INVESTIGATION OF FLIGHT-TO-QUALITY PHENOMENA BETWEEN GREEN BONDS AND STOCK MARKET INDICES DURING COVID-19 IN EUROPEAN MARKETS

Lappeenranta–Lahti University of Technology LUT
Master's Programme in Strategic Finance and Business Analytics
2024
Erica Haranen
Examiner(s): Associate Professor, Jan Stoklasa
Visiting Researcher, Tomáš Talášek

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Business and Management

Business Administration

Erica Haranen

Investigation of flight-to-quality phenomenon between green bonds and stock market indices during COVID-19 in European markets

Master's thesis

2024

60 pages, 15 figures, 4 tables

Examiner(s): Associate Professor, Jan Stoklasa and visiting researcher Tomáš Talášek

Keywords: green bonds, flight-to-quality, DCC-GARCH

The concept of flight-to-quality phenomenon stems from investor behavior, characterized by a shift from riskier assets to safer ones during periods of turmoil experienced in the financial market. Utilizing the Dynamic Conditional Correlation (DCC) GARCH model, this study analyzes the correlations between a paired Solactive Green Bond index and the 10 European stock market indices within OECD economies. The analysis spans from June 2016 to the beginning of 2022, capturing daily returns from the pre-pandemic, pandemic, and post-pandemic periods. The aim is to determine whether evidence of flight-to-quality is present for the paired assets or is there evidence of cross-asset contagion.

The findings reveal that the flight-to-quality phenomenon is present to varying degrees for the investigated bond-stock pairs, with the suggestion that there has been a shift from stocks to green bonds, albeit to varying degree across European markets. Based on the observed averages in the correlations, green bond index paired with an Austrian market index seems to have supported the primary role of the safe haven after the market downturn as it had the largest negative correlation on average (-0.2823) with respect to other observed pairs. However, for green bond index paired with Danish market index seems to provide evidence for cross-asset contagion as the correlation has stayed positive throughout the observed period.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT-kauppakorkeakoulu

Kauppatieteet

Erica Haranen

Tutkimus laadukkaisiin sijoituksiin siirtymäilmiöstä vihreiden joukkovelkakirjalainojen ja pörssi-indeksien välillä COVID-19 kriisin aikana Euroopan talousalueella

Kauppatieteiden pro gradu -tutkielma

2024

60 sivua, 15 kuvaa, 4 taulukkoa

Tarkastaja(t): Apulaisprofessori Jan Stoklasa ja vieraileva tutkija Tomáš Talášek

Avainsanat: vihreät joukkovelkakirjalainat, laatuun pakeneminen, DCC-GARCH

Flight-to-quality-ilmiö juontaa juurensa sijoittajien käyttäytymisestä, jolle ominaista on siirtyminen riskipitoisemmista rahoitusinstrumenteista turvallisempiin markkinaturbulenssin aikana. Tutkimuksessa hyödynnetään Dynamic Conditional Correlation (DCC) GARCH-mallia analysoimaan korrelaatioita vihreiden joukkovelkakirjalaina indeksin ja OECD-maiden kymmenen euroalueen pörssi-indeksien välillä. Analyysi kattaa ajanjakson kesäkuusta 2016 vuoden 2022 alkuun, ja siinä tarkastellaan päivittäisiä tuottoja ennen pandemiaa, pandemian aikana ja pandemian jälkeen. Tavoitteena on määrittää, onko flight-to-quality-ilmiö havaittavissa rahoitusinstrumenteille ja analysoida ilmiön suuruus joukkovelkakirjalaina-osakeparille.

Tulokset paljastavat, että flight-to-quality on läsnä vaihtelevissa määrin tutkituille joukkovelkakirjalaina-osakepareille, joskin vaihtelevassa määrin eri Euroopan markkinoilla. Tarkasteltaessa keskimääräistä korrelaatiota joukkovelkakirjalaina-osakeparille tutkimuksessa huomattiin, että Itävallan kohdalla flight-to-quality efekti on ollut suurimmillaan (-0.2823) muihin pareihin verrattuna. Tämän lisäksi Tanskan kohdalla korrelaatio on pysyt positiivisena koko ajanjakson läpi ennen ja jälkeen kriisin, mikä voi olla näyttöä mahdollisesta tartunnasta kahden instrumentin välillä näiden liikkuessa samaan suuntaan.

SYMBOLS AND ABBREVIATIONS

Abbreviations

CBI	Climate Bonds Initiative
CBS	Climate Bond Standard
ICMA	International Capital Markets Association
GBP	Green Bond Principles
KPI	Key Performance Indicator
SME	Small and medium-sized Enterprise
SDG	Sustainable Development Goal
BEKK	Baba-Engel-Kraft-Kroner
DCC-GARCH	Dynamic Conditional Correlation Generalized Autoregressive Conditional Heteroskedasticity
WHO	World Health Organization

Table of contents

Figures

Tables

1 Introduction

In recent years, the concept of sustainable investment and environmentally friendly financing has generated attention. The shift is not only a response to the need for action on the sustainability front but also reflects a more significant change in the investor priorities as the topic is growing in academia (Leitao, Ferreira and Santibanez-Gonzalez, 2021; Martiradonna, Romagnoli and Santini, 2023a; Tolliver, Keeley and Managi, 2020) According to a study made by Boston Consulting Group (Kachaner, Nielsen, Portafaix and Rodzko, 2020), the COVID-19 pandemic has left an impact globally and raised environmental concerns highlighting the commitment of changing the behavior to promote sustainability. The survey has also shown that there is more demand for aggressive environmental actions and economic plans should see these as a priority.

The rise of the Coronavirus (COVID-19) in the end of 2019 infected population worldwide leading up to a declaration of a pandemic on 11 March 2020 (WHO, 2023). The virus not only impacted public health, social and cultural life but also the economy on a global scale. Such instability in the market can provide grounds for a flight-to-quality phenomenon where investors shift from riskier financial instruments to what can be generally perceived as less risker. Assuming that all investors are risk-avoidant in the crisis scenario, we assume a hypothesis of flight-to-quality where increased risk is especially observed for illiquid assets as the perceived risk in the market betas increase particularly affecting them as their risk exposure tends to increase during the times when market is experiencing unstable conditions. Therefore, the concept of quality assumes an important characteristic of assets, which is high liquidity appearing as less risky (Caballero & Krishnamurthy, 2008; Vayanos, 2004). Empirical studies conducted on this topic present evidence of the existence of flight-to-quality phenomenon as investors switch from stock to bond markets and Andersson et al. (2008) have observed that one of the characteristics for the phenomenon is uniform movement of stock and bond prices during the high inflation periods. Additionally, Baur and Lucey (2009) have uncovered that flight-to-quality can occur at the same time in many countries during crisis periods. Additionally, the authors expand on the phenomenon bringing forth the concept of cross-asset contagion, which exists in situations where the level of correlation stays positive between the asset pairs resulting in co-movement, which contradicts flight-to-quality where the assets move in different directions. This study will be observing the effects of flight-to-quality phenomenon and the possibility of cross-asset contagion investigating the relationship between the European market indices and green bonds, a financial instrument that targets the use of its proceeds to refinance sustainable projects (Banga, 2019).

Flight-to-quality research is in its extent a very relevant topic concerning the current world affairs with the variety of crises that the financial market has experienced in the past decade. However, the existing literature so much as only touches base on the European market analysis as most of the research focuses mainly on overseas markets such as the United States and China as they are the largest economies (Marsh and Pfleiderer, 2013; Naeem et al., 2021; Tachibana, 2020; Yadav, Mishra and Ashok, 2023). Green bonds have been on the rise in the European markets with notable issuances such as a European Green Deal (European Commission, 2019) providing a roadmap for sustainable economic development in the area and raising the largest issuance to date of €12 billion labeled as NextGenerationEU (European Commission, 2021). Green bonds currently have two standards, both voluntary but widely accepted by the market – The Green Bond Principle (GBP) and Climate Bond Initiative (CBI). The former requires specific characteristics for the eligibility of being labeled as green, such as transparent reporting on the use of proceeds, project evaluation procedures, and management of the proceeds. The CBI is quite similar in many aspects to the GBP and provides a criterion for assessing the eligibility of green bonds (CBI, 2023b; Tang and Zhang, 2020). Climate Bonds Standard launched by the Climate Bonds Initiative (CBI) characterizes eligible projects by a taxonomy requiring an external verification of pre- and post-issuance disclosure for issuers to obtain the CBS certificate.

The target of this research is to shine light on the studies related to green bonds and investigate whether the recent financial crisis that was due to COVID-19 has provided evidence of flight to quality between green bonds and stocks. As the investigation of the ‘safeness’ of green bonds has not been that extensively investigated during the turbulent periods in the market, including the studies surrounding the recent COVID-19 pandemic, it provides a base for an interesting investigation on the green bonds and their impact on investment strategies and risk management in comparison with the other financial assets.

1.1 Objectives of the study and research questions

With our study, the aim is to shed light on the flight-to-quality analysis bringing forth the European stock markets indices under OECD economies and investigating whether the COVID-19 pandemic had increased the shifting from riskier to a safer asset during times of market volatility. Chosen markets include Luxembourg (LUX), Ireland (ISEQ), Belgium (BEL), Germany (DAX), Netherlands (AEX), Sweden (OMXS), Finland (OMXH), Austria (ATX), Denmark (OMXC), and Iceland (OMXI) based on the literature and their combined green bond issuances accounting over 50% (CBI, 2023a; Yadav, Mishra and Ashok, 2023) of total EU issuances. As the green bond market continues to grow, with many issuances and policies for regulation there is a need to understand the dynamics of flight-to-quality behavior and whether the sustainable option could prove for a good option of diversification target during the economically challenging times as its plain vanilla counterpart or government bonds (Baur and Lucey, 2009; Pereira and Lagoa, 2019; Tachibana, 2020). The conducted research focuses mostly on the effects of the COVID-19 pandemic instilled on the chosen green bond benchmark index, which in this study the Solactive Green Bond EUR USD IG Index will be considered. Examination of the relationship between stocks and bonds provides an even broader possibility for investors to understand the asset allocation and risk management of two different asset classes. The study aims to contribute to the existing literature by providing evidence of whether the chosen green bond index offers a better option for diversification than stock market indices during turbulent market period. The characteristic can be identified as a negative correlation between a bond-stock pair which will be considered as flight-to-quality phenomena. In addition, majority of studies focus on investigating the flight-to-quality comparing government bonds with other financial instruments – mostly stocks, whereas this study takes into specification green bonds that have been gaining a wider spotlight in academic papers in the recent years.

In the light of the target of this research the objective is to understand and explore

1) *Is there evidence of flight-to-quality between the green bond and stock market index pairs?*
2) *Is there evidence of cross-asset contagion between the green bond and stock market index pairs?*

The research questions will be investigated by adopting a DCC-GARCH model and utilizing it to identify flight-to-quality during the COVID-19 pandemic which impacted financial markets globally in the beginning of 2020. The choice for the model is based on the previous literature as it has been widely used for identification of flight-to-quality and contagion (Celik, 2012; Hemche et al., 2016; Pereira and Lagoa, 2019). The multivariate specifications in the model provide a way for identification of time-varying conditional correlations in time-series pairs, making it an advantageous tool for investigating the response to crises.

1.2 Scope and structure of the thesis

The study examines chosen European market indices and investigates their relationship to the green bond index that has been identified as Solactive Green Bond EUR USD IG Index based on the availability of the LUT University's provided database – Refinitiv Datastream. The information and daily prices were only available for the selected index as other major indices investigated in prior research such as MSCI and S&P green bond indices were not available in the database and behind a paywall. Considering we can only investigate one index it is limiting the broader study on the how other major indices have been affected by the flight-to-quality phenomenon and narrowing our scope to one.

This paper consists of 6 sections, as the introduction is followed by a literature review and a theoretical background as a framework of what has been done before and how we can utilize the knowledge in this field of study. Fourth section covers the methodology where the appropriate model is proposed to be based on DCC-GARCH model. The chapter also includes the description of data that has been retrieved for this research. The fifth section provides the results that the analysis has produced, and the discussion based on findings. The last chapter concludes the research and contributes insight on how the results could be utilized including suggestions for extending this research for future cases.

2 Key concepts and a theoretical background

This chapter intends to provide a broader definition for the flight-to-quality phenomenon and green bonds including outline of the primary purpose and benefit they provide for the investors. This research is focusing on the analysis of whether green bonds are subject to flight-to-quality, and thus the main goal is to produce insight that could prove meaningful to the investors, especially during the period of market turmoil.

2.1 Flight-to-quality phenomenon: what it is and how has it has been studied?

During economically uncertain times individual investors prefer to secure invested assets in the market before a sudden period of instability occurs. In such scenarios, it is critical to understand the risk and return trade-off in the financial markets. Flight-to-quality phenomenon originates from the uncertainty in the markets and exists when the correlation between assets is negative and generates a need for liquidity that increases with volatility (Chang and Hsueh, 2013; Tachibana, 2020). The behavior can be examined as investors fleeing from riskier assets into what are generally considered as ‘safe’ and more stable and liquid counterparts, such as government bonds as the governments are not easily defaulted on. The effect of flight-to-quality can be observed in the example of 2008 financial market crisis, where capital shifted globally from emerging markets to ‘higher quality’, which is considered as developed markets (Cho et al., 2016). This is a very natural response to any stressful situation as humans are recognized for the majority being risk avoidant. Risk aversion is considered as a fundamental property of human nature, and extensive research on the topic has contributed to our understanding of economic behaviors and concepts (Zhang, Brennan & W. Lo, 2014). Assuming that all investors are risk-avoidant in the crisis scenario, we assume a hypothesis of flight-to-quality where increased risk is especially observed for illiquid assets as their perceived risk in the market increases, particularly affecting the illiquid assets as their market betas increase. This implies that the definition of quality in the said context assumes an important characteristic of assets, which is high liquidity (Caballero and Krishnamurthy, 2008; Vayanos, 2004).

