Vaasan yliopisto
UNIVERSITY OF VAASA

Taneli Mäki-Torkko

Hedging Bitcoin cryptocurrency with green bond and gold

Can sustainable green bond provide better hedging results?

School of Accounting and Finance
Master's thesis in Finance
Master's Degree Programme in Finance

Vaasa 2024

UNIVERSITY OF VAASA
School of Accounting and Finance
Author: Taneli Mäki-Torkko
Title of the Thesis: Hedging Bitcoin cryptocurrency with green bond and gold: Can sustainable green bond provide better hedging results?
Degree: Master of Science in Economics and Business Administration
Programme: Master's Degree Programme in Finance
Supervisor: Anupam Dutta
Year: 2024 **Pages:** 100

ABSTRACT:

Green investing has notably gained traction in recent years as a sustainable and responsible investment strategy, focusing on financing assets that support environmental goals. Green bonds, in particular, have emerged as popular financial instruments which are used to finance projects that promote sustainable development. In the past few years, alongside traditional investment assets and green investing, there has been a notable increase in the popularity of cryptocurrencies such as Bitcoin. This trend has been driven by Bitcoin's potential income generation and diversification opportunities. This study examines the hedging benefits of green bond and gold against Bitcoin, employing DCC-GARCH and ADCC-GARCH models.

The purpose of this study is to investigate the dynamic relationships among these financial instruments over two distinct periods. The main sample period extends from January 2015 to March 2022, which consists of 1,813 daily observations per instrument. The second sample period covers COVID-19 period from February 2020 to March 2022, which consists of 540 daily observations per instrument. The findings reveal significant dynamic correlations between green bond and Bitcoin and between gold and Bitcoin. The results from the DCC-GARCH model suggest that past volatilities and past news have a significant impact on current correlations, indicating that these instruments can be utilised as potential hedge tools both in normal market conditions and during market shocks. The ADCC-GARCH model further supports these results and confirms the effectiveness of green bonds and gold as hedges against Bitcoin.

The statistically significant safe-haven properties of green bonds are observed in the COVID-19 period since they show a stronger hedging effect against Bitcoin compared to gold. This finding is crucial for investors considering diversification and seeking effective hedging tools for their investment portfolios during market crises. The growing popularity of sustainable investing also increases the importance of green bonds, as they provide not only financial hedging benefits but also environmental benefits. The research results indicate that green bonds are effective hedging tools and efficient in risk management, especially in a market environment of higher volatility. According to the findings, a portfolio combining green bonds and Bitcoin, or gold and Bitcoin is less risky than a corresponding portfolio consisting of only Bitcoin. Among these two types of portfolios, a consistently lower risk has been observed during both examined periods in the portfolio consisting of green bonds and Bitcoin.

KEYWORDS: Hedging, Volatility transmission effects, Green bond, Gold, Bitcoin, Diversification, Safe-haven asset, DCC-GARCH

VAASAN YLIOPISTO
Laskentatoimen ja rahoituksen yksikkö

Tekijä:	Taneli Mäki-Torkko		
Tutkielman nimi:	Hedging Bitcoin cryptocurrency with green bond and gold: Can sustainable green bond provide better hedging results?		
Tutkinto:	Kauppatieteiden maisteri		
Oppiaine:	Rahoitus		
Työn ohjaaja:	Anupam Dutta		
Valmistumisvuosi:	2024	**Sivumäärä:**	100

TIIVISTELMÄ:

Vihreä sijoittaminen on onnistunut kasvattamaan merkittävästi suosiotaan viime vuosina kestävänä ja vastuullisena sijoitusstrategiana, joka keskittyy ympäristöä tukevien varojen rahoittamiseen. Erityisesti voidaan nostaa esiin vihreät joukkovelkakirjat, jotka ovat nousseet suosituiksi rahoitusvälineiksi ja joilla rahoitetaan kestävää kehitystä edistäviä hankkeita. Viime vuosina on voinut havaita myös perinteisten sijoituskohteiden ja vihreän sijoittamisen lisäksi Bitcoinin kaltaisten kryptovaluuttojen kasvavan suosion, johon on vaikuttanut Bitcoinin tuotto- ja hajautusmahdollisuudet. Tämä tutkimus tarkastelee vihreiden joukkovelkakirjojen ja kullan suojauskeinoja Bitcoinia vastaan hyödyntämällä DCC-GARCH ja ADCC-GARCH malleja.

