,48%. Besides, TO indicates the total directional spillovers to others from each of the series and FROM indicates the total directional spillovers from others to each series. We can see that total directional spillovers from others to the investment performance of the clean energy markets (CLEAN) and the stock market volatility (VIX) are relatively large, with the spillovers from others explaining 38,60% and 38,58%, respectively, followed by energy market volatility (OVX) and investment performance of the oil market (OIL). Likewise, the total directional spillovers from the CLEAN and VIX to the others is at most, with 43,73% and 43,48%, respectively. Specifically, VIX and CLEAN are both those that have the greatest impact on other series and those that are most affected by other series. Green bond returns are affected by other series, at 13,12%.

The spillover between the series is also observed on Table 13. For instance, when the GSVI row is analyzed, it is seen that 0,24% of the external shock to the investor attention (GSVI) is due to the stock market volatility (VIX), 0,23% to green bond returns (SPGB), 0,18% to investment performance of the clean energy market (CLEAN), 0,12% to investment performance of the gas market (GAS), 0,11% to the investment performance of the oil market (OIL), 0,11% to oil market volatility (OVX) and 0,10% to bond market volatility (MOVE). Similarly, when the SPGB row is analyzed, the largest share of external shocks to the green bond returns stems from the investment performance of the clean energy market (8,07%) after the shocks that occur within their own system (86,88%). Additionally, it is clear that the largest share of external shocks to the stock market volatility (VIX) stems from the performance of clean energy investments (CLEAN) with a rate of 18,99%. As for the net directional spillovers, the largest are from the CLEAN to others with 5,12%. Additionally, the total spillover index is 23%, which means that 23% of the forecast error variation in all series is, on average, a result of spillovers throughout the entire sample. Finally, we can reach the conclusion that while the SPGB, MOVE, OIL and GAS are a net receiver of the shocks, GSVI, VIX, OVX and CLEAN are a net transmitter of the shocks according to the static model.

Table 13 Static Connectedness among Variables

	GSVI	SPGB	VIX	OVX	MOVE	OIL	GAS	CLEAN	FROM
GSVI	98,91	0,23	0,24	0,11	0,10	0,11	0,12	0,18	1,09
SPGB	0,26	86,88	1,05	0,89	1,70	0,50	0,65	8,07	13,12
VIX	0,24	0,12	61,42	7,88	7,91	3,19	0,25	18,99	38,58
OVX	0,07	0,17	8,37	66,29	3,55	15,73	0,23	5,59	33,71
MOVE	0,15	1,05	10,40	4,52	75,71	2,15	0,50	5,52	24,29
OIL	0,15	0,18	4,23	17,83	2,26	69,96	1,01	4,37	30,04
GAS	0,23	0,14	0,43	0,67	0,51	1,53	95,48	1,01	4,52
CLEAN	0,14	4,04	18,75	6,39	4,40	4,31	0,57	61,40	38,60
TO	1,25	5,92	43,48	38,29	20,42	27,53	3,34	43,73	183,96
Inc. own	100,1	92,80	104,91	104,58	96,13	97,49	98,82	105,12	Total spillover index: 183.96/800=23%
NET	0,15	-7,20	4,91	4,58	-3,87	-2,51	-1,18	5,12	

Source: Author’s calculations.

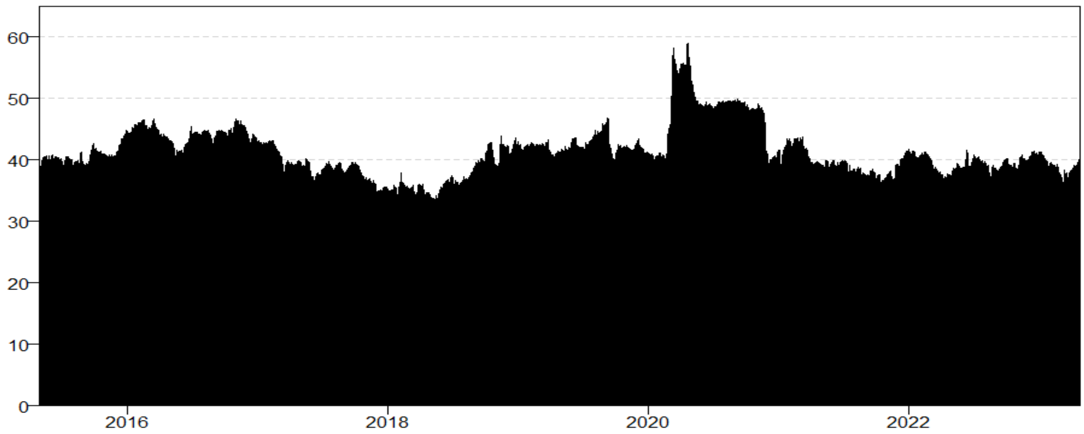
According to the dynamic model results presented in Table 14, while the total spillover index is 23% in the long run, it increases to 41,14% in the short run. This shows that the variables affect each other more in the short run. While investor attention accounts for only 0,26% of external shock to green bond returns in the long run, it accounts for 3,59% in the short run. Similarly, while green bond returns accounts for only 0,23% of the shocks to the investor attention in the long run, it accounts for 3,83% in the short run. These findings reveal that the association between investor attention and green bond returns exhibits a significant influence on one another in the short term; however, this association diminishes over time. This observation is consistent with the prior investigations conducted by Pham and Huynh (2020) and Pham and Cepni (2022) that investigate the association between investor attention and green bond returns. This is an indication of that investors adjust their decisions quickly by monitoring price fluctuations in financial markets and analyzing market conditions. This is the ideal way for an investor to maximize their profits while minimizing their losses. Furthermore, the biggest shock spillovers from investor attention to other series in the short run are found to be toward bond market volatility (MOVE) with 3,63%, green bond returns (SPGB) with 3,59%, investments of the gas market (GAS) with 3,52%. Additionally, it is evident that VIX and CLEAN are the ones that affect the other series most strongly in the short run as well as in the long run. One of the most important differences is that while the effect of investor attention on other series is 1,25% in the long run, it jumps to 22,55% in the short run. Finally, although their coefficients have various sizes, their status as shock transmitters and receivers remains the same, except for investor attention. Investor attention shifts from being a net transmitter of shocks in the static model to a net receiver in the dynamic model. This could be because green bonds have become attractive to investors seeking to make investments that align with sustainability objectives. As a result, investor attention will continue to rise in the long run. However, in the short run, investors may become net receiver of shocks due to fluctuations in market conditions.

Table 14 Dynamic Connectedness among Variables

	GSVI	SPGB	VIX	OVX	MOVE	OIL	GAS	CLEAN	FROM
GSVI	72,64	3,83	4,42	4,14	3,71	3,73	4,14	3,38	27,36
SPGB	3,59	62,98	5,26	4,30	6,93	4,67	3,83	8,44	37,02
VIX	2,85	3,74	48,50	8,87	9,44	5,15	2,44	19,00	51,50
OVX	2,96	3,46	9,27	53,35	5,34	14,81	3,78	7,04	46,65
MOVE	3,63	5,67	11,22	5,79	57,81	4,75	2,90	8,24	42,19
OIL	3,40	3,26	5,94	16,36	4,76	56,13	4,00	6,14	43,87
GAS	3,52	4,54	4,40	4,68	4,02	5,16	69,16	4,53	30,84
CLEAN	2,60	6,06	20,11	7,00	6,48	5,12	2,36	50,27	49,73
TO	22,55	30,57	60,61	51,13	40,68	43,39	23,45	56,77	329,16
Inc. own	95,19	93,55	109,1	104,48	98,50	99,51	92,61	107,05	Total spillover index: 329.16/800 =41,14%
NET	-4,81	-6,45	9,11	4,48	-1,50	-0,49	-7,39	7,05	

The information provided by the dynamic total connectedness index (Fig. 23) allows for the analysis of the impact of structural changes and crisis times on the connectedness levels of the series over time. Our sampling period encompasses the significant developments such as the Fed's decision to raise interest rates and the slowdown of the Chinese economy in 2016, Donald Trump being elected as US President in November 2016, the British government's formal start of the process of exiting from the EU (Brexit) in 2017, declaring Covid-19 a pandemic by WHO on March 11, 2020, Brexit officially taking place on 31 January 2020, and Russia starting to invade Ukraine on 24 February 2022. In line with these developments, it is understood that the system's shock spillover is heightened during particular periods. Dynamic total connectedness index mostly fluctuates between thirty-five and forty-five percent. However, there is one very important exception, which is the declaration of global pandemic in 2020. The index has dramatically increased over the fifty percent. The Covid-19 pandemic's rapid global spread has a significant impact on financial markets all around the world. Investors suffered substantial losses in a short period of time as a result of the unprecedented level of risk it produced. At the same time, a rapid spread of market turmoil in global financial markets was triggered by four consecutive meltdowns in the US stock market and the subsequent decrease in the oil market (Zhang et al., 2020a, p. 1; Huang et al., 2023, p. 3). The armed conflict between Russia and Ukraine, which produced market uncertainty around the world, does not result in a major spike in the index, as it did with Covid-19. The primary reason for this is that the market reaction to this conflict did not last as long as it did to Covid-19.