Studies on financial contagion and flight-to-quality focus explicitly on the crisis periods in the economies. To understand flight-to-quality, most researches have been focusing on the subprime and euro sovereign debt crisis, where it was found that the flight-to-quality occurred in a way where investors shifted from the Mediterranean bond markets to German market highlighting increased correlation between the Portugal and Greece during the period (Pereira and Lagoa, 2019); the 2008 financial crisis where authors found that stock and bond returns assume negative relationship which showed that government bonds were considered a safe option on the contrast to stocks as a financial instrument (Chang and Hsueh, 2013; Marsh and Pfleiderer, 2013). The concept focuses on the study of correlations between the selected bond and stock return pairs which essentially provide very valuable information for decision making in finance concerning the topics from risk management to portfolio optimization strategies. The asset combination allows for investment diversification and targets to protect against various risks in the financial markets. As previously elaborated by Chang and Hsueh (2013), portfolio consisting of two assets that produces a significant negative correlation contributes to the existence of flight-to-quality and thus may provide a better hedge for the investors.

Authors studying the flight-to-quality have utilized several methods for its identification. These include the use of Granger causality with the premise that assets with higher risk can predict the movements in less riskier assets (Narayan, Rizvi and Sakti, 2022), the two-state regime-switching copula approach to understanding the intensity and the dependence between domestic and cross-country stock-bond pairs (Tachibana, 2020), copula-based models with time-varying dependence structures assessing the marginal distributions of two financial instruments (Chang and Hsueh, 2013; Durand, Junker and Szimayer, 2010) and multivariate DCC-GARCH models to assess the existence of contagion between government bond markets (Pereira and Lagoa, 2019) where the latter will be used as a method in this research.

The majority of bond-stock analyses have provided more evidence on how two different asset classes interact. Chang and Hsueh (2013), Durand et al. (2010) and Kearney (2006) uncover in their studies that the returns of stock and sovereign bond indices exhibiting negative correlation demonstrate the flight-to-quality in the sample during the crisis periods.

Additional research (Kemper, Lee & Simkins, 2012) expands on the topic by introducing the diversification benefits in a study of understanding co-movement in portfolios consisting of stocks and bonds finding that during extreme stress posed on the markets a greater negative correlation occurs between the two asset classes.

2.2 Green Bonds

Understanding the differences when comparing green bonds and their traditional counterpart the former strives to provide transparency to the investors and include similar features as the conventional bonds being described as fixed-income instruments that have stricter guidelines for managing the proceeds only towards the “green” projects. (TEG Report, 2019; Lin and Su, 2022) Differing from the traditional plain vanilla bonds, the funds raised for green bonds are refinanced targeting projects, activities or assets that support the market shift to a greener direction. (European Comission, 2023a) Highlighting the importance of Environment, Social and Governance (ESG), the issuers can benefit in the form of a reputational boost, showing the investors their agenda for tackling the climate change. For investors in a similar manner, green bonds can prove to be an appealing asset to meet their own ESG targets and diversify their portfolio to include more greener investments. After the first issuance of a ‘green’ bond in 2007, there has been an increasingly identified need for a proper labelling as it has been raised that corporate bonds at minimum require to have a verification in order to achieve better premia. (Bachelet, Becchetti and Manfredonia, 2019). Therefore, these bonds can have some disadvantages such as additional costs of qualification which can occur when issuers apply for a Climate Bond Initiative’s certificates (chapter 2.1.1) and having a limited scope of potential projects as the framework for project selection for a green bond to get the “green” label is dictated by the Green Bond Principles (chapter 2.1.2). However, considering that Plumlee et al. (2015) show in their research that investors highly value voluntary environmental disclosures and externally produced information of high quality the certificates can be considered of great importance in issuances.

Compliance to achieve the green label provides issuers with a more competitive advantage for example on pricing as strong green credentials are a crucial factor for influencing investment decisions and demand (Sangiorgi and Schopohl, 2021). Other challenges that the green bond market experiences are reduced awareness of benefits, lack of guidelines, and cost of meeting green bond requirements along with difficulties for international investors accessing local markets (OECD, 2017). Regulators are updating frameworks and best practices for the rising demand for green investment assets to address potential risks and misinterpretations of green investments and understand the proper definition of a word “green” to support not only investors but the issuers as well. The demand for such investment types is coming from the perspective of exposure to the uncertainty that climate change poses, there is a need for more comprehensive policies to further the agenda for driving more sustainable investments.

EU taxonomy is an initiative fostered by the European Union aimed at identifying sustainable activities designed to achieve the climate and energy objectives for 2030 (European Commission, 2021). This taxonomy is meticulously designed to afford issuers and investors with a comprehensive definition of the economic activities that fall under the definition of sustainable action. This aids in mitigating the prevalence of greenwashing, which is an act of spreading deceptive claims of any environmental benefits or impacts. (European Commission, 2023c) The European Commission has adopted a framework regarding the green bond issuance, encouraging not only issuers but investors as well to participate in improving the conditions in markets. The Commission has first proposed a road map for a more sustainable economy in the EU region in 2019 introducing European Green Deal with a target of boosting the continent to be first in becoming climate-neutral by 2050. (European Commission, 2019; European Commission, 2023b)

The largest issuance to date has been raised by the European Commission of €12 billion labelled as NextGenerationEU green bond setting the EU as the largest bond issuer by far. This issuance is targeted specifically to fund green and sustainable investment across the European Union. The NextGenerationEU green bond program is a commitment that EU is trying to set for its sustainability agenda and towards a recovery from the COVID-19 pandemic, focusing on transparent activities emphasizing investor-centric mindset and driving the recovery of Europe to a more sustainable direction. The bond’s framework is fully compliant to GBP set by ICMA. (European Commission, 2021; European Commission, 2023)

During the spring 2023, the EU Commission has agreed on the European green bond standard focusing on future issuances, establishing a voluntary high-quality standard for green bonds, requiring fund allocation in activities that are in line with the taxonomy. In addition, the standard also actively battles against green washing as it allows investors to easily compare and judge the sustainability status of their investments. (European Commission, 2023c)

2.2.1 Green bond screenings

The green label provides important value promoting trust and confidence that invested funds will be directed to the appropriate projects and assets that are in accordance with the Paris Agreement. Thus, Climate Bonds Standard (CBS) has introduced a framework for defining which projects are in line and consistent in reaching the goals set by the Paris Agreement (CBI, 2019). The voluntary framework provides valuable information as environmental disclosures and existing certifications provide assessing not only predict firm profitability but also the contribution to address climate change. (CBI, 2019; Plumlee et al., 2015)

Climate Bonds Standard launched by the Climate Bonds Initiative (CBI) characterizes eligible projects by a taxonomy requiring an external verification for issuance disclosure in order to prove eligible for receiving a certificate. The CBS and Certification Scheme is entirely voluntary and designed for investments that in line with the Paris Climate Agreement goals. The standard itself was designed as a credential for green bonds and other debt instruments aiding investors with decision making. However, Certification Scheme is now expanding the gap between existing guidance on transition financing. (CBI 2023b)

According to CBI their offering provides a possibility for issuers to gain a certification for the issued green bond with the benefit of an endorsement of the green debt instrument and increased visibility to investors. Minimum fee disclosed by CBI for issuers is $1,000 and $2,000 in developing and developed countries respectfully with an additional variable fee of 1/10th basis point of the issued amount. (CBI 2023) Overall, as an international organization, the CBI focuses mainly on mobilizing global capital for climate action and provides different methods by screening the bonds against the global taxonomy to determine how aligned the green bonds are with the set standards which could potentially provide even better understanding for investors on green investment possibilities.

2.2.2 Green Bond Principles

Green Bond Principles (GBP) – a voluntary framework created by International Capital Market Association (ICMA), outlines the best practices for bond issuers regarding social and/or environmental purposes. It serves as a process guideline for issuing and understanding the definition of green bonds. As per the released handbook the minimum considered requirements for a green bond issuance should align with the following four components (International Capital Market Association, 2022):

1) Use of proceeds

A target project the security is being issued for needs to have a sufficient legal description regarding the project's environmental objectives. The category falling under the eligible projects includes all environmentally beneficial activities having a sufficient reporting manner. The use of proceeds should be clear and solely applied to the project that actively promotes climate actions and environmental sustainability purposes.

2) Process for project evaluation and selection

An elaborate communication between issuers and investors is needed for whether the issued green bond has the sufficient sustainability objective that is eligible to be identified as a green project. It is highly encouraged by the GBP that issuers should provide as much information as possible to disclose their own sustainability agenda, strategy and/or processes relating to sustainability.

3) Management of proceeds

Appropriate tracking measures of the proceeds shall be clear and concise. GBP recommends high-level transparency in the management of proceeds and that a third-party verifier shall be included in the process of a tracking and allocation of the proceeds.

4) Reporting

Reports on the projects with information on the use of proceeds including a description, amount allocated to the specified project, and the expected impact shall be reported for the sake of transparency. Whether the information is protected via a confidentiality agreement, GBP suggests a disclosure using generic terms to avoid breaching any classified information.

The largest green bond issuance in 2022 according to the CBI’s yearly conducted market report (CBI, 2022) has been in EU with an amount of US$6.5 billion. In addition, Europe is considered as the source of the advanced policy measures and largest number of investment mandates dominating green bond issuance, hence the European market will be taken as a focus point for our research to investigate and compare the green bonds with stock market indices. In Europe, green bond issuances have been growing at a very fast pace, ever since the first issuance in 2013. The market in the area is accounted for the largest green bond market with overall cumulative issuance of over 190 USD ever since the first issuance in 2007 (CBI, 2023a).

Figure 1 presents total issuances of green bonds per year in Europe that are either certified climate bonds aligned with the definition of ‘green’. (International Capital Market Association, 2023)

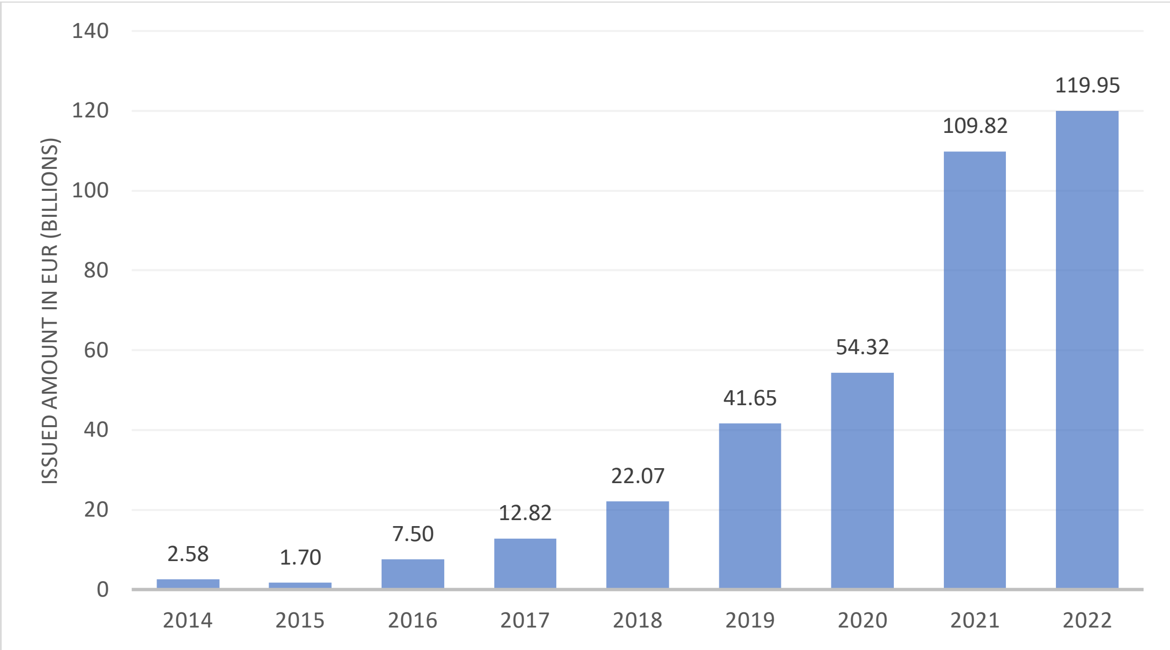

Figure 1. Yearly green bond issuances aligned to CBI requirements in EUR in European markets 2014-2022 (Refinitiv Datastream, 2023)

2.3 Effects of COVID-19 pandemic in the financial system

It has been over a decade since a major pandemic tested the global financial system until COVID-19. Implications of COVID-19 on the green bond market has been observed by Yi et al. (2021) uncovering increase in cumulative abnormal returns in the bond markets due to the crisis. The disease was first detected in China in December 2019 after which World Health Organization (WHO). This eventually led to a declaration of a pandemic on 11 March 2020 (WHO, 2023), which resulted in a global financial market crash. According to Mazur et al. (2021) the global decline is considered the first in economic history when it occurred due to mandatory shutdowns by government officials including population lockdowns and halt in the service industry when the underlying economic indicators were rather strong during the time. From the environmental point of view COVID-19 pandemic provided some indirect positive effects on air quality and reduction of environmental noise, which is described as high volume produced by transit vehicles and industrial or commercial activities. (San Juan-Reyes, Gómez-Oliván and Islas-Flores, 2021; Zambrano-Monserrate, Ruano and Sanchez-Alcalde, 2020)

Klose and Tillman (2021) published a study covering the responses of European countries to the policy announcements that were triggered as a response to COVID-19 on both country and European level. Government and central bank responses were found to initially be seen as drops in stock prices and increased yields of government bonds. Additionally, depending on the effects of COVID-19 pandemic on the countries provided evidence of increase in bond yields while for the less affected countries' yields were left the same. Bagão, Dias, Heliodoro and Alexandre (2021) investigated the relationship of the confirmed cases and deaths with the stock market for the European countries where the results provided a suggestion for investors retaining from stock investments under the influence of pandemic and increasing the diversification of the portfolio, which serves as a basis for our assumption of a possible flight-to-quality occurring during the crisis period.

3 Previous research on green bonds

Green bond connectedness with other assets has provided a lot of studies as the topic provides increasing insight on developing hedging, and portfolio management strategy which is of high interest especially for the investors (Reboredo, Ugolini and Aiube, 2020; Naeem, Conlon and Cotter, 2022; Arif et al., 2022; Abakah, Tiwari, Sharma and Mwamtambulo, 2022; Hammoudeh, Ajmi and Mokni, 2020). One of the first research related to the studying the volatility behavior has been provided by Pham (2016), where it was uncovered that the labelled green bond market exhibits significant volatility clustering receiving volatility spill overs from the conventional bond market. The conclusion includes information of green and conventional bonds being priced adjacent to one another.