Tutkimuksen tavoitteena on tutkia näiden rahoitusinstrumenttien dynaamisia suhteita kahdella eri ajanjaksolla. Varsinainen tutkimusajanjakso on tammikuun 2015 ja maaliskuun 2022 väliseltä ajalta, joka koostuu 1 813 päivähavainnosta per instrumentti. Toisena tutkimusajanjaksona on COVID-19 ajanjakso, joka on helmikuun 2020 ja maaliskuun 2022 väliseltä ajalta, joka koostuu 540 päivähavainnosta per instrumentti. Tulokset osoittavat merkittäviä dynaamisia korrelaatioita vihreiden joukkovelkakirjojen ja Bitcoinin sekä kullan ja Bitcoinin välillä. DCC-GARCH-tulokset viittaavat siihen, että aikaisemmin tapahtuneet volatiliteetit ja uutiset vaikuttavat merkittävästi nykyisiin korrelaatioihin. Tämä tarkoittaa, että näitä instrumentteja voidaan käyttää potentiaalisina suojauskeinoina sekä normaalissa tilanteessa että markkinashokkitilanteessa. ADCC-GARCH-malli tukee edelleen näitä tuloksia ja vahvistaa vihreiden joukkovelkakirjalainojen ja kullan tehokkuutta suojautumisvälineinä Bitcoinia vastaan.

Vihreiden joukkovelkakirjojen tilastollisesti merkittävät turvasatamaominaisuudet voidaan havaita COVID-19 ajanjaksolla siitä, kun ne osoittavat vahvempaa suojausvaikutusta Bitcoinia vastaan kultaan verrattuna. Havainto on tärkeä sijoittajille, jotka pohtivat hajauttamista ja pyrkivät löytämään tehokkaita suojauskeinoja sijoitusportfoliota varten markkinakriisin aikana. Kestävän sijoittamisen kasvava suosio lisää samalla myös vihreiden joukkovelkakirjojen merkitystä, sillä ne mahdollistavat taloudellisten suojauskeinojen lisäksi myös ympäristöhyötyjä. Tutkimustulokset indikoivat vihreiden joukkovelkakirjojen hyviä suojauskeinoja ja tehokkuutta riskienhallinnassa, erityisesti korkeamman volatiliteetin markkinaympäristössä. Tulosten mukaan portfolio, jossa yhdistyvät vihreät joukkovelkakirjat ja Bitcoin tai kulta ja Bitcoin ovat matalariskisempiä kuin vastaava portfolio, joka koostuu vain Bitcoinista. Näistä kahdesta portfoliosta matalampaa riskiä voidaan toistuvasti havaita molemmilla tarkasteluajanjaksoilla portfoliosta, joka koostuu vihreistä joukkovelkakirjalainoista ja Bitcoinista.