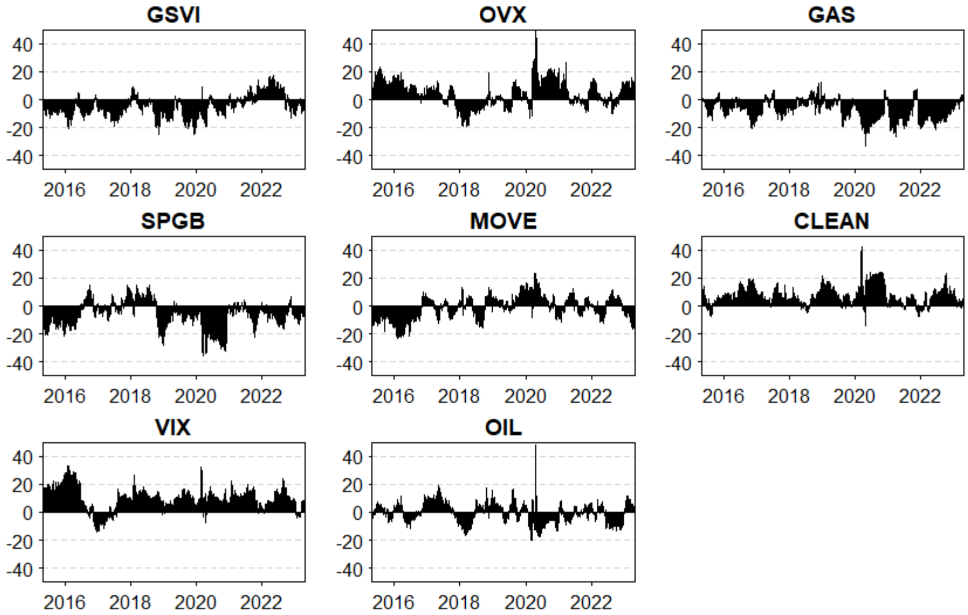
Figure 23 Dynamic Total Connectedness Index



Source: Author’s calculations.

TO_i denotes how series i affects all series, whereas $FROM_i$ demonstrates how all series influence series i. The NET total directional connectivity shows their difference. The last row (NET) in Table 14 gives the average value of the total NET variable over time, but there may also be periods when the net variable changes from positive (net shock transmitter) to negative (net shock receiver) or from negative to positive over time. Dynamic net total directional connectedness (Fig. 24) allows us to observe these behaviors. If the series has a value above the x-axis, it indicates the periods when the relevant series is a net shock transmitter, and a value below the x-axis indicates the periods when the relevant series is a net shock receiver. While GSVI, SPGB, GAS have generally maintained the status of shock receiver in all periods, OVX, VIX, CLEAN have continued to be shock transmitter in general. The NET row in Table 14 indicates that MOVE and OIL are net shock receivers; nevertheless, throughout time, because of both internal and external dynamics, their status has changed. After the declaration of global pandemic by WHO, OVX, VIX, MOVE and CLEAN are net shock transmitters whilst SPGB, along with GAS, becoming a major shock receiver.

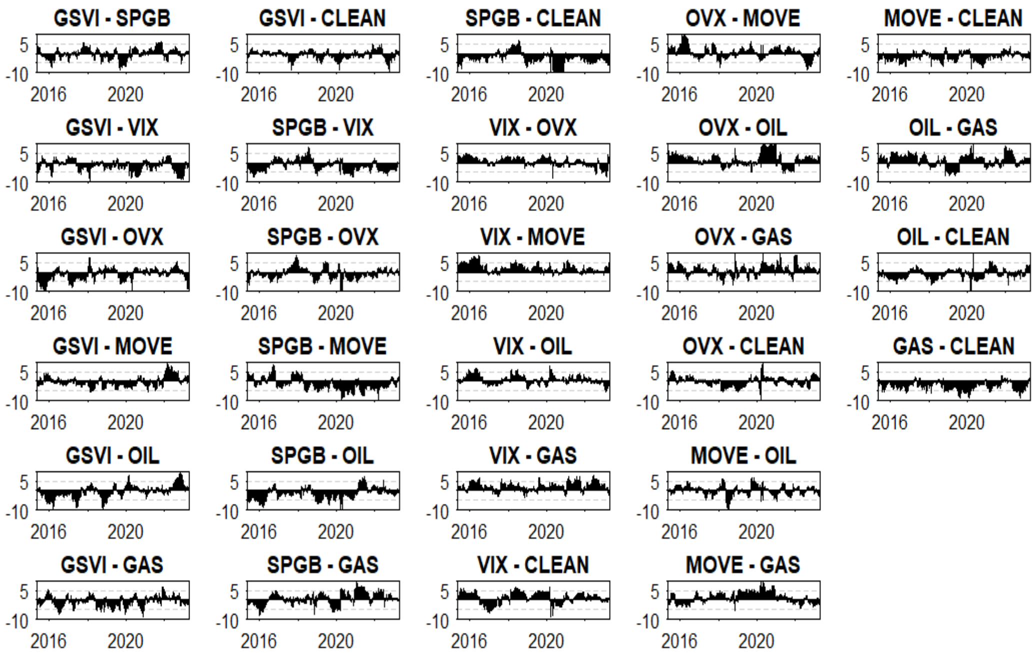
Figure 24 Dynamic NET Total Directional Connectedness



Source: Author's calculations.

Fig. 25 demonstrates the net pairwise spillovers between the series. If $NPSO_{ij} > 0$ ($NPSO_{ij} < 0$), then series i affects series j more (less) than series j affects series i. Accordingly, based on the observed net pairwise spillover between investor attention (GSVI) and green bond returns (SPGB), it can be inferred that green bond returns which receive net shocks from investor attention are more likely to be succeeded by green bond returns that transmit net shocks. This demonstrates the existence of a feedback effect between the returns of green bonds and the attention of investors. It conveys the connection between the degree of attention displayed by investors in green bonds and its impact on the returns of these bonds. As investor attention towards green bonds grows, so may the returns of these bonds. This may attract the attention of investors. During the time period under examination, green bond returns (SPGB) have a net reception role in their pairwise relations with all other series (with the exception of their relationship to investment performance of the gas market (GAS)). On the other hand, spillover from green bond returns increased at the end of 2017 and early 2019 (see Fig. 24), due to the fact that the green bond market grew by 82% to $158,5 billion in 2017 compared to 2016, and by $269,1 in 2019 (CBI, 2023b) due to the high level of liquidity in the system and the growing awareness of these assets among businesses and investors, these shocks are transmitted to OVX, VIX, MOVE and CLEAN. Furthermore, after the declaration of Covid-19 as a global pandemic, CLEAN is more effective on GSVI than GSVI on it, while GSVI is more effective on GAS and OIL in the same period. After Russia declared war on Ukraine, GSVI has more influence on CLEAN, OIL and GAS. However, the influence of GAS and CLEAN on GSVI increases in subsequent periods. On the other hand, SPGB is more impacted by CLEAN, VIX and MOVE throughout both the war and the Covid-19 periods than SPGB impacts on them. In terms of investment performances, during the first declaration of Covid-19 and war, CLEAN has a greater impact on SPGB, while SPGB has a greater impact on GAS than GAS has on SPGB.