Issuer reputation and the importance of a certification of a green bond also plays its part as institutional bonds are more liquid and display a negative premium. This is considered as an additional cost on the green bond as according to Agliardi and Agliardi (2021) it will make it more expensive than other bonds issued by the same issuer. Divergently, privately issued green bonds need the green verification in order to reach a better bond premia (Bachelet et al., 2019). The green bond market provides extensive benefits to issuers as the stock market prices increase around the green bond issuances (Tang and Zhang, 2020), however, the existing studies on diversification benefits seem to provide various results. Some research adds evidence on diversification benefits of green bonds while others tend to underline minor to no diversification benefits while comparing the green instrument to traditional bonds (Liu et al., 2021; Park, Park and Ryu, 2020; Reboredo, 2018).

Kanamura (2020) expands on the performance of green bonds and the relationship with commodities to examine the green characteristics in the green bonds. The study shows that Bloomberg Barclays MSCI and S&P green bond indices correlate positively with industry indices. However, the Solactive green bond index shows indication of negative correlation, which according to the author may not represent the green features properly and there is a suggestion that it does not track the green bond market thoroughly. Delving deeper into the research, the author suggests that while the expected returns of green bond premiums remain positive, there is a minor yet gradual decline over time. This suggests the outperformance of green bonds over the traditional bonds by yielding higher returns with a marginally diminishing risk profile over time. Consequentially, it is quite imperative for issuers to capture the substantiating advantages of the green bonds as an investment target and present this to the larger base of investors. One effective strategy conveying the benefits could prove to be through the certifications of green bonds that have already been established providing more trust and confidence with a credible endorsement of a more transparent reporting on the environmental value and financial potential.

3.1 Connectedness between green bonds and other asset classes

The research surrounding the connectedness between green bonds and other financial instruments focuses for the majority on the price and volatility dependence between the two. This subject acts as a helpful indication to investors in developing their portfolio and hedging strategy management, in addition to providing policy makers with a better understanding of regulatory requirements that the green bond market needs. One of the important strands of literature tries to adhere to the findings of connectedness between the green bond and the stock market highlighting the volatility and risk spillover between the two.

Reboredo et al. (2018, 2020) have studied co-movements between international green bond indices with other non-green market indices finding that green bonds couple clearly with other corporate and treasury bonds and have a weaker co-movement with other types of financial instruments such as stocks. The connectedness and dependence when comparing green bonds with other financial assets has also provided some insight into the attractiveness of green bonds as both an investment and a hedge (2020). The coupling of green bonds with treasury bonds and comparison against stock and energy commodity markets by utilizing threshold generalized autoregressive conditional heteroskedastic (GARCH) model has provided evidence (2018) that there are small to no diversification benefits within the market for assets other than in stock and energy markets. Significant co-movement has also been identified between green bonds and conventional bonds. Thus, recognizing the relationship between the green bond and stock market is highly valuable for determining the development of the green bond market and their role in managing the portfolio risk, understanding the benefits from investing in either.

As green bonds provide a large amount of funding to the clean energy, Liu et al. (2021) find it essential to consider the link between these markets and focus on the dynamic dependency structure and risk spill over. By using constant and time-varying bivariate copula describing the dependency structure between green bond and clean energy markets the analysis provides evidence of an average positive time-varying dependence. The study reveals that large movement in the clean energy market has a spillover effect on green bond market in addition to being an asymmetric one between the two (Liu et al., 2021). Additional studies, similar to Liu et al. (2021) observe the relationship between the green bonds and explore them by coupling with general stock market. Park et al. (2020) have analyzed the volatility spill overs by utilizing Baba-Engle-Kraft-Kroner (BEKK) model and the dynamic conditional correlation-generalized autoregressive conditional heteroskedasticity (DCC-GARCH) model it is similarly uncovered that in an existing state of asymmetric volatility between the two financial instruments green bonds, exhibit a distinctive feature of volatility that is sensitive to positive shocks – contrast to the stock market which is a comparable finding to Liu et al. (2021).

Large institutional investors have taken part in investing their assets in the portfolios connected with sustainable and environmentally friendly activities. So far, studies related to the connectedness of green bonds with other types of assets such as stocks have been giving general results that are in line with the existence of diversification benefits (Kanamura, 2020; Naeem et al., 2021). Additionally, the green bond market and green financial market in general have proven to contribute some hedge during the time when more turbulence is experienced in the financial markets (Arif et al., 2022). This could prove beneficial to study especially during the COVID-19 pandemic as it has been found that adding green bonds in a portfolio for diversification can prove to be a good defensive strategy (Martiradonna, Romagnoli and Santini, 2023), especially for the risk-averse investors, since the green bonds are seemingly less volatile than stocks in the times of a recession (Shaydurova et al., 2018; Agliardi and Agliardi, 2021).

3.2 The appeal of green bonds in the times of a turbulent market

Arif et al. (2022) and Narayan et al. (2022) present interesting remarks regarding the volatility and correlation between asset classes during an unstable period in the markets by employing multivariate GARCH model adding a dynamic conditional correlation to obtain variance and correlations between assets including a VAR model to test the flight-to-quality hypothesis. At the inception of COVID-19 pandemic green bonds were found to have worse performance compared to the conventional bonds due to the initial fear in the market. As the turmoil caused by the pandemic eased over time, the green bonds seemed to bounce back significantly (Cicchiello et al., 2022).

For exploring the interconnectedness and the volatility of multiple asset classes, Narayan et al. (2022) utilized a multivariate GARCH model for testing the evolution of risks and returns as it was previously explained in more detail. Dividing the sample into a one that preceded COVID-19 and a sample that includes the pandemic period the correlation of asset pairs in the case of this research are created by pairing multiple asset classes with green bonds in the Indonesian market. The study examines the flight-to-quality hypothesis, where it is indicated that investors shift away from risky assets that in the study were perceived to be stocks to more ‘safer’ perceived instruments [bonds] during economically distressed times.

Yadav, Mishra and Ashok (2023) explore top ten European countries under OECD economies while investigating the dynamic connectedness of green bonds with other assets. The study employs a Diebold-Yilmaz and Barunic & Krehlic test for observing the connectedness between the green bonds and the economies. The results seem to be indicative of S&P Dow Jones Green Bond Index acting as a neutral volatility contributor, especially during the short time frame. The authors argue that risk mitigation could only be proposed for only short periods of time, as then the risk transmission is the most effective, but this would not be an attractive investment target for long-term investors. Liu (2022) has found that there exist significant negative abnormal returns due to the COVID-19 pandemic induced shock including that the green bond volatility is predominantly driven by the uncertainty of the traditional fixed-income market.

Solactive Green Bond Index, and Bloomberg Barclays MSCI Green Bond Index are the most researched indices in the global market, and it has been uncovered by Martiradonna, Romagnoli and Santini (2023) that the former provides better diversification benefits on average during crisis period as the green bond indices appeared to negatively co-move with the stock market indices and showed lower losses during bear market period. In addition to this, the study explores the behavioral dimension of risk-aversion, which by the suggestion would enable to identify investor risk preferences shedding light at the same time also on which of the indices would offer greater benefit as such. For identifying the values and the changes in the pairwise dynamic conditional correlation, the authors employ the use of DCC-GARCH models and dynamic copulas to each pair of a green bond and stock index showing that despite a variety of portfolio allocation strategies Solactive is proven to be exclusively selected when the target of the investment diversification strategy focuses on maximization of returns.

Hedging and safe-haven abilities of green bonds in the extreme market conditions have been measured by Arif et al. (2022) with green bonds' association to several conventional investments uncovering more appeal on the COVID-19 timeframe, as the pandemic period showed more potential for an appealing investment and hedge for currency and commodity instruments, especially for medium and long-term investors. In comparison to results provided by Yadav, Mishra, and Ashok (2023) Arif seemed to find some contraction. The comparison between the green bonds and conventional financial assets has not sparked a clear line of understanding in the previous research in terms of the appeal of a hedge for specific investor strategy. More consensus is needed to understand the asset's behavior under the intense market turmoil which would benefit the investors. All in all, there is a noticeable growth in the literature focusing on how the green bonds could essentially prove to be an interesting investment target especially for a more risk-averse crowd of investors during the time of turmoil in the market.

The purpose of this study is to follow up on the base created by the identified research in the literature review and build up on it focusing on the flight-to-quality effect which is motivated by the investors preferring less riskier assets on average than riskier in comparison during the crisis period in the market. Afterwards, based on the investigation of various models the previous research has employed, we will explain the reasoning behind the chosen model for this study and utilize it to investigate, whether there has been any flight-to-quality effect observed in the data we have gathered on the chosen green bond and stock market indices. Subsequently, we will present the results and investigate the implications that the COVID-19 pandemic has had on the chosen sample.

4 Methodology & Data

The objective of this section is to introduce the retrieved data and examine the methodology used for this research. The information and historical financial data of the chosen indices has been retrieved entirely by utilizing Refinitiv Datastream's database.

4.1 Data

Considering the extensive initiatives that EU has set up revolving around sustainability and the future of green financing such as the Green Bond Standard (European Commission, 2023a), we take into consideration for this study 10 European countries under OECD economies and their representative indices and examine their connectedness the chosen benchmark index for green bonds that is in line with the CBI's taxonomy. The choice is made not only based on the number of literature investigating the European markets under COVID-19 pandemic and their relationship with the green bonds as the latter is a growing topic among the academic literature as explained in previous chapters but also due to the extensive European green bond market which is a source for the most advanced policy measures with enormous number of investment mandates (CBI, 2023a). The EU is the most advanced in policy regulation as it has introduced numerous regulations for promoting sustainability and has dominated in the green bond issuances being the dominant region constituting for around 40% of global green bond issuances (CBI, 2023; Dan and Tiron-Tudor, 2021), which establishes the basis for investigation of connectedness between the selected EU financial markets and the green bonds. The use of individual market indices is to observe and compare the flight-to-quality effect or the lack of it between the European countries.

A green bond benchmark index has been taken into consideration as a proxy for this study as per availability in the database provided by LUT University: Solactive Green Bond EUR USD IG Index (index code: SOLGREEN), consists of investment grade rated green bonds and is inclusive of both EUR and USD denominated issuances calculated as a total return index denominated in euro currency. The selection comprises of green bonds that are considered as such by utilizing CBI's framework and are screened via external independent counterpart for ESG criteria by two categories: Global Compact Compliance, where if the issuer is classified non-compliant the bond is excluded; Country UN Sanctions, based on which the bond is included if the issuer is classified as a non-sanctioned. Furthermore, the index imposes a requirement of at least 300 million of outstanding issue size (Solactive, 2019). This data has been chosen based on the availability of the benchmark index in Refinitiv Datastream and evidence in the past literature by Arif et al. (2022), Naeem et al. (2021) and Martiradonna, Romagnoli and Santini (2023). The index has clearly experienced a very steep performance from 2018, which could be explained by green bonds trending among EU markets and the constantly developed frameworks and policies that support the issuances of various sustainable bonds. Solactive elaborates on their ESG factors applied in the Benchmark Methodology that they only consider instruments classified as green bonds by the CBI's framework being eligible for inclusion in their green bond index (Solactive, 2023).

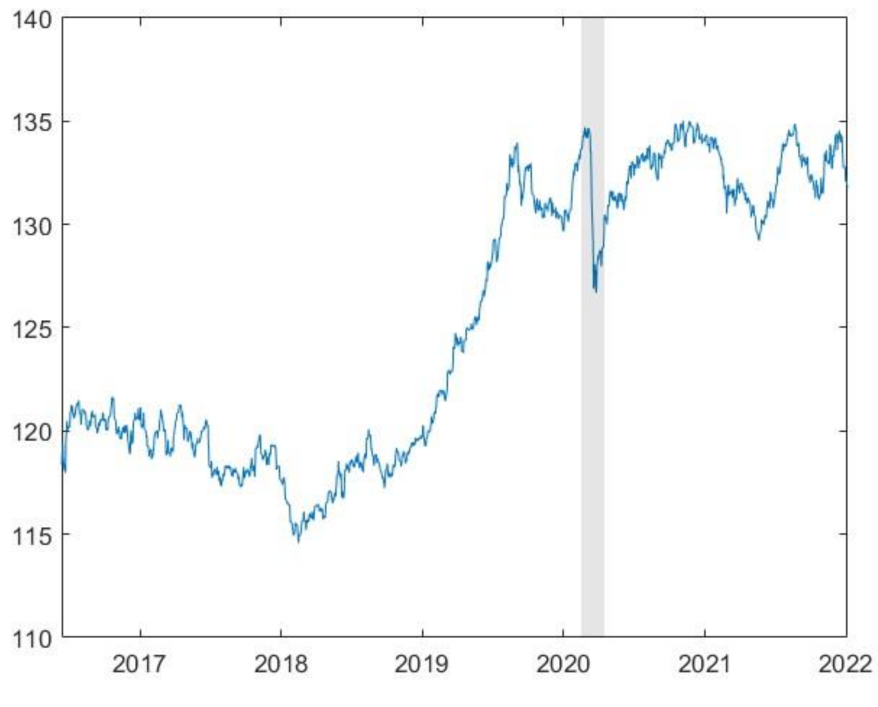

Figure 2. Development of Solactive Green Bond EUR USD IG Index (SOLGREEN) from 2016 to 2022 highlighting the observed financial market crash in the beginning of 2020 due to the worldwide pandemic announcement by the WHO (Refinitiv Datastream, 2023)

The data for Solactive Green Bond index has been retrieved based on the earliest data available provided by Refinitiv starting from June 2016 up until the beginning of January 2022 – approximately 5-year and 7-month sample period. The Solactive Green Bond index in figure 2 has been growing rapidly between 2018 to 2020, until experiencing decline in price, which is presumed when the COVID-19 effects are reflected in the global financial market. The analysis has been done by calculating daily returns (figure 3) for the entire sample data by utilizing the following equation:

$$r_t = \ln(P_t) - \ln(P_{t-1}) \tag{1}$$

where r represents daily returns and P_t closing price at time t.