AVAINSANAT: Suojaus, Volatiliteetin siirtymisvaikutukset, Vihreä joukkovelkakirja, Kulta, Bitcoin, Hajauttaminen, Turvasatamavarallisuus, DCC-GARCH

Table of Contents

Figures

Tables

Abbreviations

ADCC	Asymmetric Dynamic Conditional Correlation
ARCH	Autoregressive Conditional Heteroskedasticity
DCC	Dynamic Conditional Correlation
ESG	Environmental, Social and Governance
ETF	Exchange Traded Funds
GARCH	Generalized Autoregressive Conditional Heteroskedasticity
GBP	Green Bond Principles
HE	Hedging Effectiveness
ICMA	International Capital Market Association

1 Introduction

In the development of the financial world, sustainable investing has become a significant trend, which reflects a wider societal transition towards more environmentally friendly activities (Dutta et al., 2020a, p. 1). Green bonds serve as an example of responsible investment instruments, supporting environmental projects such as renewable energy, energy efficiency enhancements, and sustainable agriculture (Dutta et al., 2021). The popularity of green bonds has grown substantially, as they offer the opportunity to combine financial goals and environmental protection needs, which has become increasingly important in combating climate change and promoting sustainable development (Bodhanwala & Bodhanwala, 2019; Dutta et al., 2021). Investing in green bonds makes it possible for individuals and organizations to contribute to projects with measurable and positive environmental benefits, aligning with their financial goals and ethical values. This synergy of financial returns and environmental impact makes green bonds an attractive option for investors who are environmentally conscious and are prioritizing environmental responsibility.

At the same time, Bitcoin and other cryptocurrencies have brought a new dimension to the global financial market. Bitcoin, the most well-known cryptocurrency, is known for its large price fluctuations and the potential for large profits (Baur et al., 2017). Platanakis and Urquhart (2020) demonstrate that when using Bitcoin-stock or Bitcoin-bond portfolio, the benefits of Bitcoin are relatively high with significantly higher risk-adjusted returns. In portfolio allocation wise, their study indicate that Bitcoin could be beneficial for investors.

Additionally, Brière et al. (2015) highlight that even a minimal investment in Bitcoin, when placed to a diversified portfolio, could substantially enhance the risk-return trade-off. According to their study, these results show that moderately risk-averse investors should consider Bitcoin as one investment opportunity. Bitcoin is characterized by a high-risk, high-return profile, meaning that a small investment could potentially increase portfolios return but also substantially increase the overall risk. Investors looking to manage their portfolio risk due to the volatility that Bitcoin brings often look for assets that provide protection against these volatility swings. These assets are called safe havens or hedges. Baur and Lucey (2010) and Baur and McDermott (2010) define an asset as hedge when it exhibits, on average, either no correlation or a negative correlation with other asset classes. For example, in periods of market turmoil, a safe haven asset provides protection benefits. The difference between the characteristics of hedge and safe haven is the duration of the hedging effect. According to Baur and Lucey (2010), an asset that serves as a safe haven is that type of asset which have a negative correlation with other assets, especially during extreme market conditions.

In this context, traditional safe havens, such as gold, have retained their value. Historically, gold has been recognized as a reliable asset that protects against economic uncertainty and inflation (Baur & Lucey, 2010). Its role as a hedge against financial uncertainty and inflation continues to make it a popular choice for risk-conscious investors. However, green bonds offer a new approach to portfolio diversification. Although not traditionally classified as a safe haven, green bonds can provide unique stability by supporting projects with long-term positive environmental impacts (Bouri et al., 2021). This stabilization can be especially valuable during times of high volatility in cryptocurrencies such as Bitcoin. Arif et al. (2022) indicates that including green bonds in a portfolio can provide a dual benefit: promoting environmental sustainability and also at the same time reducing the risks of highly volatile assets when green bond can act as a safe-haven instrument.

As financial markets continue to develop, the interplay between traditional safe haven assets, such as gold, and new sustainable instruments, like green bonds, will become increasingly significant. Understanding these relationships and their effectiveness as hedging strategies can clarify their role in addressing the challenges faced by investors. This area of research offers a promising opportunity for those interested in harmonizing risk management, return and sustainability in their investment strategies.

1.1 Research Motivation and Hypotheses

The main motivation behind this study arises from the need to identify alternative investment strategies that can provide stability in volatile market conditions. Traditional safe-haven investments, such as gold, have long been valued for their ability to preserve wealth during economic downturns. However, green bonds have emerged as financial instruments supporting environmental sustainability, offering a new opportunity to achieve both financial and environmental goals. This makes them particularly attractive in the current investment environment.