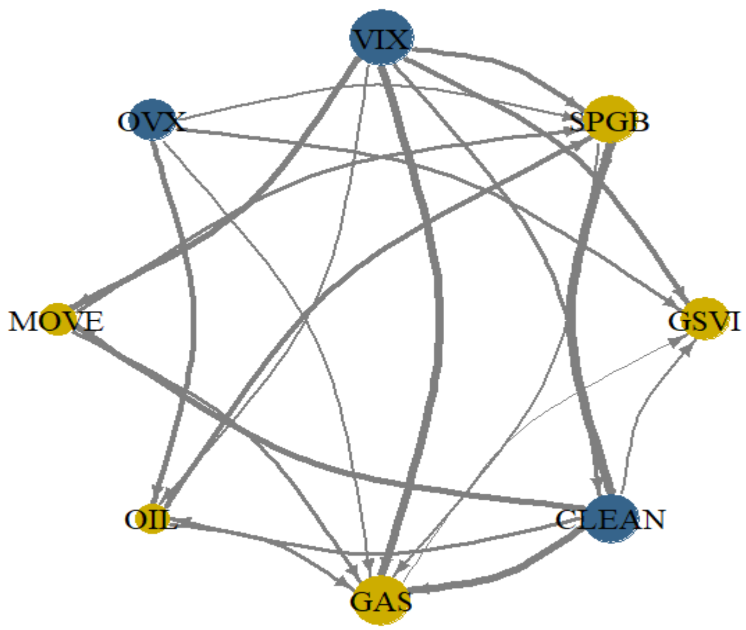
Figure 25 Net Pairwise Directional Connectedness (NPSOij)



Source: Author’s calculations.

With the aid of network analysis, Fig. 26 depicts the shock distribution between the series in order to make it easier to see how the average net relationships between the series have changed over time. The arrow’s direction indicates which series, on average over time, delivered shocks to which series. For example, investment performances of clean energy market are, on average, a net shock transmitter to green bond returns, as shown by the arrow from CLEAN to SPGB. The strength of connectedness between the two series is determined by how thick the edge between them is; hence, thicker edges signify a stronger relationship. Accordingly, connectedness between SPGB and CLEAN is the one that is most strongly connected, followed by the connectedness between VIX and GAS. Being the strongest connectedness between green bond returns and investment performance of the clean energy market, as well as being a net shock transmitter of investment performance of the clean energy market to green bond returns, is reasonable. Because green bonds are solely utilized for environmentally friendly investments and that the majority of green bond issuance, roughly 32%, is used for clean energy investments (CBI, 2023b). This is corroborated by Yan et al. (2022, p. 6479), who show that a rise in clean energy stocks has a favorable impact on green bond markets, and by Tang et al. (2023, p. 20), who find that the impact of the green bond market on the clean energy and fossil fuel industries is minimal (explains why the direction of the arrow is CLEAN to SPGB and not SPGB to CLEAN). The magnitude of each circle represents the aggregate extent of the net total directional connectedness for each series. We can see that the greater the circle, the more it impacts the system as a transmitter of shocks between series, and the more it is influenced by the system as a receiver of shocks. Besides, the color of each circle helps determine whether a series is a net transmitter or a net receiver. In the network plot below, a series is depicted in blue if it is the net shock transmitter within the network and in yellow if it is the net shock receiver. Accordingly, VIX and CLEAN are the largest shock transmitters on average across time, whereas SPGB and GAS followed by GSVI are the largest shock receivers. It is understandable that the VIX index, also known as the fear index, is in the position of the variable that spreads shocks the most to the other series because it is used to determine the general expectation about the near future of the market and because a high VIX index makes investments riskier and forces the investor to act more cautiously.

Figure 26 Network Analysis



Source: Author's calculations.

3.5.1. Net-Pairwise Directional Connectedness in Sub-Periods

The connection can be individually investigated in sub-periods to better comprehend the effects of Covid-19 and the Russian invasion of Ukraine in related dynamic relationships. There are three sub-periods: Pre-Covid-19 (March 31, 2014 – March 10, 2020), Covid-19 (March 11, 2020 – February 23, 2022), and the Russian invasion of Ukraine[33] (February 24, 2022 – April 28, 2023). According to Table 15, SPGB remains constant and maintains to be a net shock receiver during all sub-periods. VIX is the largest shock transmitter in all sub-periods. The largest shock recipient during pre-Covid-19 is GSVI, but during Covid-19 and war, the biggest shock recipient is SPGB. The analysis reveals that the degree of interconnectedness exhibited by the OIL is notably lower during both the pre-Covid-19 and Covid-19 periods. However, it is seen that the amount of interconnectedness experiences a notable increase during periods of war. MOVE exhibits the lowest degree of interconnectedness during war. Additionally,

[33] It will henceforth be referred to as the war period.

GSVI is the largest shock receiver prior to Covid-19, but during Covid-19 and war, it is transitioning from being a net receiver to a net transmitter.

Table 15 Net Directional Connectedness in Three Sub-Periods

	Pre-Covid-19	Covid-19	Russian invasion of Ukraine
GSVI	-7,22	1,13	1,54
SPGB	-4,13	-8,20	-6,76
VIX	10,09	12,09	8,24
OVX	2,77	1,47	-5,42
MOVE	-3,32	0,69	-0,57
OIL	1,08	-0,10	-5,33
GAS	-5,81	-8,14	-2,51
CLEAN	6,55	1,07	10,81

Notes: (+) Net-transmitter, (-) Net-recipient.
Source: Author’s calculations.

Table 16 depicts the dynamic connectedness between SPGB and GSVI in three sub-periods. Investor attention has the biggest impact on green bond returns during the Covid-19 period, with a 5,69%. This is corroborated by Pham and Cepni (2022, p. 200), who find that investor attention has a significant impact on green bond returns under extreme conditions. On the other hand, green bond returns significantly affect investor attention in pre-Covid-19 period with 3,25%. There is a significant decrease in their connectedness in the war period. Compared to the other two periods, the trend toward green energy is stronger during the Covid-19 period. The implementation of green recovery plans by governments in reaction to the epidemic attracts investors' attention to clean energy investments and raises stock values (Wan et al., 2021, pp. 1-2; Ghabri et al., 2021, p. 4962). However, Russia’s invasion of Ukraine brought the problem of energy security to the highest level, but as a result of the impossibility of a rapid transition to clean energy in a short time, countries dependent on Russian oil and gas preferred to procure oil and natural gas from other countries. Countries planning to accelerate the transition to clean energy by closing their coal and nuclear power plants have decided to postpone their plans for now (Pfeifer, 2022).

Table 16 Dynamic Connectedness between Green Bond Returns and Investor Attention in Three Sub-Periods

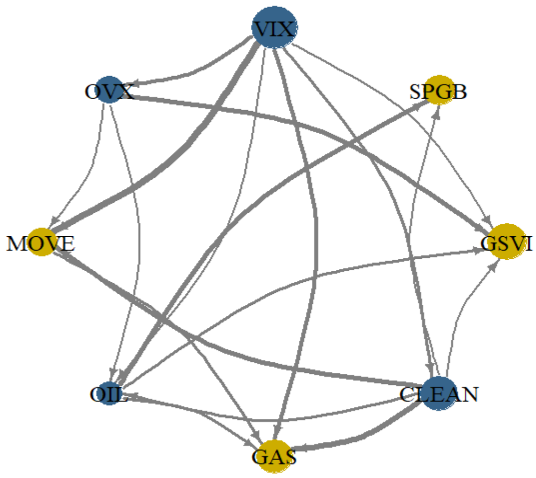
Pre-Covid-19			**Covid-19**			**Russian invasion of Ukraine**		
	GSVI	SPGB		GSVI	SPGB		GSVI	SPGB
GSVI	75,36	3,25	GSVI	80,60	3,05	GSVI	95,33	0,13
SPGB	2,75	70,79	SPGB	5,69	65,83	SPGB	0,10	63,04

Source: Author's calculations.