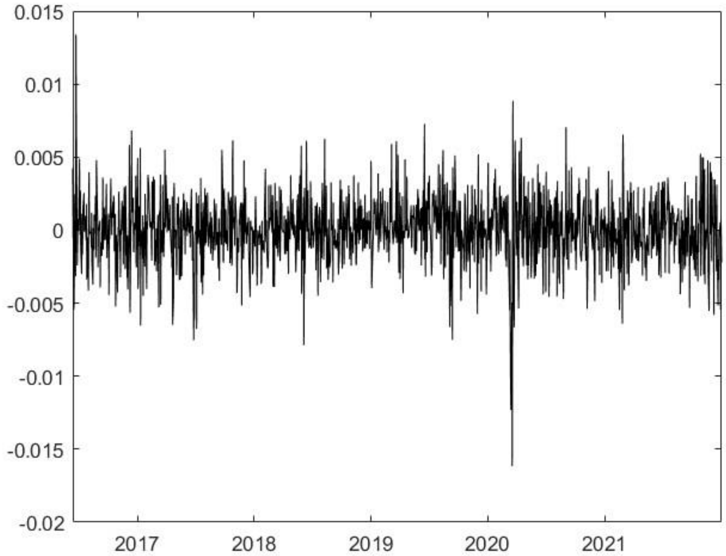

Figure 3. Daily returns of the Solactive Green Bond Index (SOLGREEN) between June 2016 to Jan 2022 (Refinitiv Datastream, 2023)

As seen from figure 3, the daily returns for green bond index experience slight fluctuations but are overall quite stable before the drop in 2020 after which we can observe some volatility clustering.

Relatively for comparison against the green bond index, 10 European market indices under OECD economies have been collected based on the highest rate of adoption of green bonds in the countries from 2019 to 2022 (Eurostat, 2023), and essentially their availability in the database. As the green adoption is on the rise in the specified countries they could potentially enlighten the investors' behavior towards green finance by investigating if there is evidence of shift from the stocks directly to green bonds and flight-to-quality effect during the pandemic period: Luxembourg Stock Exchange (LUX), Euronext Dublin (ISEQ), Brussels Stock Exchange (BEL), Euronext Amsterdam (AEX), Iceland Stock Exchange (OMXI), OMX Copenhagen (OMXC), Helsinki Stock Exchange (OMXH), OMX Stockholm (OMXS), Austrian Stock Index (ATX) and German Stock Index – Deutscher Aktienindex (DAX). The development of selected indices can be observed to be quite steady over the years (figure 4) before the market crash occurred in the beginning of 2020, to which markets reacted quite strongly. However, prices rebounded quickly after the initial shock all around Europe and rose above the initial drop latest in the beginning of 2022.

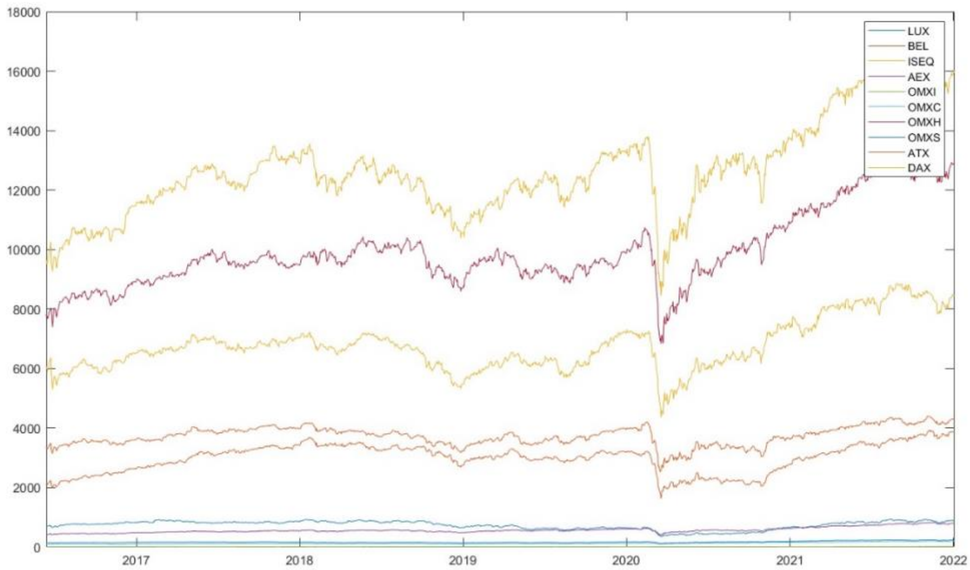

Figure 4. Development in price of the selected European market indices between June 2016 to Jan 2022 (Refinitiv Datastream, 2023)

Additionally, as seen from Figure 4 representing the daily returns of 10 European market indices, it is clearly noticeable how COVID-19 in 2020 had a huge impact on all selected indices. Additionally, for most of the indices, there seems to be a beginning of a volatility cluster and the magnitude of a daily return fluctuation is clearly much higher in 2020 in comparison to the green bonds.

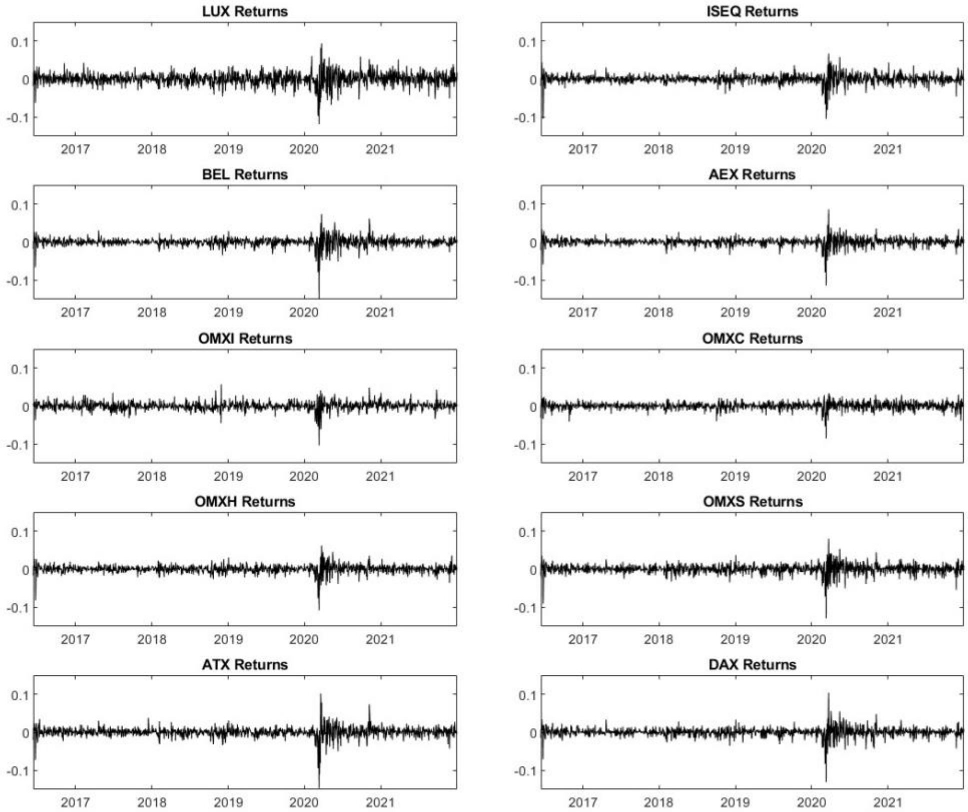

Figure 5. Selected 10 European market index returns under OEDC economies between June 2016 to Jan 2022 (Refinitiv Datastream, 2023)

The entire sample represents observations between mid-2016 to the beginning of 2022. The descriptive statistics with a total of 1451 observations are presented in table 1.

Observing the entire sample data of daily returns from 13 June 2016 to 1 January 2022 in table 1 containing the COVID-19 period all the indices as well seem to have a positive mean. LUX variable is indicating being the most volatile index with the largest standard deviation of 0.016 in the sample. All indices seem to be displaying left skewness; however, it is noticeable that from other indices BEL exhibits largest skewness. Moreover, there is indication of leptokurtic distribution with asymmetric tails as the kurtosis values for all indices is greater than three and especially high for BEL (30.1), ATX (24.9) and DAX (21.2). The green bond exhibits more property of a safe asset due to low standard deviation and kurtosis which demonstrates low likelihood of extreme loss occurrences. In addition, for normality testing, Jarque-Bera test has been performed rejecting the null hypothesis of normality for all series at the 1% level.

*Table 1. Descriptive statistics for daily returns of original variables from 13 June 2016 to 1 January 2022. Jarque-Bera is used as a normality test ***denoting the rejection of the null hypothesis of normality at the 1% significance level.*

	Min	Max	Mean	St Dev	Skewness	Kurtosis	Jarque-Bera
LUX	-0.11839	0.09353	0.00018	0.01631	-0.43706	8.01602	1567.354***
BEL	-0.15328	0.07361	0.00018	0.01162	-2.10130	30.11126	45505.912***
ISEQ	-0.10465	0.06710	0.00024	0.01228	-1.34900	16.11767	10843.346***
AEX	-0.11376	0.08591	0.00043	0.01047	-1.22918	19.94809	17731.296***
OMXI	-0.10316	0.05729	0.00047	0.01083	-0.80069	12.21086	5284.325***
OMXC	-0.08504	0.03364	0.00047	0.00968	-0.89711	8.86033	2270.974***
OMXH	-0.10788	0.06192	0.00035	0.01050	-1.35443	17.49265	13142.110***
OMXS	-0.12899	0.08008	0.00037	0.01251	-1.21434	15.77104	10217.337***
ATX	-0.14675	0.10206	0.00042	0.01310	-1.49919	24.93157	29623.629***
DAX	-0.13055	0.10414	0.00035	0.01191	-1.06549	21.21104	20325.058***
SOLGREEN	-0.01617	0.01340	0.00008	0.00237	-0.31431	6.18433	604.451***

The daily returns of the indices exhibit to some extent stationarity which is tested by an Augmented Dickey Fuller (ADF) test in table 2. The test statistics of the indices were more positive than the indicated critical value (-1.9416) and thus the null hypothesis of non-stationarity is not rejected pointing towards that equity indices and the green bond indices return data being non-stationary. Utilizing the Ljung-Box statistic we checked for presence of autocorrelation for all indices. The results present that null hypothesis of no serial autocorrelation is rejected for the majority of indices except for OMXC, OMXS and SOLGREEN. This is later reapplied to standardized residuals which results in a better fit when estimating the DCC-GARCH model for the data (table 3).

Table 2. Unit root and autocorrelation test statistics of the daily index returns from 13 June 2016 to 1 January 2022 including p-value and significance levels in brackets.

	ADF test statistic	Ljung-Box test statistic
LUX	0.2613 (0.7477)	54.7103 (4.5361e-05)***
BEL	0.4656 (0.8150)	69.9466 (1.8583e-07)***
ISEQ	0.6454 (0.8552)	56.8844 (2.1371e-05)***
AEX	1.6486 (0.9761)	53.8063 (6.1800e-05)***
OMXI	2.2187 (0.9938)	40.9252 (0.0038)***
OMXC	2.1728 (0.9929)	23.4518 (0.2672)
OMXH	1.2357 (0.9451)	46.6700 (6.5170e-04)***
OMXS	1.1874 (0.9401)	24.8729 (0.2063)
ATX	1.1069 (0.9308)	105.0186 (1.5765e-13)***
DAX	0.9976 (0.9164)	70.1914 (1.6949e-07)***
SOLGREEN	1.1631 (0.9373)	17.9373 (0.5915)

** 10% significance, **5% significance, *** 1% significance*

This study is conducted as a quantitative study focusing on whether European markets exhibit flight-to-quality phenomena specifically from stocks to green bonds over the COVID-19 pandemic period. Testing for flight-to-quality effect this study looks at the changes in correlation between pairs of green bond and stock market indices where negative correlation with another asset indicates evidence of flight-to-quality (Hemche et al., 2016; Pereira & Lagoa, 2019, Tachibana, 2020). According to the authors, the effect of contagion between the observed pair of financial instruments becomes evident when the correlation coefficient increases between the pair significantly in a crisis period, relative to the period of normality. In contrast, flight-to-quality is observed in correlation of financial assets assuming a negative value. Studying the relationship between a bond-stock pair flight-to-quality would mean flow of movement from stocks to bonds. Focus on identifying contagion of financial crises has provided a possibility for different methods of which this study will use the DCC-type model – specifically the multivariate DCC-GARCH model (Engle, 2002). The reasoning behind the use of the model is that it is designed to account for changing volatility in the data ensuring minimal bias from volatility fluctuations and provides reliable assessment between observable variable relationships (Pereira and Lagoa, 2019).

4.2 ARCH and GARCH models

Engle and Bollerslev (1986; 1982) first presented Autoregressive Conditional Heteroscedasticity (ARCH) and Generalized-ARCH (GARCH) models to provide a means for volatility analysis in time series. ARCH(q) class models are used for forecasting and motivating volatility clustering describing the tendency of large (small) changes in asset prices, which in a similar manner follow large (small) changes. The model has a constant mean but does not assume a constant variance implying a possibility of heteroscedasticity in the errors. However, the model is subject to restrictions and limitations including a specification regarding value of (q), where too large of a value can result in a non-parsimonious model. ARCH has been widely used in areas such as exchange rate returns, changes in treasury bills and growth rates of monthly composite indices (Brooks, 2008).

GARCH(p,q) models elucidate the dynamics of the conditional variance in the error term by depending on its previous lags. The GARCH(p,q) type models make use of an analogy which is based on a moving average process including the lags of volatility, which in the end enables the prediction of volatility with much greater accuracy. The model is a parsimonious alternative to a high order ARCH and its estimation is accomplished by utilizing the maximum likelihood approach. This is due to the inadequacy of the Ordinary Least Squares method, as the model deviates from the conventional linear form. GARCH is one of popular models for understanding and estimating the topics of volatility analysis which consider returns for stocks, bonds, and market indices – similarly to ARCH. (Brooks, 2008; Bollerslev, 1982; Hemche et al., 2016)

DCC-GARCH model proposed by Robert Engle (2002) offers a flexible description of the conditional variance and correlation of financial series. This is primarily accomplished by employing dynamic correlation coefficients and cross-market conditional correlations via the breakdown of the covariance matrix, leading to conditional standard deviations and a correlation matrix which are similarly observed in previous models. Additionally, the multivariate specifications provide a way for the identification of fluctuating conditional patterns in important pairs of time series, making it an advantageous tool for financial analysis. (Hemche et al., 2016) Highlighting the changing correlation between asset returns provides important information for strategies that rely on it such as asset allocations and risk assessment. The DCC-GARCH model is essentially built on the foundation that ARCH and GARCH models introduced for modeling volatilities for financial time series and has been also utilized for assessing the contagion between financial markets (Liu et al., 2021; Martiradonna, Romagnoli and Santini, 2023b; Pereira and Lagoa, 2019).