Bitcoin, the first major cryptocurrency, has changed financial practices. Its decentralized structure and blockchain technology offer a new type of investment option that challenges traditional financial systems and brings with it unique opportunities and risks (Brito & Castillo, 2013). Bitcoin's rapid appreciation and high volatility have attracted both private and institutional investors, but this volatility raises questions about its reliability as a store of value and its role in a decentralized portfolio (Baur et al., 2017).

At the same time, the rising awareness of environmental issues has resulted in the emergence of the green bond market. Green bonds are aimed to fund environmentally positive projects and reflect the transition to more responsible investing by combining financial returns with environmental benefits (Bodhanwala & Bodhanwala, 2019). These bonds not only promote environmental goals, but also offer potential financial rewards, making them an attractive option for risk-averse investors looking to diversify their portfolios.

Gold has traditionally served as a safe haven, providing stability during times of economic uncertainty and inflation. Its role as money and store of value has made it a central part of investment strategies, especially in times of crisis (Baur & McDermott, 2010). In today's financial markets, comparing gold to new asset classes such as Bitcoin and green bonds can give valuable insights into optimal hedging strategies and portfolio diversification.

The research is also based on the need to understand how these asset classes correlate and how their volatility interacts with each other. The period from 2015 to 2022, including the extraordinary financial disruptions caused by the COVID-19 pandemic, provides an excellent opportunity to examine the behaviour of these relationships under different market conditions. Using advanced econometric models such as DCC-GARCH and ADCC-GARCH, this study intends to analyse the dynamic correlations and volatility flows between Bitcoin, green bond and gold, providing comprehensive information on their hedging potential.

The study hypothesizes that green bonds could have effective hedging properties against Bitcoin volatility, potentially surpassing the effectiveness of traditional safe-haven assets such as gold. The primary inquiry of this study is to determine if there is a significant relationship between green bond and Bitcoin, and how this relationship differs when compared to that between gold and Bitcoin. To address this research question, the null hypothesis is defined as follows:

> *H_0:* Green bond does not exhibit significant hedging properties against Bitcoin when compared to gold, under both stable and crisis market conditions.

Based on this null hypothesis, alternative hypotheses are developed, building on the null hypothesis and aligning with the analytical capabilities of the chosen empirical approaches.

> *H_1: Green bonds have significant hedging properties against Bitcoin, under both stable and crisis market conditions.*
> *H_2: Gold remains a strong hedge but may be less effective than green bond in extreme market conditions.*

H_3: The dynamic correlations between Bitcoin and green bond and between Bitcoin and gold vary significantly between normal and crisis periods, with even stronger hedging effects observed during market shocks.

The results of the study have significant practical implications for investors and portfolio managers. As financial markets become more complex with new asset classes and investment products, it is vital to understand the risks and returns of different asset classes. This research aims to provide information to help identify the best hedging tools and improve portfolio diversification. In addition, by integrating green bonds into the analysis, the research emphasizes the possibility of combining financial performance with environmental sustainability, supporting the broader goals of sustainable finance.

In summary, this study examines how to navigate the evolving financial landscape consisting of the rise of cryptocurrencies, the growth of the green bond industry, and the continued significance of gold. By examining the dynamic correlations of these assets, the study aims to provide valuable insights to investors looking to improve their risk management strategies. By understanding the interplay between green bonds, gold and Bitcoin, investors can make informed decisions and optimize their portfolios for both financial stability and environmental impact.

1.2 Limitations and Assumptions

This study is based on several assumptions and identifies several limitations that may affect the interpretation of the results and their generalizability. These factors are important for understanding the scope and limits of the study and for guiding future research.