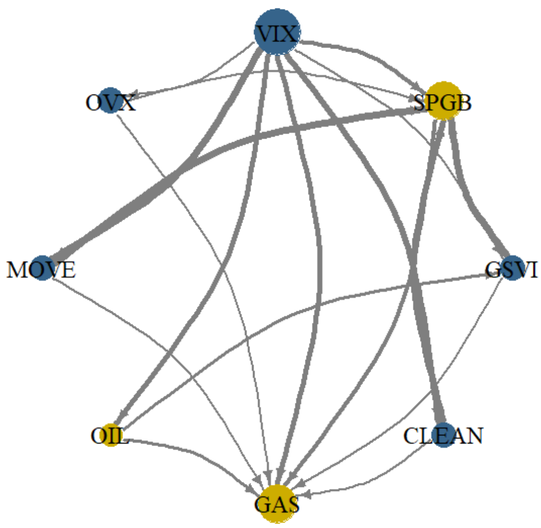
Fig. 27 shows that total connectedness index is particularly weakening from pre-Covid-19 period to war period (from 38,82% in the period before Covid-19 to 33,05% in the period of Covid-19 and to 27,82% in the period of war). VIX and CLEAN are net shock transmitter in all sub-periods, while SPGB and GAS are net shock receiver. This is in line with the results obtained by Tiwari et al. (2022, p. 3) who find that green bonds are the primary net recipients of shocks whereas clean energy is the primary net transmitter of shocks. OIL is a net shock transmitter before Covid-19, but during Covid-19 and the Russian invasion of Ukraine, it becomes a net shock receiver. It may be inferred that negative NET effects during the Covid-19 and war are more pronounced for the oil and gas markets, in line with the findings of Karkowska and Urjasz (2023, p. 13). Furthermore, the net shock transmitter of CLEAN to SPGB and VIX to MOVE is the same in all sub-periods. GSVI is a net shock receiver from VIX, OVX, OIL and CLEAN in pre-Covid-19. However, in Covid-19 period, GSVI is a net shock receiver from OIL and VIX, whereas GSVI is a net transmitter to SPGB and GAS in Covid-19 period. In the war period, GSVI is a net shock transmitter only to OIL. It can be concluded that GSVI has become a net shock transmitter during the periods of Covid-19 and war. Moreover, the frequency of shocks increases during the Covid-19 period, that is, when volatility is high. In times of crisis, a strong correlation can arise between market volatility and oil, gas, and energy investments. These investments may be more exposed to the effects of market fluctuations. For example, volatility in the stock market and energy markets increases the risk perception of investors and affects their investment decisions. High volatility may cause investors to be more cautious (Balash et al., 2021, p. 20). However, frequency of shocks decreases in the period of war. One possible explanation is that both Covid-19 and the war have created financial market volatility and shifts in investors' risk appetite. However, the Covid-19 epidemic has caused a higher volatility shock due to its global economic impact. In addition, the Russian-Ukrainian conflict has not been as severe as the Covid-19. This is explained by market assumptions that the war wouldn't last very long (Izzeldin, 2023, p. 12).

Figure 27 Network Analysis in Three Sub-Periods

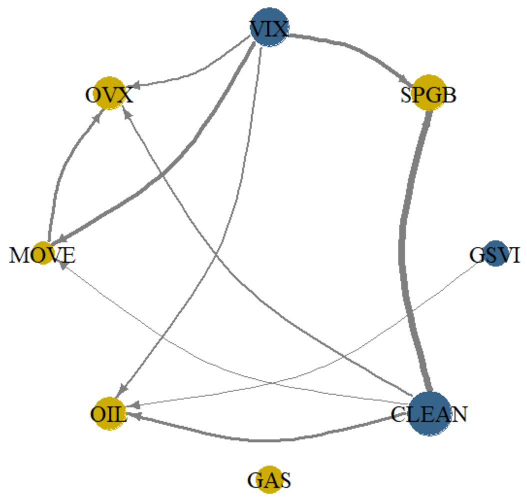
Pre-Covid-19 (Total connectedness: 38,82)



Covid-19 (Total connectedness: 33,05)



Russian invasion of Ukraine (Total connectedness: 27,82)



Source: Author's calculations.

3.6. CONCLUSIONS AND POLICY IMPLICATIONS

This study attempts to examine the interdependence between investor attention and green bond returns. Specifically, we investigate how volatility in stock, bond and energy markets and investment performances of clean energy, oil and gas markets affect investors' attention to green bonds and consequently green bond returns. We employ Diebold-Yilmaz's (2012) connectedness approach and the dataset included in this study comprises daily data spanning from July 31, 2014 to April 28, 2023.

Our main findings are as follows. First, while investor attention only contributes 0,26% of external shocks to green bond returns in the long run, it contributes 3,59% in the short run. This finding suggests that the dynamic model, as opposed to the static model, better represents the relationship between investor attention and green bond returns. Furthermore, it implies that there is a larger correlation between investor attention and returns on green bonds over the short term than over the long term. This finding is consistent with the prior research conducted by Pham and Huynh (2020) and Pham and Cepni (2022). To put it more precisely, the Covid-19 period has the most pronounced impact of investor attention on green bond returns. The aforementioned effect experiences a reduction during the war period. Second, while green bond returns accounts for only 0,23% of the shocks to the investor attention in the long run, it accounts for 3,83% in the short run. This finding indicates the positive but small spillover effects between investor attention and green bond, which aligns with the findings of Pham and Huynh (2020) and Piñeiro-Chousa et al. (2021). Third, in contrast to the long run, where the impact of investor attention on other series is 1,25%, the short-run impact is 22,55%. This is an indication of the swift adjustments made by investors in the financial markets. Fourth, when examining the net pairwise spillover effects between the returns of green bonds and investor attention, it can be observed that green bond returns that are a net receiver of shocks from investor attention likely to be followed by green bond returns that are a net transmitter of shocks. This demonstrates the existence of feedback channel between green bond returns and investor attention. This result is consistent with Pham and Huynh (2020). Fifth, during the Covid-19 pandemic, market volatilities exert a greater influence on investor attention and green bond returns compared to the impact that investor attention and green bond returns have on market volatilities. This finding is supported by Pham and Nguyen (2022), who discover strong correlations between green bond returns and the uncertainty indices (VIX, OVX, and EPU) during times of high uncertainty. Finally, VIX, CLEAN and OVX are the shock transmitters in the network, but OVX affects the system less than other shock transmitters. This finding seems to be consistent with the previous study from Nguyen (2020, p. 56) where OVX has a statistically less significant impact on the returns on green bonds when compared to the volatility in the energy and stock markets (VXXLE and VIX, respectively). In addition, VIX has a greater effect on the green bond returns than other types of market volatility (MOVE and OVX), which is consistent with Nguyen's findings (2020, p. 57), who discover that VIX has a greater effect on the performance of the green bond market than VXXLE and OVX.

There are several implications. First, the presence of a feedback effect between investor attention and green bond returns indicates that investor attention significantly influences the performance of green bonds. In other words, as investors' attention on green bonds grows, so does demand for these bonds, driving prices to climb and yields to decline. This could result in better returns for investors who hold these bonds. As a result, green bonds can serve as an alternative funding mechanism for the transition to a low-carbon economy. Second, green bond returns are often affected in a similar way to conventional bonds during extreme market conditions. However, since green bonds are issued specifically considering environmental, social and governance factors, the returns of green bonds may be less affected than other bonds in some cases. For instance, investor attention is higher in the Covid-19 period than in the pre-Covid period. This highlights the importance of examining how green bonds behave under normal and extreme market conditions. Making a general assessment may lead to insufficient information about how green bonds behave in extreme market conditions. Besides, in instances of highly volatile market conditions, the attention of investors can serve as a valuable instrument for predicting the performance of green bonds. However, it is important for investors to exercise caution, as the correlation between green bonds and investor attention is subject to fluctuations over time.