The DCC-GARCH model is built on a combination of non-linear univariate GARCH models and by proposition of Kearney and Poti (2006) would require a two-step estimation procedure for providing more consistent estimates for the conditional correlation matrix. In addition, Lahiani and Nguyen (2013) provide research showing that DCC-GARCH model specification can on top of testing market co-movements prove to be valuable for calculating the degree of market independence. This study utilizes GARCH process that each asset follows with a simple form of univariate GARCH (1,1) where considering an example asset i:

$$h_{i,t} = \mu_i + \alpha_i e_{i,t-1}^2 + \beta_i h_{i,t-1} \tag{2}$$

h_t will represent the conditional variance, e_t the residual with zero mean and constant μ_i including ARCH α_i and β_i GARCH effects. The target is to eliminate the autocorrelation in residuals and get zero mean by using an ARIMA model after which the estimation univariate GARCH models (2) is feasible to obtain the standardized residuals ε_t in a form of a matrix to use and create a DCC-GARCH model used in this study via two steps proposed by Hemche et al. (2016). After the first step of estimating the univariate GARCH (1,1) model for each asset, we generalize the constant conditional correlation to estimate the DCC model that has been derived by utilizing the obtained standard residuals from the first step. Thus, specifying the DCC (1,1)-GARCH (1,1) the below process for returns is used, where following Hemche's steps (2016):

$$r_t|\Omega_{t-1} \sim N(0, H_t) \tag{3}$$

$$r_t = \mu_i + \varepsilon_t \, , \varepsilon_t|F_{t-1} \sim N(0, H_t) \tag{4}$$

r_t is denoting the bond- and stock return vector, μ_i represents the conditional mean, ε_t the error term, F_{t-1} is characterized by all data available until t-1, and returns, H_t is $k \times k$

matrix of time-varying variances. The conditional variance-covariance matrix can be stated as:

$$H_t = D_t R_t D_t \tag{5}$$

following D_t which is the diagonal matrix of conditional standard deviations of return series $D_t = diag\sqrt{\{H_t\}}$ and R_t is the time-varying correlation matrix. Engle's (2002) proposed DCC model of correlation is given below,

$$R_t = diag(Q_t)^{-1} Q_t diag(Q_t)^{-1} \tag{6}$$

$$Q_t = (1 - \alpha - \beta)\bar{Q} + \alpha\varepsilon_t - \varepsilon_t - \varepsilon_t{}' + \beta Q_{t-1} \tag{7}$$

where in the equation 6, Q N x N unconditional correlation matrix, following in equation 7, its standardized residuals ε_t with $\alpha - \beta < 1$ non-negative parameters measuring the effect of a shock with α and delayed dynamic correlation with β .

4.3 Model specifications

The unit root was previously tested with the Augmented Dickey Fuller test (table 2) uncovering the non-stationarity as all indices' test statistics were quite more positive than indicated critical value of -1.9416. This study will utilize a simple GARCH (1,1) model that assumes only one order. According to Hansen and Lunde (2005) simple one order model has seen better results in comparison to other models, which provides support for the sufficiency of using it in this study. The GARCH (1,1) model has been heavily utilized in literature to capture the volatility-clustering dynamics of financial assets (Hsu Ku and Wang, 2008) and was found to outperform other models.

Table 3 provides estimated parameters for the DCC (1,1) – GARCH (1,1) model observing the stock-bond pairs where the estimated results show significance on a 1% level for all observed pairs in their ARCH(α) and GARCH(β) coefficients.

Table 3. Presenting 10 DCC (1,1) – GARCH (1,1) models for the stock-bond pair sample period 2016-2022

	LUX	ISEQ	BEL
μ	7.6359e-05	6.5854e-05	1.6975e-04
	(3.6004e-04)	(2.4438e-04)	(1.8252e-04)
h	-0.0717***	-0.0610***	-0.1197***
	(0.0097)	(0.0138)	(0.0086)
α	0.1215***	0.1587***	0.1715***
	(0.0184)	(0.0154)	(0.0163)
β	0.9743***	0.9890***	0.9788***
	(0.0068)	(0.0043)	(0.0031)

	AEX	OMXI	OMXC	OMXH
μ	1.6832e-04	4.3481e-04	3.6766e-04	1.8582e-04
	(1.9400e-04)	(2.3215e-04)	(2.3031e-04)	(2.1066e-04)
h	-0.1490***	-0.0801	-0.1031***	-0.0908***
	(0.0105)	(0.0125)	(0.0127)	(0.0113)
α	0.1903***	0.2014***	0.1243***	0.1476***
	(0.0178)	(0.0237)	(0.0151)	(0.0217)
β	0.9591***	0.9345***	0.9545***	0.9687***
	(0.0056)	(0.0116)	(0.0097)	(0.0048)

	OMXS	ATX	DAX
μ	-5.6672e-05	3.9949e-04	2.6180e-04
	(2.5724e-04)	(2.3730e-04)	(2.3366e-04)
h	-0.2466***	-0.1121***	-0.1180***
	(0.0548)	(0.0099)	(0.0078)
α	0.1433***	0.1796***	0.1266***
	(0.0178)	(0.0184)	(0.0156)
β	0.9720***	0.9714***	0.9717***
	(0.0061)	(0.0048)	(0.0044)

** 10% significance, **5% significance, *** 1% significance*

Standard errors in parenthesis

5 Results

For determining whether flight-to-quality has indeed occurred between green bonds and the stock market indices, we determined 10 bond-stock pairs and used multivariate DCC (1,1)-GARCH (1,1) model to obtain correlation coefficients where we observe the full period and dive deeper to investigate the differences in correlation between the pairs before the COVID-19 period (June 2016 – December 2019) and during the turbulent period (January 2020 – April 2020).

5.1 Time-varying correlation for bond-stock pairs

The study presents the correlations between the SOLGREEN and the European market indices of the entire sample period to investigate the development of the relationship between the two asset classes over the years in the following (figures 6, 7, 8, 9, 10, 11, 12, 13, 14, 15). First through graphical analysis we identify that the bond-stock pairs are volatile, and a coherent positive or negative return linkage cannot be determined for the sample. For all pairs the estimates are significantly negative in the beginning of the sample (mid-2016 until beginning of 2017) as low as -0.8 moving closer to the zero region, which can be due to different factors challenging the financial markets that could have had potentially implications for a larger flight-to-quality phenomenon during that period. In the subsequent years the correlation increases and seems to fluctuate around -0.2 and 0.2 which is not quite significant during the turbulent period which we consider the COVID-19 to had been. The second important finding is that at the beginning of 2020, the emergence of pandemic sample period, correlation estimates experience a significant positive rise in the correlation and a drop in the beginning of 2020 for all bond-stock pairs.

The graphical analysis of the SOLGREEN-LUX pair (Figure 6) is evidently showing some variation between -0.2 and 0 before the pandemic after which the beginning of 2020 shows a significant increase to a positive correlation between the two markets. The DCC (1,1)-GARCH (1,1) model is not on the positive side besides from the significant peak in 2020 and seems for the majority of the period to fluctuate on the negative side of the spectrum.

The constructed pair for SOLGREEN-BEL (figure 7) seems to follow the same trend as SOLGREEN-LUX albeit experiencing more positive correlation before 2020 and similarly experiencing a significant positive correlation during the beginning of the pandemic. Compared to the previous pair the SOLGREEN-ISEQ (figure 8) bond-stock pair experiences a lot more fluctuation even before the pandemic period. SOLGREEN-AEX (figure 9) seems to have experienced less high positive correlation as the correlation in the beginning of 2020 barely reaches 0.2. In contrast to other pairs, SOLGREEN-OMXI (figure 10) seems to be fluctuating less as the correlation seems to have taken a more linear trend between -0.1 and 0 values. The SOLGREEN-OMXI linkage is very different from other markets as it is relatively closer to zero and seems to be the most stable over the period of time. However, it still replicates the exact same high correlation as all other pairs during the beginning of 2020. SOLGREEN-OMXC (figure 11) compared to others seems to experience more fluctuation above zero. SOLGREEN-OMXH (figure 12) exhibits strong peaks throughout the sample fluctuating between negative and positive values. Figure 13 for SOLGREEN-OMXS exhibits high correlation in the same way as previous pairs, both SOLGREEN-OMXS and SOLGREEN-DAX (figure 15) seem to be mimicking each other with relatively same fluctuations. SOLGREEN-ATX (figure 14) exhibits most peaks reaching zero with an additional 2020 spike in the correlation which all other pairs have as well.

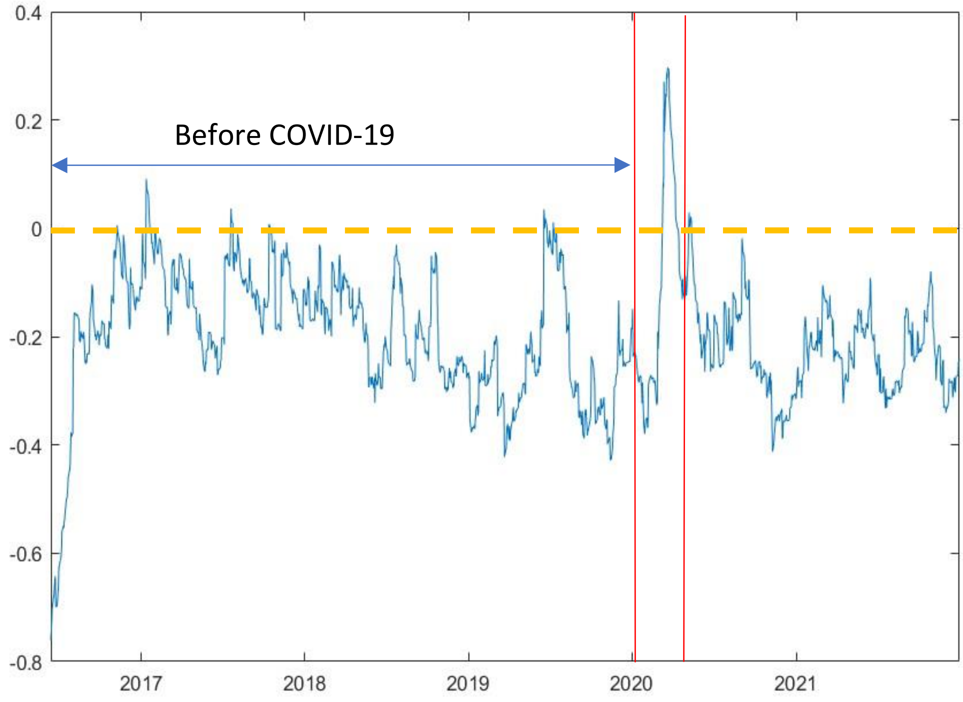

Figure 6 Time-varying correlation between SOLGREEN and LUX bond-stock pair (DCC (1,1)-GARCH (1,1) model)

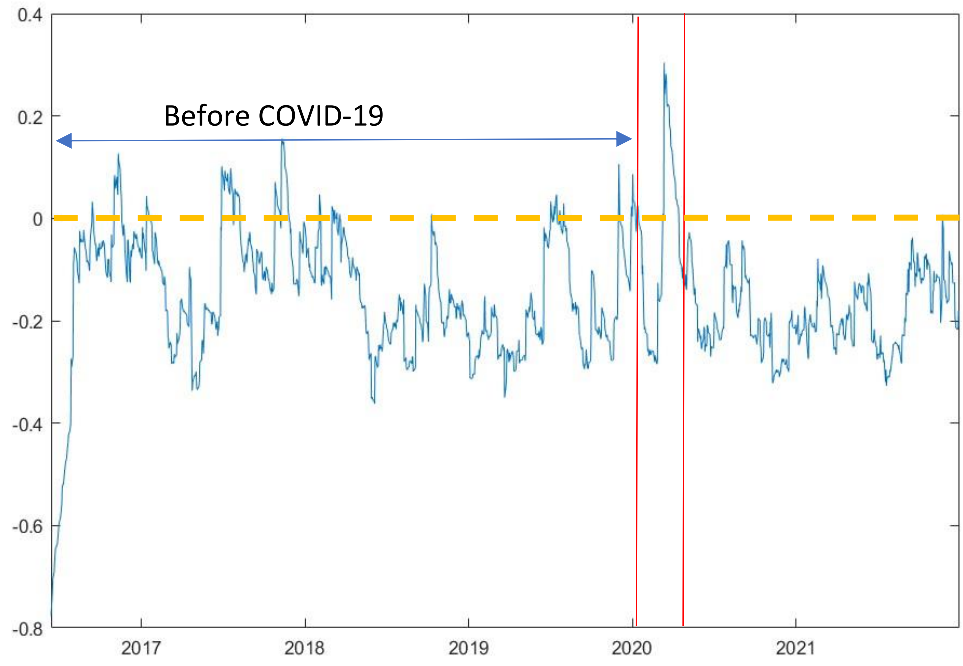

Figure 7 Time-varying correlation between SOLGREEN and BEL bond-stock pair (DCC (1,1)-GARCH (1,1) model)