CONCLUSION

This thesis examines the advancement of clean energy in different perspectives. On the one hand, this study investigates the impact of oil price shocks on the returns of clean energy stocks at both the global and European levels. Additionally, it analyzes the effects of gas price shocks on clean energy stock returns specifically in the European market. This is because unlike oil markets, natural gas markets are not yet global. Natural gas prices are mainly determined by regional supply and demand. Hence, our objective is to ascertain the presence of a substitution effect between oil and clean energy, both at the global and European level. Besides, after the European Commission's endorsement of gas as a transition fuel in July 2022 due to its capacity to serve as backup for intermittent renewables, we test whether gas is viewed by investors as complementary to clean energy in European financial markets. On the other hand, we examine the impact of investor attention on the returns of green bonds, which are exclusively used for clean energy, in three distinct sub-periods: Pre-Covid-19, Covid-19, and the Russian invasion of Ukraine. The objective is to investigate whether investor attention fluctuates during periods of uncertainty, and we also analyze how uncertainties in the stock, bond, and energy markets, as well as the investment performances of the clean energy, oil, and gas markets affect the connectedness between green bonds and investor attention. Because global markets have been significantly impacted by significant events over the past ten years, including Covid-19 and Russia's invasion of Ukraine. Both events raised market ambiguity on a global scale. The impact of the crisis between Russia and Ukraine has not been as severe as it was in Covid-19, though. Due of its repercussions on the world economy, the Covid-19 outbreak created a greater volatility shock than the Russia-Ukraine war. Market expectations that the war will end quickly account for this. Both worldwide developments have had distinct but substantial effects on the clean energy sector. On the one hand, Covid-19 has caused industrial production to slow down, and travel restrictions have a negative influence on airlines transportation, which has put downward pressure on oil prices. Consequently, the most noticeable drop in oil prices happened during the time period in question. The sudden decreases in oil prices and adjustments in oil supply and demand brought on by Covid-19 caused companies to lose interest in fossil fuel projects. Companies opted to postpone new ventures and cease any costly activity in response to the reduction in oil prices. Additionally, Covid-19 has sparked the idea that a transition to clean energy is essential to decarbonizing the global economy. As clean energy sources become more affordable, numerous governments are setting ever-more ambitious goals for the transition to clean energy. This situation made the transition to low-carbon and greener energy policies easier for oil-producing countries (OECD, 2020, pp. 2-3). On the other hand, Russia's invasion of Ukraine escalated the issue of energy security, but countries reliant on Russian oil and gas preferred to import oil and natural gas from other nations due to the impossibility of a swift transition to clean energy in a short period of time. The closure of coal and nuclear power facilities, which was intended to speed up the switch to clean energy, has been delayed for the time being (Pfeifer, 2022). This demonstrates how market developments affect the clean energy sector differently since it shapes whether or not investors tend to clean energy based on how much they are affected by the markets.

Chapters one and two aim to investigate, with the use of a SVAR, the effects of oil price shocks on clean energy stock returns on the global level and, on the other hand, the effects of gas and oil price shocks on clean energy stock returns at the European level. In the model for the global level, we employ monthly data from 2001:01 to 2022:06, covering the recent financial crisis, the Covid-19, and the Russia-Ukraine war. Since the ECO and NEX indices are available since 2001, the sample period starts from 2001. In this model, we could not identify gas price shocks because gas market has a local market structure. In the model for the European level, we employ monthly data from 2008:01 to 2021:12. We could not enhance the data covering the Russia-Ukraine war because we could not find monthly natural gas production data for Europe after 2021:12. Furthermore, we define Europe's overall gas supply as the sum of its domestic production and imports from its suppliers, which are primarily Russia, Norway, Algeria and Qatar. However, Algeria and Qatar are not included in the empirical analysis due to data unavailability on monthly gas production. The goal of the third chapter is to study whether the global Covid-19 pandemic and the ensuing energy security issues brought on by the Russia-Ukraine war have an impact on investor attention in green bonds by using Diebold-Yilmaz (2012) connectedness method. By doing this, we will also look into how market uncertainty in the stock, bond, and energy, as well as the investment performances of the clean energy, oil, and gas markets affect the connectedness between green bonds and investor attention. Since the launch date of the green bond index is July 31, 2014, our data set ranges from July 31, 2014 to April 28, 2023, with a total of 2275 daily observations.

We can reach the conclusion that while there is a substitution effect between oil and clean energy at the European level, oil and clean energy are not substitutes for one another on the global level. It is presumed that the shift towards clean energy will be facilitated by the rising price of oil. However, we have demonstrated that high oil prices are insufficient to speed the transition to clean energy sources on the global level, and so there is no substitution effect between oil and clean energy. Because the fact that rising oil prices encourage increased investment in clean energy may be subject to alteration under situations characterized by a high degree of unpredictability, like as the Covid-19 pandemic. Despite the decline in oil prices because to the Covid-19 pandemic, we observed a rise in the stock returns of clean energy companies and a decline in the stock returns of oil and gas companies. This shows that investor sentiment changes when there is significant uncertainty during financial and economic crises, and that the renewable energy sector has the ability to compete successfully with oil even as oil prices fluctuate at recent lows. Besides, analysis of the time under consideration indicates that the renewable energy industry deteriorated due to unstable government support during the 2008 global financial crisis. However, the market experienced improvement when more stable and ambitious policies were implemented during the Covid-19 period. Hence, the facilitation of this transition necessitates government intervention, as the growth of investments in clean energy is likely to be enhanced by the implementation of stable government subsidies on clean energy and the reduction in costs of renewable energy technology. Therefore, it is left to future research to investigate the substitution effect between oil and clean energy by incorporating investor sentiment and government support into the model.

Besides, we find that even if the European Commission endorsed gas as a green course thinking to its complementarity with intermittent renewables, investors in Europe do not consider gas this way, and shocks in the market generate substitution towards clean energy. In the actual context of rising fossil fuel prices due to the Ukrainian conflict, we are likely to observe a strong substitution of those sources with clean energy, good news for European energy sovereignty as well as for the transition to a net-zero economy. Due to the unavailability of data beyond December 2021, a direct analysis of the impact of the Russia-Ukraine war on the European oil and gas market was not possible. Europe’s significant reliance on gas and oil amplifies its vulnerability to shocks in these markets. Consequently, the responses during the Covid-19 era and the responses during the war can be examined independently, just as on the global level, and the ways in which investors’ inclination toward clean energy responds to varying degrees of uncertainty can be examined. Delaying the closure of coal and nuclear power plants in the post-war period may nullify the presence of the substitution effect. This remains to be investigated in future research.

Finally, we can conclude that there is a feedback effect between investor attention and green bond returns. This suggests that the performance of green bonds is highly influenced by investor attention. As investors increasingly focus on green bonds, the demand for these bonds rises, causing prices to increase and yields to decrease. This could lead to enhanced profits for investors who retain ownership of these bonds. Consequently, green bonds can function as an alternate means of financing the shift towards a low-carbon economy. Besides, we find that the influence of investor attention on the returns of green bonds is amplified during periods of heightened volatility, such as the Covid-19 pandemic. It is crucial to analyze the behavior of green bonds in both normal and exceptional market conditions. Formulating a comprehensive evaluation may result in inadequate data regarding the behavior of green bonds during exceptional market circumstances. Moreover, during periods of extreme market volatility, the attention of investors can be a significant tool for forecasting the performance of green bonds. Nevertheless, it is crucial for investors to exercise prudence, as the relationship between green bonds and investor attention is susceptible to variations over time. Last but not least, commonly, research on green bonds focuses on four specific areas: Examining the disparities between green bonds and conventional bonds, exploring the correlation between oil prices and the dynamics of green bonds, investigating the influence of green bond issuance on the financial performance of companies, and analyzing the connection between green bonds, clean energy, and environmental performance. Studying how it interacts with behavioral finance is a recently developed area of research. There is a limited body of research investigating the correlation between behavioral finance and green bonds. It is crucial to broaden the existing body of literature in this context. The following suggestions are proposed for conducting further analysis in future study. First, TVP-VAR could be a useful alternative methodology for future research. This model has the ability to detect and analyze significant changes in the structure of the data set, such as financial crises or economic recessions, and forecast the consequences of these changes. Therefore, both the date of Covid-19 being officially designated a pandemic and the date of war being officially proclaimed may be classified as a shock in the model, and their impacts can be examined in more detail. Second, the impact of investor attention on green bonds in the USA and China, the two main green bond issuers, can be investigated in addition to the relationship between green bonds and investor attention on the global level. An examination can be conducted to determine the degree to which market uncertainties impact investor attention in two countries.