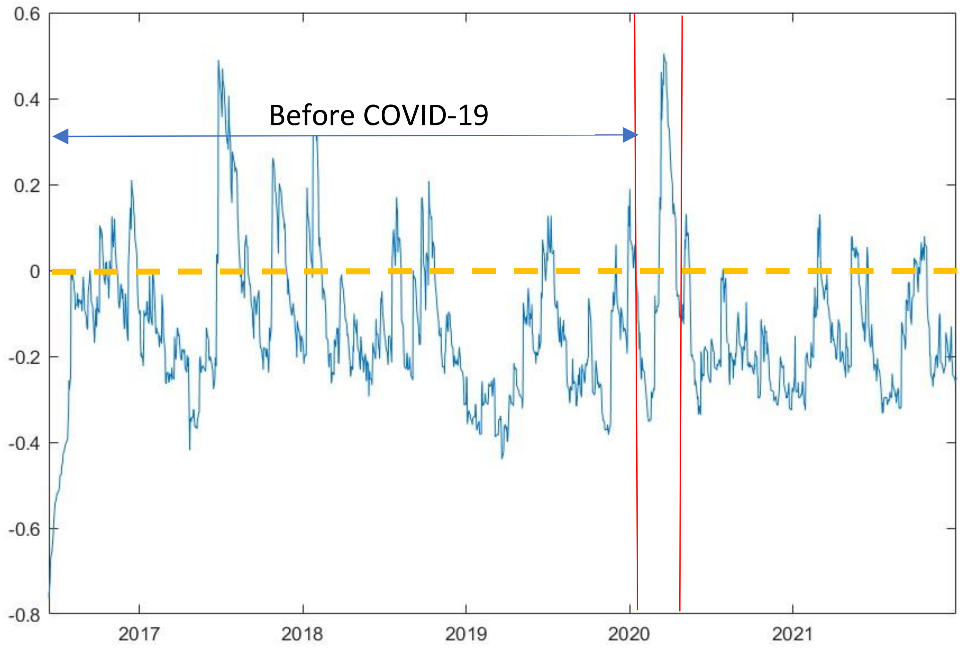

Figure 8 Time-varying correlation between SOLGREEN and ISEQ bond-stock pair (DCC (1,1)-GARCH (1,1) model)

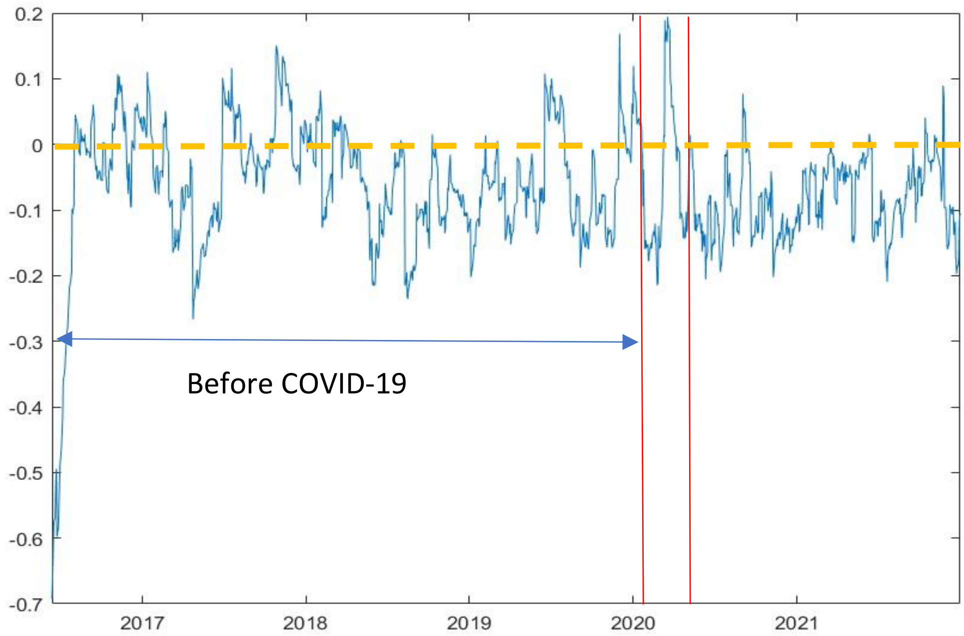

Figure 9 Time-varying correlation between SOLGREEN and AEX bond-stock pair (DCC (1,1)-GARCH (1,1) model)

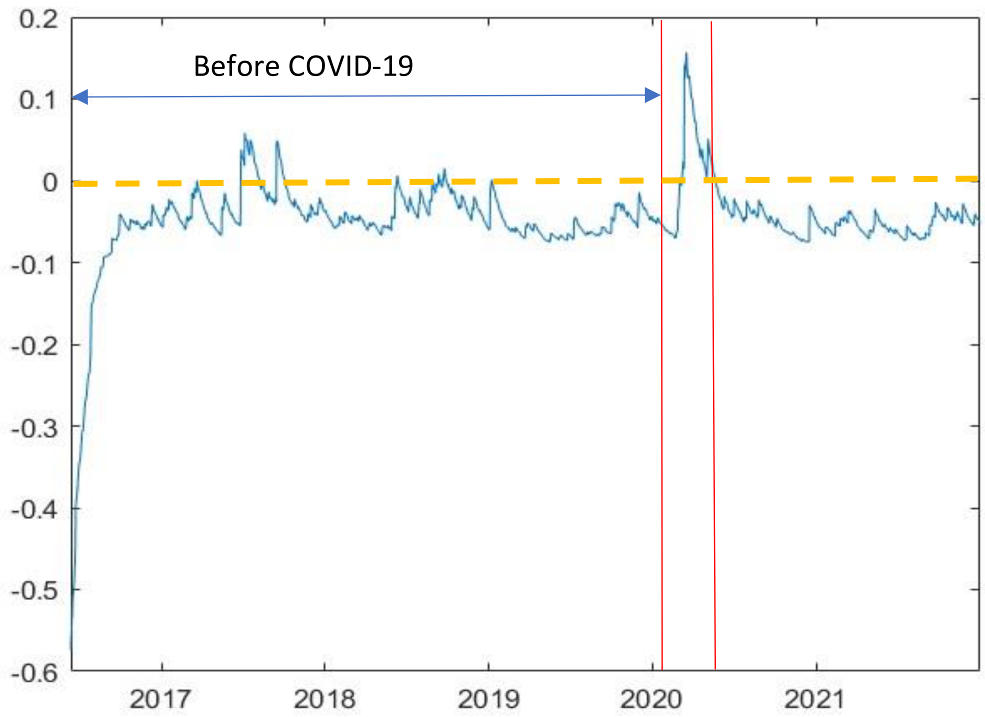

Figure 10 Time-varying correlation between SOLGREEN and OMXI bond-stock pair (DCC (1,1)-GARCH (1,1) model)

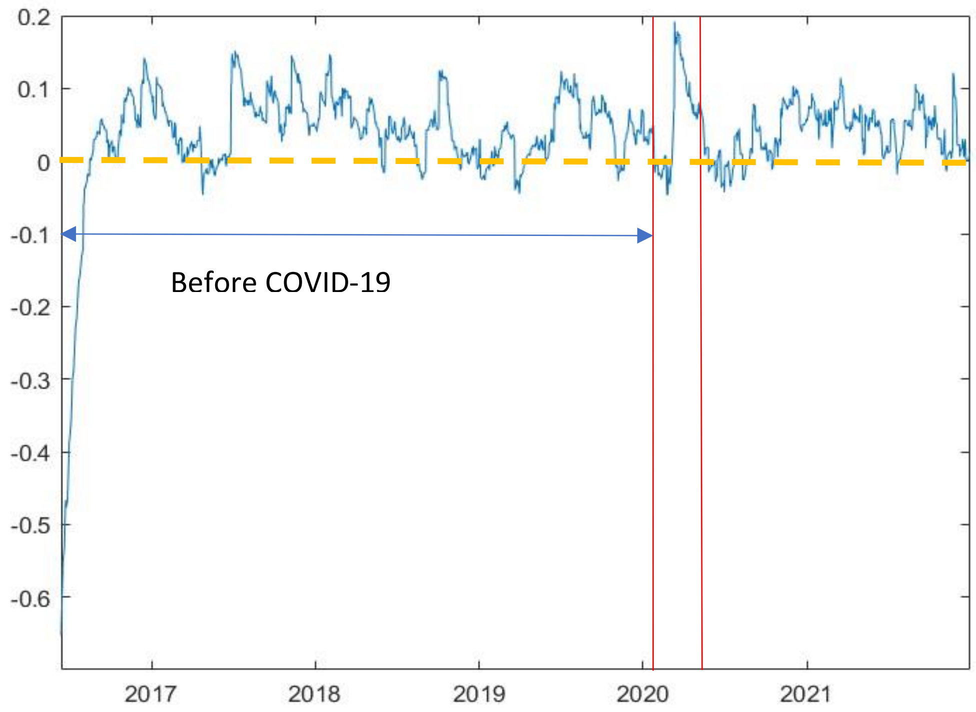

Figure 11 Time-varying correlation between SOLGREEN and OMXC bond-stock pair (DCC (1,1)-GARCH (1,1) model)

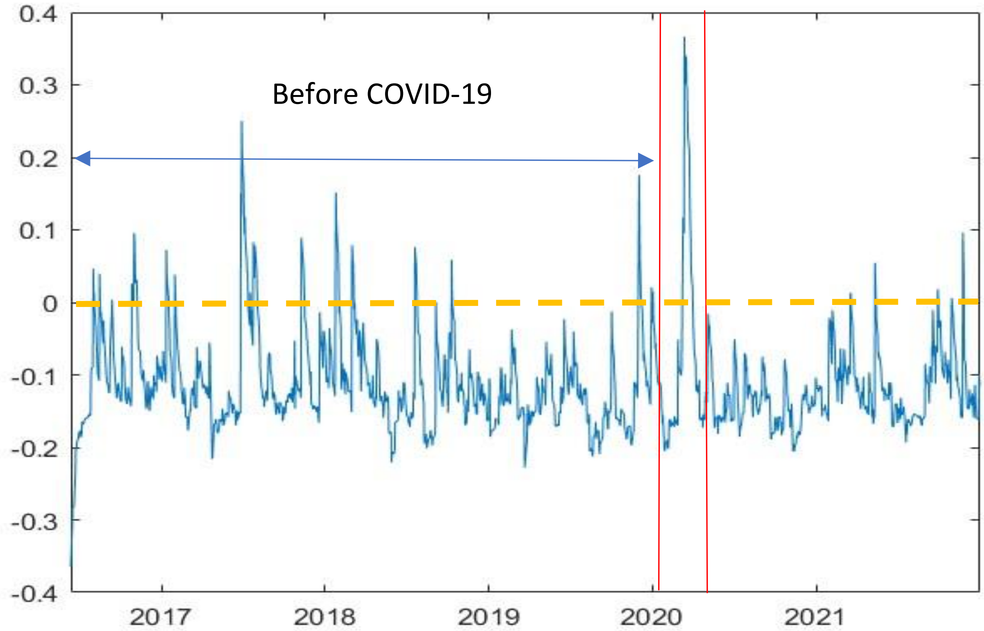

Figure 12 Time-varying correlation between SOLGREEN and OMXH bond-stock pair (DCC (1,1)-GARCH (1,1) model)

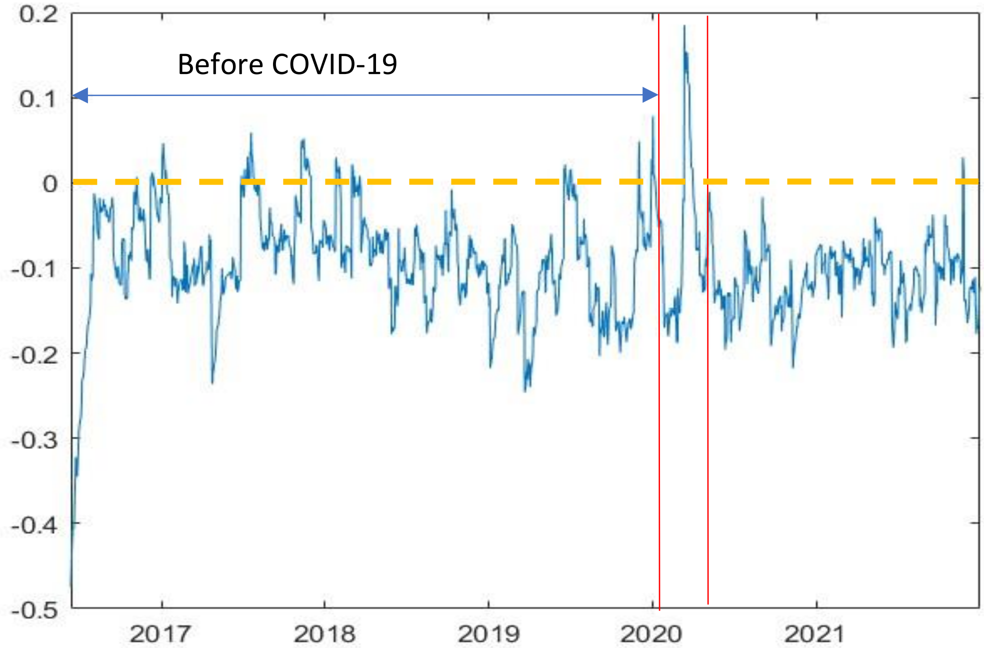

Figure 13 Time-varying correlation between SOLGREEN and OMXS bond-stock pair (DCC (1,1)-GARCH (1,1) model)

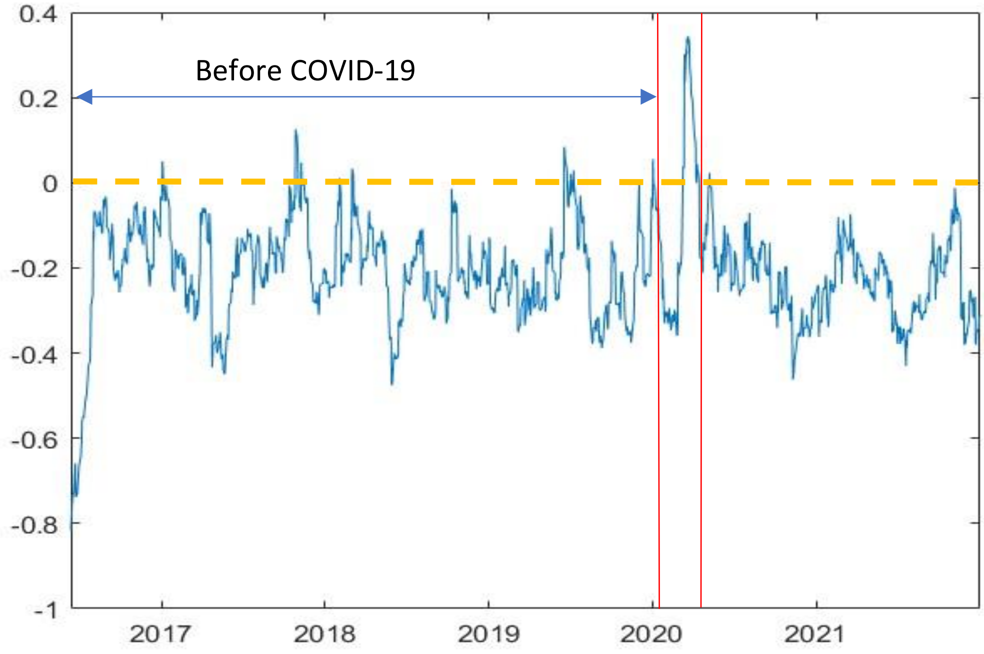

Figure 14 Time-varying correlation between SOLGREEN and ATX bond-stock pair (DCC (1,1)-GARCH (1,1) model)