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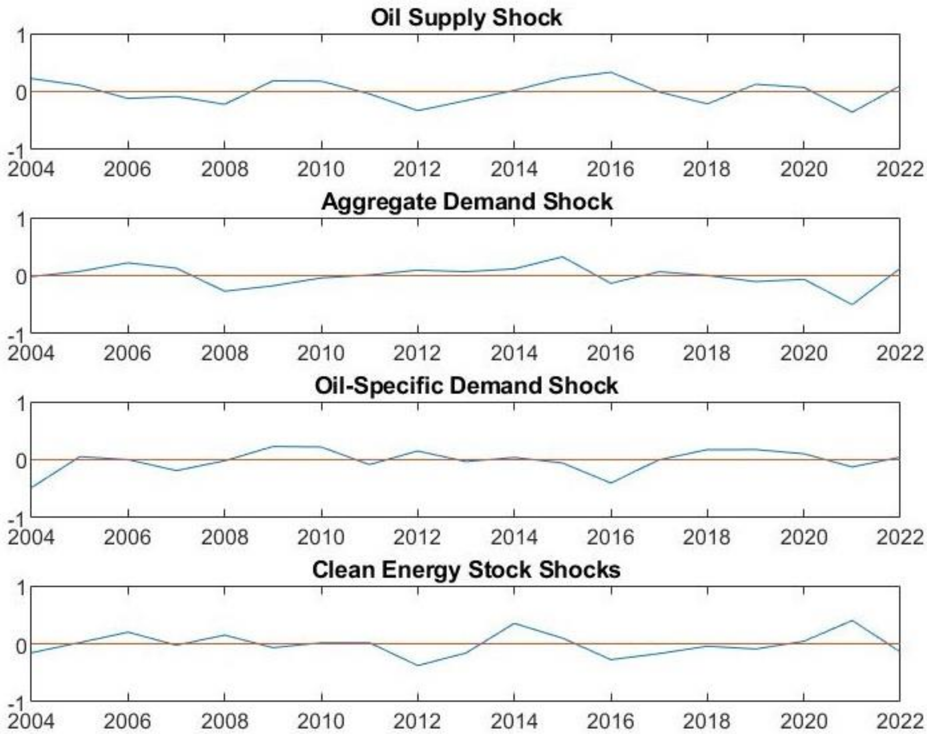
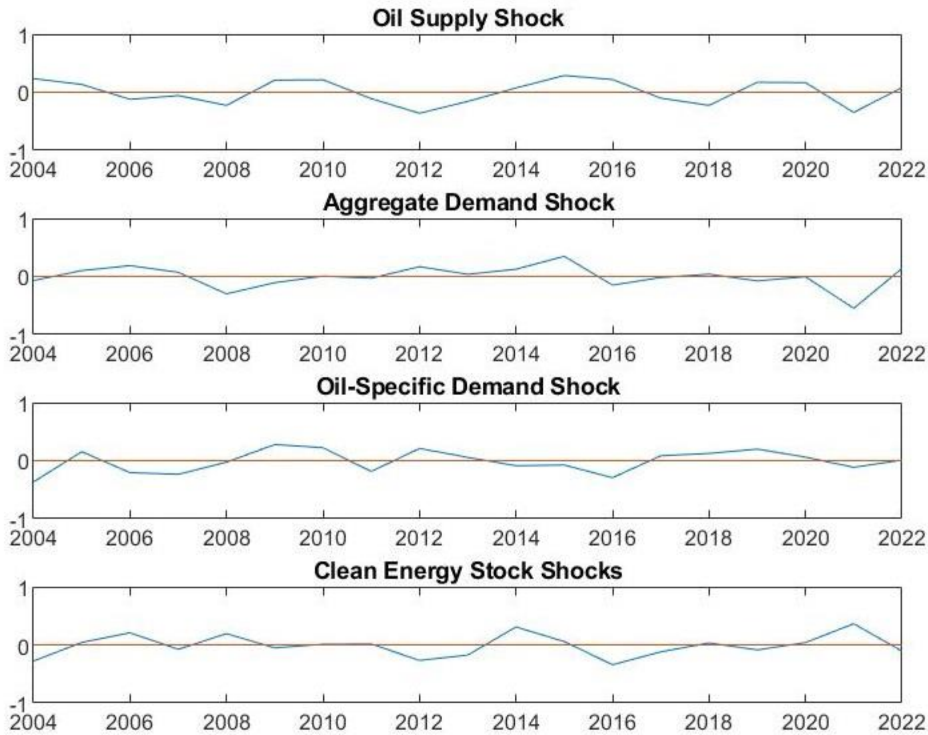
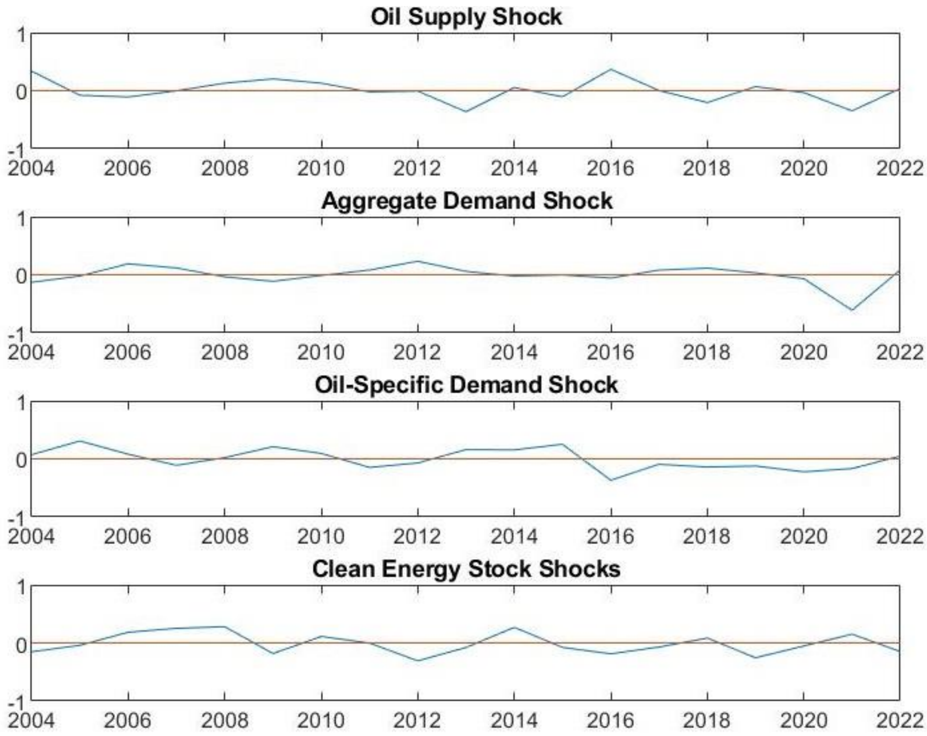
APPENDIX1. HISTORICAL EVOLUTION OF THE STRUCTURAL SHOCKS WITH ECO INDEX AND WTI



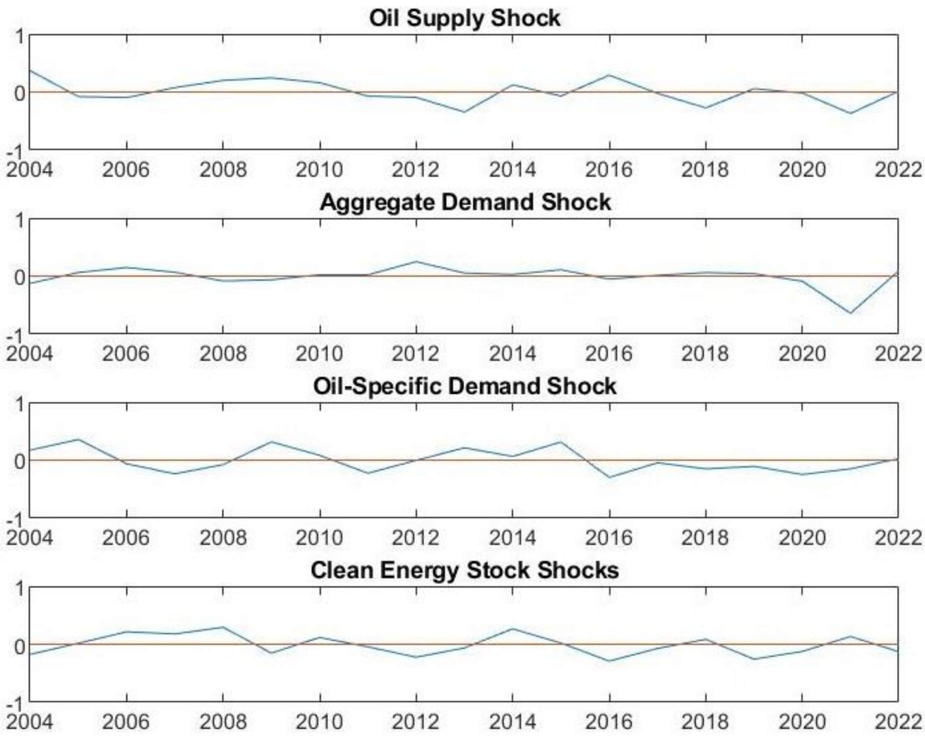
APPENDIX2. HISTORICAL EVOLUTION OF THE STRUCTURAL SHOCKS WITH ECO INDEX AND BRENT