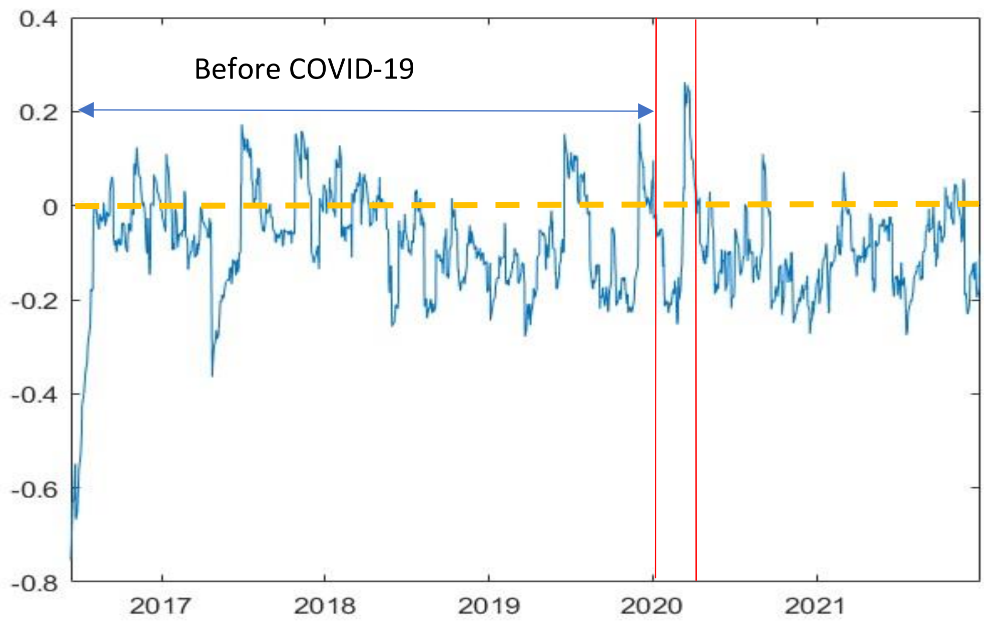

Figure 15 Time-varying correlation between SOLGREEN and DAX bond-stock pair (DCC (1,1)-GARCH (1,1) model)

The European bond-stock market correlations seem to be for the most part behaving quite similarly in comparison with an exception of Denmark – SOLGREEN-OMXC (figure 11) as the correlation for the most seems to be on the positive side whereas for others it clearly stays below zero on the negative spectrum when investigating the beginning of the sample period and the COVID-19 period in the beginning of 2020. The correlation between green bond and Finland's (OMXH) stock market shows the higher positive values while the higher negative values occur for the Austrian (ATX) stock-bond pair.

The worthwhile finding of the graphical analysis is that as a lot of green bond and stock market index pairs exhibit frequent changes in the correlation, indicating that there has been change in demand between stocks and bonds throughout the sample period. For the most, the bond-stock pairs seem to be negative, with the exception of SOLGREEN-OMXC, where it can be observed that the dynamic correlations take more positive values implying that there may be some degree of financial interdependence and co-movement between the two asset classes and possible implication of cross-asset contagion (Baur and Lucey, 2009).

5.2 Bond-stock pair analysis through crash dates

The stock market collapse during the month of March 2020 has been considered one of the biggest crashes in history as it affected countries on a global scale. Mazur et al. (2021) established that the global decline is considered the first in economic history when it occurred due to mandatory shutdowns by government officials when the underlying economic indicators were rather strong. Table 4 presents the averages for daily correlations for all green bond and stock market index pairs estimated through DCC (1,1)-GARCH (1,1) model. We observe the mean correlation starting from June 2016 up to the end of 2019, the mean correlation during the observed market crash which occurred during the COVID-19 pandemic more precisely reflecting on the month of March 2020 where our sample date starts from the first Monday when the stock market opens, and the mean correlation of the entire COVID-19 period up until the end of the rest of the sample period to the beginning of 2022 considering this the aftermath of the market crash.

Table 4. Identified correlations before, during and after crisis dates for the green bond and index pairs

SOLGREEN-LUX	
01/06/2016-31/12/2019	-0.191
02/03/2020-31/3/2020	0.296
01/04/2020-01/01/2022	-0.277

SOLGREEN-ISEQ	
01/06/2016-31/12/2019	-0.1014
02/03/2020-31/3/2020	0.5045
01/04/2020-01/01/2022	-0.2012

SOLGREEN-OMXI	
01/06/2016-31/12/2019	-0.035
02/03/2020-31/3/2020	0.157
01/04/2020-01/01/2022	-0.0813

SOLGREEN-OMXC	
01/06/2016-31/12/2019	0.047
02/03/2020-31/3/2020	0.192
01/04/2020-01/01/2022	0.0165

SOLGREEN-ATX	
01/06/2016-31/12/2019	-0.2073
02/03/2020-31/3/2020	0.341
01/04/2020-01/01/2022	-0.2823

SOLGREEN-DAX	
01/06/2016-31/12/2019	-0.0521
02/03/2020-31/3/2020	0.262
01/04/2020-01/01/2022	-0.1715

SOLGREEN-BEL	
01/06/2016-31/12/2019	-0.1237
02/03/2020-31/3/2020	0.304
01/04/2020-01/01/2022	-0.231

SOLGREEN-AEX	
01/06/2016-31/12/2019	-0.0354
02/03/2020-31/3/2020	0.194
01/04/2020-01/01/2022	-0.1408

SOLGREEN-OMXH	
01/06/2016-31/12/2019	-0.092
02/03/2020-31/3/2020	0.366
01/04/2020-01/01/2022	-0.1686

SOLGREEN-OMXS	
01/06/2016-31/12/2019	-0.0639
02/03/2020-31/3/2020	0.233
01/04/2020-01/01/2022	-0.1749

What can be highlighted is that for all pairs except for SOLGREEN and OMXC, is the negative correlation persisting before and after the COVID-19 period. For SOLGREEN-OMXC pair, where correlation is slightly positive (0.047) before the market crash in March 2020 there is an indication of co-movement between the two instruments. This appears to be the only pair where the averages are mostly positive, as for the other green bond and stock pairs the averages of DCC take negative values. Based on the established base for the flight-to-quality as a decrease to negative values in correlation during after the crash period we can identify to some extent flight-to-quality being present between the pairs.

As previously referred, the plots are quite suggestive, but it appears through observation of the correlations that they have averaged between 0.1 and 0.3 during the date of the market crash in the month of March 2020, and most have gone in a more positive direction when looking at the averages of the COVID-19 period. The largest drop of correlation when investigating the averages of before and after the turbulent period in March 2020 the SOLGREEN-DAX pair appears to have the highest difference as the correlation before the turbulent period -0.0521 rose to -0.1715. Following a month of the observed crash period in March 2020 all of the bond-stock pairs seem to revert back to their original negative state, except for SOLGREEN-OMXC, which seem to have a near zero correlation as they seem to not have a clear relationship with each other.

Overall, the results show that during the pandemic period regardless of whether the investor invests directly in the market indices or the green bonds, the direction of returns for both financial instruments tend to move in the opposite which implies the existence of a flight-to-quality phenomenon. Furthermore, it appears that the following month of the market crash in 2020, all stock-bond pairs seemed to rise in the same direction to a positive side. Revisiting our proposed hypothesis for the study, we uncovered that based on the definition provided in the literature review flight-to-quality phenomenon where it was established that it originates from the uncertainty in the markets and exists when the correlation between the observed assets is negative generating the need for liquidity that increases with volatility (Chang and Hsueh, 2013; Tachibana, 2020). The same effect does exist in the markets, albeit with different intensities in their correlations. This phenomenon can only be perceived after the initial shock on the market during March 2020, after which the majority of the pairs' correlations shifted to negative. However, during the inception of the financial crisis on March 2020, all correlations for the country pairs of bond and stock had increased due to the initial shock on the markets there seems to be evidence of cross-asset contagion (Baur and Lucey, 2009). The joint decline in the price for both stock and bond indices, which has been also identified in all indices in figures 2 and 4 shows that the investors seek much safer assets during the peak of market turmoil and uncertainty, but after the initial shock tend to prefer bonds rather than stocks.

6 Conclusions

The study examined the flight-to-quality hypothesis between the selected Solactive Green Bond and the 10 European stock market indices under OECD economies by utilizing the Dynamic Conditional Correlation DCC (1,1)-GARCH (1,1) model and applying it to analyze our hypothesis. The effect of flight-to-quality was observed for a Solactive green bond index we chose as a benchmark paired with the European stock market indices to observe the relationships and the differences between the countries during the COVID-19 pandemic. In order to capture and analyze the relationship during market turmoil the sample period of mid-2016 to beginning of 2022 was considered based on the earliest available data for green bond index.

Obtaining the daily returns data for the chosen financial assets via logarithmic transformation we investigated the initial statistics of the indices presenting the facts on descriptive statistics including the means and standard deviations as well the skewness, kurtosis and the normality analysis on the data where we found that there is indication of leptokurtic distribution with asymmetric tails and non-stationarity rejection pointed towards the stationarity of our return data. Additionally, for model specifications testing we conducted unit root and autocorrelation for model validations.

We observed the sample for the entire period initially via graphical analysis to uncover first the whole picture of the relationship between the observed asset pairs, after which we delved deeper into the market crash dates where we considered averages of the correlations and perceived that for all pairs the correlations had decreased with respect to the average correlation that occurred during the turbulent month of March 2020. We find that flight-to-quality phenomena exists in all the observed countries, albeit the differences in the intensities across the markets. Results of the DCC (1,1)-GARCH (1,1) model indicate that there is an increase in correlation between the pairs of green bond and stock market indices during the perceived market crash in March 2020, which we consider a turbulent period in the market. The period before the 2020 pandemic and after in the data was observed for all bond-stock pairs having negative correlation with the exception of the comparison between green bond index and the index for Denmark's stock market index OMXC. The correlation for the pair has stayed positive on average throughout the sample period. However, the correlation dropped after the initial reaction to market turbulence from 0.192 to 0.0165, suggesting that there might be indication of some co-movement that provides evidence of cross-asset contagion instead of flight-to-quality between the two asset classes. Based on the observed averages in the correlations, green bond index paired with an Austrian market index (ATX) seemed to have supported the primary role of the alternative investment target after the market downturn in the month of March of 2020 as it had the largest negative correlation on average (-0.2823) with respect to other observed pairs, suggesting that it could serve as a diversifier asset for the investors to add in their portfolio and thus has provided clear indication of flight-to-quality compared to other pairs.

Overall, the highest observed dynamic correlations between the selected bond-stock pair were at the beginning of 2020 COVID-19 pandemic period of great instability that occurred globally and affected the majority of European markets. The research provided by academia on the topic of contagion where various studies (Hemche et al., 2016; Pereira and Lagoa, 2019; Tachibana, 2020) showed that the existence of contagion becomes imminent as during the turmoil period in the market the correlation coefficient increases significantly between the observed bond-stock pair. The observation has been noted in our study as during the pandemic period the beginning of 2020 significantly increased the correlation coefficient to the positive between all selected pairs of green bond and stock indices, thus suggesting a possible contagion on the month of March 2020. The investigation on contagion between the markets could prove as a good extension of this research to understand the cross-country relationships during economically challenging times.

Empirical studies conducted on this topic present evidence of the existence of flight-to-quality from stock to bond markets where Andersson et al. (2008) have observed that stock and bond prices move uniformly in the same direction during the high inflation periods. Additionally, Baur and Lucey (2009) have uncovered that the flight-to-quality between stocks and bonds occurs at the same time in many countries during crisis periods which we have as well observed in the study. Thus, the crisis periods to provide us a bit of more understanding on the behavior of the different financial assets, especially for the investors that seek addition to their portfolios – especially considering the green financial instruments. Not only it could prove to be a good diversifier, but it also supports the “green” environmentally conscious projects which strive to support the European Commission’s agenda for a more sustainable finance. (European Commission, 2021)

The findings of this study can prove beneficial for investors as the flight-to-quality phenomenon can suggest better diversification strategies between the green bond and stock markets during the market turmoil. Additionally, participation in the green bond market can offer an interesting substitute to the plain vanilla or government bonds within the market and thus attract more investors. Thus, the analysis could be expanded on investigating the relationships between the traditional bonds and the green bonds. What can be argued for the more environmental conscious investor base is the potential in the green bonds acting as a hedge as the green financial asset as the European Union enhancing taxonomies and supporting issuances with new policies and introducing targets of boosting the continent to be first in becoming climate-neutral by 2050. In the light of our study and the possibility of acting as a stabilizing factor in the stability of financial markets green bonds could be further analyzed by investigating the financial performance of the green bonds during the market uncertainty and delving deeper into whether there have been any spillover effects comparing green bonds with another “green” financial asset. Further studies could also consider employing a new model for estimating the flight-to-quality such as copula-based models, which could provide additional information on the phenomenon.

References

Abakah EJA, Tiwari AK, Sharma A and Mwamtambulo DJ (2022) Extreme Connectedness between Green Bonds, Government Bonds, Corporate Bonds and Other Asset Classes: Insights for Portfolio Investors. Journal of Risk and Financial Management 15(10): 477.

Agliardi E. and Agliardi R (2021) Corporate Green Bonds: Understanding the Greenium in a Two-Factor Structural Model. Environmental & Resource Economics 80(2): 257-278.

Ali, Q., Parveen, S., Yaacob, H., Zaini, Z., & Sarbini, N. A. (2021). COVID-19 and dynamics of environmental awareness, sustainable consumption and social responsibility in Malaysia. Environmental science and pollution research international, 28(40), 56199–56218.