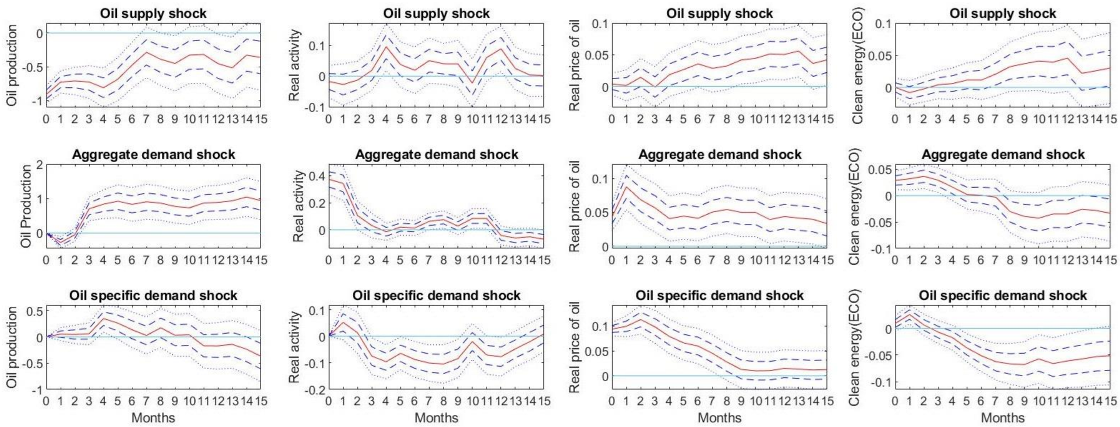
APPENDIX3. HISTORICAL EVOLUTION OF THE STRUCTURAL SHOCKS WITH NEX INDEX AND WTI



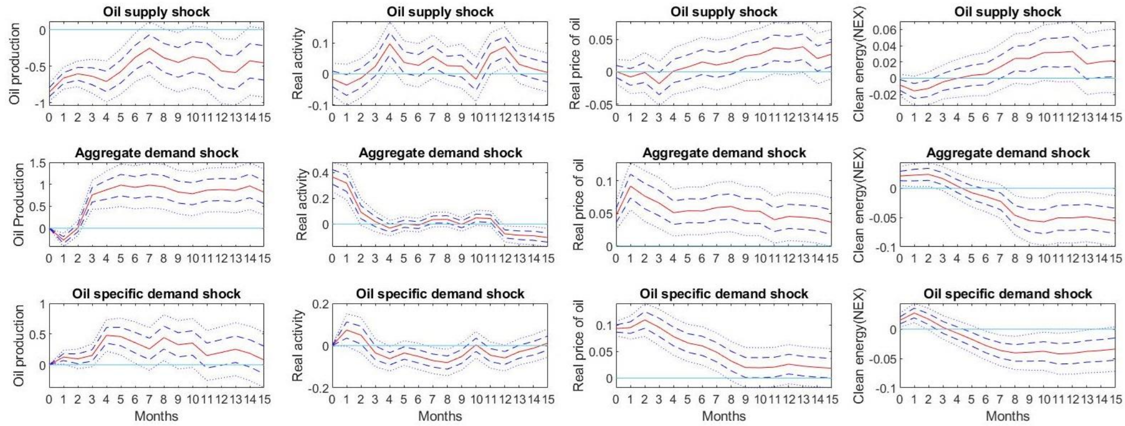
APPENDIX4. HISTORICAL EVOLUTION OF THE STRUCTURAL SHOCKS WITH NEX INDEX AND BRENT



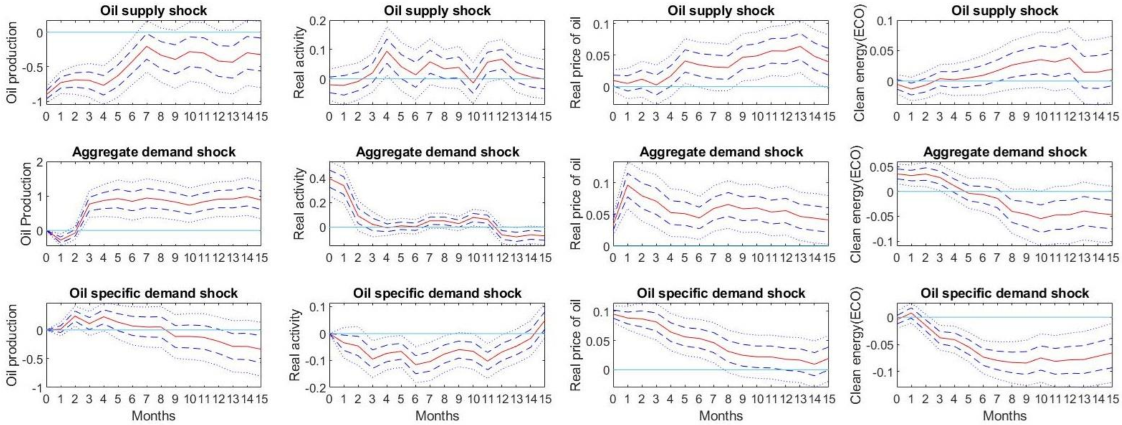
APPENDIX5. RESPONSES TO THE THREE STRUCTURAL SHOCKS (WTI-ECO)



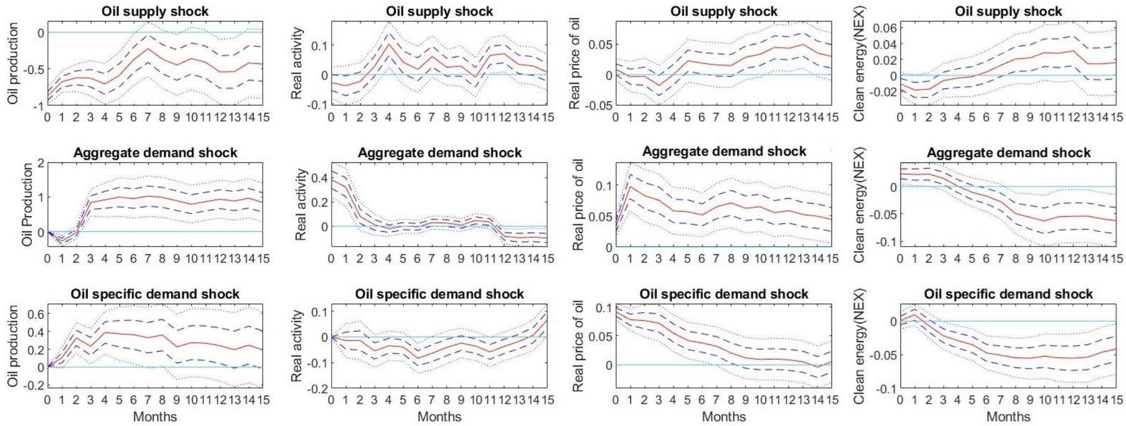
APPENDIX6. RESPONSES TO THE THREE STRUCTURAL SHOCKS (WTI-NEX)



APPENDIX7. RESPONSES TO THE THREE STRUCTURAL SHOCKS (BRENT-ECO)



APPENDIX8. RESPONSES TO THE THREE STRUCTURAL SHOCKS (BRENT-NEX)



APPENDIX9. THE RESULTS OF KPSS UNIT ROOT TESTS

	Level	First Difference
GSVI	3.557934	0.114995
SPGB	1.245856	0.214976
CLEAN	5.279434	0.053723
OIL	1.332081	0.128074
GAS	1.209557	0.079140
MOVE	1.174274	0.055899
OVX	0.657324	0.046267
VIX	2.287568	0.022605
Critical values: 1%, 5% and 10% are 0.739000, 0.463000, and 0.347000, respectively.		

APPENDIX10. ORIGINALITY REPORT

	HACETTEPE ÜNİVERSİTESİ SOSYAL BİLİMLER ENSTİTÜSÜ	Doküman Kodu *Form No.*	FRM-DR-21
		Yayım Tarihi *Date of Pub.*	22.11.2023
	FRM-DR-21 **Doktora Tezi Orijinallik Raporu** *PhD Thesis Dissertation Originality Report*	Revizyon No *Rev. No.*	00
		Revizyon Tarihi *Rev.Date*	

HACETTEPE ÜNİVERSİTESİ
SOSYAL BİLİMLER ENSTİTÜSÜ
İKTİSAT ANABİLİM DALI BAŞKANLIĞINA

Tarih: 28/11/2023

Tez Başlığı*: Three Essays on Clean Energy

Yukarıda başlığı verilen tezimin a) Kapak sayfası, b) Giriş, c) Ana bölümler ve d) Sonuç kısımlarından oluşan toplam 114 sayfalık kısmına ilişkin, 28/11/2023 tarihinde şahsım tarafından Turnitin adlı intihal tespit programından aşağıda işaretlenmiş filtrelemeler uygulanarak alınmış olan orijinallik raporuna göre, tezimin benzerlik oranı % 24'tür.

Uygulanan filtrelemeler**:

1. ☒ Kabul/Onay ve Bildirim sayfaları hariç
2. ☒ Kaynakça hariç
3. ☐ Alıntılar hariç
4. ☒ Alıntılar dâhil
5. ☒ 5 kelimeden daha az örtüşme içeren metin kısımları hariç

Hacettepe Üniversitesi Sosyal Bilimler Enstitüsü Tez Çalışması Orijinallik Raporu Alınması ve Kullanılması Uygulama Esasları'nı inceledim ve bu Uygulama Esasları'nda belirtilen azami benzerlik oranlarına göre tezimin herhangi bir intihal içermediğini; aksinin tespit edileceği muhtemel durumlarda doğabilecek her türlü hukuki sorumluluğu kabul ettiğimi ve yukarıda vermiş olduğum bilgilerin doğru olduğunu beyan ederim.

Gereğini saygılarımla arz ederim.

28/11/2023

Öğrenci Bilgileri	**Ad-Soyad**	Ayşegül UÇKUN ÖZKAN	**Öğrenci No**	N17142543
	Enstitü Anabilim Dalı	İktisat		
	Programı	İngilizce İktisat		
	E-posta/Telefon	aysegul.uckun@karatay.edu.tr	4441251/7366	
	Statüsü	**Doktora** ☒	**Lisans Derecesi ile (Bütünleşik) Dr** ☐	

DANIŞMAN ONAYI

UYGUNDUR.
Doç. Dr. Özge KANDEMİR KOCAASLAN

*Tez **Almanca** veya **Fransızca** yazılıyor ise bu kısımda tez başlığı **Tez Yazım Dilinde** yazılmalıdır
**Hacettepe Üniversitesi Sosyal Bilimler Enstitüsü Tez Çalışması Orjinallik Raporu Alınması ve Kullanılması Uygulama Esasları İkinci bölüm madde (4)/3'te de belirtildiği üzere: Kaynakça hariç, Alıntılar hariç/dahil, 5 kelimeden daha az örtüşme içeren metin kısımları hariç (Limit match size to 5 words) filtreleme yapılmalıdır.

	HACETTEPE ÜNİVERSİTESİ SOSYAL BİLİMLER ENSTİTÜSÜ	Doküman Kodu *Form No.*	FRM-DR-21
		Yayım Tarihi *Date of Pub.*	22.11.2023
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		Revizyon Tarihi *Rev.Date*	

TO HACETTEPE UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
DEPARTMENT OF ECONOMICS

Date: 28/11/2023

Thesis Title (In English): Three Essays on Clean Energy

According to the originality report obtained by myself by using the Turnitin plagiarism detection software and by applying the filtering options checked below on 28/11/2023 for the total of 114 pages including the a) Title Page, b) Introduction, c) Main Chapters, and d) Conclusion sections of my thesis entitled above, the similarity index of my thesis is 24%.

Filtering options applied**:

1. ☒ Approval and Decleration sections excluded
2. ☒ References cited excluded
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4. ☒ Quotes included
5. ☒ Match size up to 5 words excluded

I hereby declare that I have carefully read Hacettepe University Graduate School of Social Sciences Guidelines for Obtaining and Using Thesis Originality Reports that according to the maximum similarity index values specified in the Guidelines, my thesis does not include any form of plagiarism; that in any future detection of possible infringement of the regulations I accept all legal responsibility; and that all the information I have provided is correct to the best of my knowledge.

I respectfully submit this for approval.

28/11/2023

Student Information				
Name-Surname	Ayşegül UÇKUN ÖZKAN	**Student Number**	N17142543	
Department	Economics			
Programme	Doctor of Philosophy in Economics			
E-mail/Phone Number	aysegul.uckun@karatay.edu.tr	4441251/7366		
Status	**PhD** ☒	**Combined MA/MSc-PhD** ☐		

SUPERVISOR'S APPROVAL

APPROVED
Assoc. Prof. Dr. Özge KANDEMİR KOCAASLAN

**As mentioned in the second part [article (4)/3]of the Thesis Dissertation Originality Report's Codes of Practice of Hacettepe University Graduate School of Social Sciences, filtering should be done as following: excluding refence, quotation excluded/included, Match size up to 5 words excluded.

APPENDIX11. ETHICS BOARD WAIVER FORM

	HACETTEPE ÜNİVERSİTESİ **SOSYAL BİLİMLER ENSTİTÜSÜ**	Doküman Kodu *Form No.*	FRM-DR-12
		Yayım Tarihi *Date of Pub.*	22.11.2023
	FRM-DR-12 **Doktora Tezi Etik Kurul Muafiyeti Formu** *Ethics Board Form for PhD Thesis*	Revizyon No *Rev. No.*	00
		Revizyon Tarihi *Rev.Date*	

HACETTEPE ÜNİVERSİTESİ
SOSYAL BİLİMLER ENSTİTÜSÜ
İKTİSAT ANABİLİM DALI BAŞKANLIĞINA

Tarih: 28/11/2023

Tez Başlığı*: Three Essays on Clean Energy

Yukarıda başlığı gösterilen tez çalışmam:
1. İnsan ve hayvan üzerinde deney niteliği taşımamaktadır.
2. Biyolojik materyal (kan, idrar vb. biyolojik sıvılar ve numuneler) kullanılmasını gerektirmemektedir.
3. Beden bütünlüğüne veya ruh sağlığına müdahale içermemektedir.
4. Anket, ölçek (test), mülakat, odak grup çalışması, gözlem, deney, görüşme gibi teknikler kullanılarak katılımcılardan veri toplanmasını gerektiren nitel ya da nicel yaklaşımlarla yürütülen araştırma niteliğinde değildir.
5. Diğer kişi ve kurumlardan temin edilen veri kullanımını (kitap, belge vs.) gerektirmektedir. Ancak bu kullanım, diğer kişi ve kurumların izin verdiği ölçüde Kişisel Bilgilerin Korunması Kanuna riayet edilerek gerçekleştirilecektir.

Hacettepe Üniversitesi Etik Kurullarının Yönergelerini inceledim ve bunlara göre çalışmamın yürütülebilmesi için herhangi bir Etik Kuruldan izin alınmasına gerek olmadığını; aksi durumda doğabilecek her türlü hukuki sorumluluğu kabul ettiğimi ve yukarıda vermiş olduğum bilgilerin doğru olduğunu beyan ederim.

Gereğini saygılarımla arz ederim.

28/11/2023

Öğrenci Bilgileri				
Ad-Soyad	Ayşegül UÇKUN ÖZKAN	**Öğrenci No**	N17142543	
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	HACETTEPE ÜNİVERSİTESİ SOSYAL BİLİMLER ENSTİTÜSÜ	Doküman Kodu *Form No.*	FRM-DR-12
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HACETTEPE UNIVERSITY
GRADUATE SCHOOL OF SOCIAL SCIENCES
DEPARTMENT OF ECONOMICS

Date: 28/11/2023

ThesisTitle (In English): Three Essays on Clean Energy

My thesis work related to the title above:

1. Does not perform experimentation on people or animals.
2. Does not necessitate the use of biological material (blood, urine, biological fluids and samples, etc.).
3. Does not involve any interference of the body's integrity.
4. Is not a research conducted with qualitative or quantitative approaches that require data collection from the participants by using techniques such as survey, scale (test), interview, focus group work, observation, experiment, interview.
5. Requires the use of data (books, documents, etc.) obtained from other people and institutions. However, this use will be carried out in accordance with the Personal Information Protection Law to the extent permitted by other persons and institutions.

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I respectfully submit this for approval.

28/11/2023

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