Andersen TM., Bhattacharya J. and Liu P. (2020) Resolving intergenerational conflict over the environment under the Pareto criterion. Journal of Environmental Economics and Management 100: 102290.

Andersson M, Krylova E and Vähämaa S (2008) Why does the correlation between stock and bond returns vary over time? Applied Financial Economics 18(2): 139-151.

Ane, T. and C. Kharoubi, 2003, Dependence structure and risk measure, The Journal of Business 76, 411–438.

Arif M, Naeem MA, Farid S, Nepal R and Jamasb T (2022) Diversifier or more? Hedge and safe haven properties of green bonds during COVID-19. *Energy Policy; Energy Policy* 168: 113102.

Bachelet, M.J., Becchetti, L. & Manfredonia, S. (2019). The Green Bonds Premium Puzzle: The Role of Issuer Characteristics and Third-Party Verification. Sustainability. [Online]. 11 (4). p.p. 1098. Available from: http://dx.doi.org/10.3390/su11041098.

Bagão M., Dias R., Heliodoro P. & Alexandre P. (2021) The impact of COVID-19 on European financial markets: an empirical analysis. In 6th LIMEN Conference Proceedings. Part of LIMEN Conference Collection 6: p. 1-11.

Banga J (2019) The green bond market: a potential source of climate finance for developing countries. Journal of Sustainable Finance & Investment 9(1): 17-32.

Baur D.G. Lucey B.M. (2009) Flights and contagion—An empirical analysis of stock–bond correlations. Journal of Financial Stability 5(4): 339-352.

Bollerslev, T. (1986) Generalized Autoregressive Conditional Heteroskedasticity. St. Louis: Federal Reserve Bank of St Louis.

Brooks, C. (2008) Introductory econometrics for finance. 2nd ed. Cambridge: Cambridge University Press. 386-414

Caballero, R.J. and Krishnamurthy, A. (2008) Collective Risk Management in a Flight to Quality Episode. *The Journal of Finance (New York)* 63(5): 2195-2230

CBI (2019) Climate Bonds Standard Version 3.0.[accessed 11.5.2023] Available: climate-bonds-standard-v3-20191210.pdf (climatebonds.net)

CBI (2023) Certification Fee Policy. Climate Bonds Initiative. [accessed 20.12.2023] Available: Certification Fee Policy | Climate Bonds Initiative

CBI (2023a) Global State of the Market Report 2022. [accessed 20.5.2023] Available: https://www.climatebonds.net/resources/reports/global-state-market-report-2022

CBI (2023b) The Climate Bonds expanded Standard and Certification Scheme. A new generation of credibility in labelled debt. [accessed 11.5.2023] Available: climate-bonds-expanded-standard-and-ertification-cheme-brochure-19032023.pdf (climatebonds.net)

Celik, S. (2012) The more contagion effect on emerging markets: The evidence of DCC-GARCH model. Economic modelling. [Online] 29 (5), 1946–1959.

Cho J, Choi JH, Kim T and Kim W (2016) Flight-to-quality and correlation between currency and stock returns. Journal of Banking & Finance 62: 191-212.

Cortellini Gand Panetta IC (2021) Green Bond: A Systematic Literature Review for Future Research Agendas. *Journal of Risk and Financial Management* 14(12): 589.

Durand RB, Junker M and Szimayer A (2010) The flight-to-quality effect: a copula-based analysis. Accounting and Finance (Parkville) 50(2): 281-299.

Engle RF (1982) Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. Econometrica 50(4): 987-1007.

Engle R (2002) Dynamic Conditional Correlation: A Simple Class of Multivariate Generalized Autoregressive Conditional Heteroskedasticity Models. Journal of Business & Economic Statistics 20(3): 339-350.

European Commission (2019) The European Green Deal Sets Out how to make Europe the First Climate-Neutral Continent by 2050, Boosting the Economy, Improving People's Health and Quality of Life, Caring for Nature, and Leaving no One Behind. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691.

European Commission (2020) Economic Forecast: A deep and uneven recession, an uncertain recovery. [accessed 10.10.2023] Available: Spring 2020 Economic Forecast: A deep and uneven recession, an uncertain recovery (europa.eu)

European Commission (2021) NextGenerationEU: European Commission Successfully Issues First Green Bond to Finance the Sustainable Recovery. [accessed 15.5.2023] Available: https://ec.europa.eu/commission/presscorner/detail/en/ip_21_5207

European Commission (2023a) European Green Bond Standard. [accessed 15.5.2023] Available: https://finance.ec.europa.eu/sustain

European Commission (2023b) Sustainable Finance: Commission Welcomes Political Agreement on European Green Bond Standard. [accessed 15.5.2023] Available: https://ec.europa.eu/commission/p

European Commission (2023c) Green Claims. [accessed 15.5.2023] Available: Green claims - European Commission (europa.eu)

Eurostat (2023) GDP per capita, consumption per capita and price level indices. [accessed 10.6.2024]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Green_and_sustainability_bonds_issued_by_governments

Forbes, K. & Rigobon, R. (1999) No Contagion, Only Interdependence: Measuring Stock Market Co-movements. NBER Working Paper Series. [Online] 7267-.

Glosten, L.R., Jagannathan, R. and Runkle, D.E. (1993) On the Relation between the Expected Value and the Volatility of the Nominal Excess Return on Stocks. The Journal of Finance, 48, 1779-1801.

Hachenberg Band Schiereck D (2018) Are green bonds priced differently from conventional bonds? *Journal of Asset Management* 19(6): 371-383.

Hacıömeroğlu HA, Danışoğlu S and Güner ZN (2022) For the love of the environment: An analysis of Green versus Brown bonds during the COVID-19 pandemic. *Finance Research Letters* 47: 102576.

Hammoudeh S, Ajmi AN and Mokni K (2020) Relationship between green bonds and financial and environmental variables: A novel time-varying causality. *Energy Economics* 92: 104941.

Hansen, Peter R., and Asger Lunde. "A Forecast Comparison of Volatility Models: Does Anything Beat a GARCH(1,1)?" Journal of applied econometrics (Chichester, England) 20.7 (2005): 873–889.

Harjoto MA, Hoepner AGF and Nilsson MA (2022) Bondholders' returns and stakeholders' interests. Review of Quantitative Finance and Accounting 59(4): 1271-1301.

Haugh, M. (2016) An Introduction to Copulas. IEOR E4602: Quantitative Risk Management.

Hemche O, Jawadi F, Maliki SB and Cheffou AI (2016) On the study of contagion in the context of the subprime crisis: A dynamic conditional correlation–multivariate GARCH approach. Economic Modelling 52: 292-299.

Hsu Ku, Yuan-Hung, and Jai Jen Wang. "Estimating Portfolio Value-at-Risk via Dynamic Conditional Correlation MGARCH Model - an Empirical Study on Foreign Exchange Rates." Applied economics letters 15.7 (2008): 533–538.

International Capital Market Association (2022) Green Bond Principles. [Accessed 15.5.2023]. Available: Green-Bond-Principles_June-2022-280622.pdf (icmagroup.org)

International Capital Market Association (2023) Guidance Handbook. [Accessed 15.5.2023] Available: The-Principles-Guidance-Handbook-November-2023-291123.pdf (icmagroup.org)

Ielasi F, Rossolini M and Limberti S (2018) Sustainability-themed mutual funds: an empirical examination of risk and performance. *The Journal of Risk Finance* 19(3): 247-261.

Kachaner N, Nielsen J, Portafaix A and Rodzko F (2020) The pandemic is heightening environmental awareness. *Boston Consulting Group*

Kanamura T (2020) Are green bonds environmentally friendly and good performing assets? Energy Economics 88: 104767.

Kearney Cand Potì V (2006) Correlation dynamics in European equity markets. Research in International Business and Finance 20(3): 305-321.

Kemper, K, Lee, A, and Simkins, B.J. (2012) Diversification Revisited. *Research in* International Business and Finance 25(5): 827-853.

Khan, Muhammad Salman et al. “Symmetric and Asymmetric Volatility Clustering Via GARCH Family Models: An Evidence from Religion Dominant Countries.” Paradigms (Lahore, Pakistan) 13.1 (2019): 20–25.

Klose, J. and Tillmann, P. (2021) COVID-19 and Financial Markets: A Panel Analysis for European Countries. Jahrbücher für Nationalökonomie und Statistik, Vol. 241 (Issue 3), pp. 297-347. https://doi.org/10.1515/jbnst-2020-0063

Lahiani, A., Nguyen, D. (2013) Equity market comovements and financial contagion: a study of Latin America and United States. Bankers, Markets & Investors Volume 126, pp. 17-29 September-October 2013.

Li Z, Kuo T, Siao-Yun W and The Vinh L (2022) Role of green finance, volatility and risk in promoting the investments in Renewable Energy Resources in the post-covid-19. *Resources Policy* 76: 102563.

Lin Band Su T (2022) Green bond vs conventional bond: Outline the rationale behind issuance choices in China. *International Review of Financial Analysis* 81: 102063.

Liu M (2022) The driving forces of green bond market volatility and the response of the market to the COVID-19 pandemic. *Economic Analysis and Policy* 75: 288-309.

Liu N, Liu C, Da B, Zhang T and Guan F (2021) Dependence and risk spillovers between green bonds and clean energy markets. *Journal of Cleaner Production* 279: 123595.

Leitao J, Ferreira J and Santibanez-Gonzalez E (2021) Green bonds, sustainable development and environmental policy in the European Union carbon market. Business Strategy and the Environment 30(4): 2077-2090.

Longin Fand Solnik B (2001) Extreme Correlation of International Equity Markets. The Journal of Finance (New York) 56(2): 649-676.

Martiradonna M, Romagnoli S and Santini A (2023) The beneficial role of green bonds as a new strategic asset class: Dynamic dependencies, allocation, and diversification before and during the pandemic era. Energy Economics 120: 106587.

Mazur M, Dang M and Vega M (2021) COVID-19 and the march 2020 stock market crash. Evidence from S&P1500. Finance Research Letters 38: 101690.

Naeem MA, Conlon T and Cotter J (2022) Green bonds and other assets: Evidence from extreme risk transmission. *Journal of Environmental Management; J Environ Manage* 305: 114358.

Naeem MA, Karim S and Tiwari AK (2022) Risk Connectedness Between Green and Conventional Assets with Portfolio Implications. *Computational Economics*: 1-29.

Narayan PK, Rizvi SAR and Sakti A (2022) Did green debt instruments aid diversification during the COVID-19 pandemic? *Financial Innovation (Heidelberg); Financ Innov* 8(1): 21.

Nguyen TTH, Naeem MA, Balli F, Balli HO and Vo XV (2021) Time-frequency comovement among green bonds, stocks, commodities, clean energy, and conventional bonds. *Finance Research Letters* 40: 101739.

OECD (2017) Mobilising Bond Markets for a Low-Carbon Transition.[Accessed 23.5.2023] Available: https://doi.org/10.1787/9789264272323-en

Park D., Park J. and Ryu D. (2020) Volatility Spillovers between Equity and Green Bond Markets. Sustainability 12(9): 3722.

Pereira I.P. and Lagoa S. (2019) Flight-to-quality and contagion in the European sovereign debt crisis: The cases of Portugal and Greece. Journal of Financial Economic Policy 11(2): 193-217.

Pham L (2016) Is it risky to go green? A volatility analysis of the green bond market. Journal of Sustainable Finance & Investment 6(4): 263-291.

Pham L (2021) Frequency connectedness and cross-quantile dependence between green bond and green equity markets. Energy Economics 98: 105257.

Plumlee M, Brown D, Hayes RM and Marshall RS (2015) Voluntary environmental disclosure quality and firm value: Further evidence. Journal of Accounting and Public Policy 34(4): 336-361.

Reboredo JC (2018) Green bond and financial markets: Co-movement, diversification and price spillover effects. Energy Economics 74: 38-50.

Reboredo JC, Ugolini A and Aiube FAL (2020) Network connectedness of green bonds and asset classes. Energy Economics 86: 104629-27.

Sangiorgi Iand Schopohl L (2021) Why do institutional investors buy green bonds: Evidence from a survey of European asset managers. International Review of Financial Analysis 75: 101738.

SanJuan-Reyes S, Gómez-Oliván LM and Islas-Flores H (2021) COVID-19 in the environment. Chemosphere 263: 127973.

Shahzad SJH, Bouri E, Rehman MU, Naeem MA and Saeed T (2022) Oil price risk exposure of BRIC stock markets and hedging effectiveness. Annals of Operations Research 313(1): 145-170.

Shaydurova A, Panova S, Fedosova R and Zlotnikova G (2018) Investment Attractiveness of "Green" Financial Instruments. 7: 710-715.

Solactive (2019) Index Guideline. Solactive Green Bond EUR USD IG Index. [Accessed 10.11.2023] Available: Index Guideline (solactive.com)

Solactive (2023) Explanation of how key elements of the benchmark methodology reflect environmental, social, and governance (ESG) factors. [Accessed 23.5.2023] Available: Benchmark Statement: Solactive Green Bond Index (DE000SLA0FS4)

Tachibana M (2020) Flight-to-quality in the stock–bond return relation: a regime-switching copula approach. Financial Markets and Portfolio Management 34(4): 429-470.

Tang D., Yand Zhang Y., (2020) Do shareholders benefit from green bonds? Journal of Corporate Finance (Amsterdam, Netherlands) 61: 101427.

Technical Expert Group on Sustainable Finance (ed.) (2019) EU Sustainable Finance Taxonomy – Techincal Report. Taxonomy. European Commission: Brussels. [Accessed 14.5.23] Available: https://www.ecologic.eu/16796

Vayanos, D. (2004) Flight to Quality, Flight to Liquidity, and the Pricing of Risk. Cambridge: National Bureau of Economic Research, Inc.

World Health Organization (2023) Coronavirus disease (COVID-19) pandemic. [accessed 1.6.2023] Available: https://www.who.int/europe/emergencies/situations/covid-19

Yadav M, Mishra N and Ashok S (2023) Dynamic connectedness of green bond with financial markets of European countries under OECD economies. Economic Change and Restructuring 56(1): 609-631.

Zhang, R., Brennan, T. J., & Lo, A. W. (2014). The origin of risk aversion. Proceedings of the National Academy of Sciences of the United States of America, 111(50), 17777–17782.