First, the analysis focuses on a time period from 2015 to 2022, with a detailed examination of the COVID-19 pandemic phase, from February 2020 to March 2022. The choice of this period may affect the results due to the unique market conditions and the extraordinary volatility caused by the pandemic.

The research utilises DCC-GARCH and ADCC-GARCH models to analyse the dynamic correlations and hedging properties of green bonds and gold against Bitcoin. Although useful for analysing variable correlations, these models assume that past volatilities and news predict future behaviour. Moreover, the DCC-GARCH and the ADCC-GARCH models are sensitive to the choice of parameters and the definition of the volatility equation. However, this assumption may not be valid in all market conditions, which may affect the accuracy of the results.

While the research focuses on green bond, gold and Bitcoin, looking at other financial instruments and hedging tools such as commodities, other cryptocurrencies and stock indices could provide further insight into hedging effectiveness. In the future, incorporating a wider range of assets could gain deeper insights into the behaviour of different investment instruments under varying market conditions. At the conclusion part of the thesis, a suggestion for future research topics is offered to address these potential issues and also provide overall conclusion from the results of study.

1.3 Structure of the thesis

This thesis adopts a structured approach to provide a comprehensive analysis of the hedging properties of green bond and gold against Bitcoin, utilizing a systematic framework. The first three chapters focus on the theoretical foundations of each asset class. The second chapter is focusing to gold whose historical role as a traditional safe haven asset and its position in investment portfolios are thoroughly explored. The third chapter examines Bitcoin's fundamental characteristics, its role in financial markets, and its historical development and volatility. In the fourth chapter it’s green bond’s turn and this chapter analyses green bonds, their goals, operating principles and their role in supporting environmental sustainability. Each chapter also analyses the risks of different assets and provides a comprehensive overview of the potential challenges for these asset classes from an investor perspective.

After this, the fifth chapter is presenting the research methodology, which includes a thorough explanation of the ARCH and GARCH models. This chapter reviews the theoretical foundations and practical applications of these econometric models, preparing the ground for empirical analysis.

The sixth chapter is focusing on data and empirical methodology. It provides a detailed description of the dataset utilised in the study and outlines the empirical methods used for the analysis. This includes summary statistics for price series and logarithmic return series in the whole data set which provide a detailed look at the characteristics of the data. Also augmented Dickey-Fuller and Philips-Perron stationarity test and Jarque-Bera test for the whole data set are introduced.

The seventh chapter presents the results of an empirical study, including DCC-GARCH estimations for green bond-Bitcoin and gold-Bitcoin pairs, time-varying correlations and the hedging effectiveness of green bonds and gold against Bitcoin. In the chapter, the research results are compared to previous literature, which enables a comprehensive analysis of the results' significance and their relationship to previous research. In addition, the chapter display robustness checks analysing the 2015-2022 time period and the COVID-19 period (2020-2022), utilizing the ADCC-GARCH model.

Finally, the conclusion chapter combines the theoretical findings with the empirical results and considers their implications also for investors. This part emphasizes the importance of research in the current literature and suggests future research topics. By combining theoretical and empirical perspectives, the study aims to provide deep insights into the effectiveness of green bonds and gold as hedges against Bitcoin. This way the study tries to contribute to a broader discussion of sustainable investment strategies and risk management in an era of growing market uncertainties.

2 Gold

This theoretical chapter of gold main idea is to explain the characteristics of gold and how it has been using. The first chapter examines the importance and multiple roles of gold throughout history and in modern finance. The chapter begins with a review of the historical development of gold, highlighting its enduring value and symbolic significance over the centuries. Next, it examines gold as a commodity and monetary asset, emphasizing its function in wealth protection and as a hedging tool against volatility changes. The chapter continues with a short introduction to gold production, focusing on global gold production. Following this, gold chapter explores various investment options in gold, including physical gold and financial instruments like exchange-traded funds (ETFs) and gold mining stocks. Finally, the chapter concludes with a brief analysis of the factors influencing gold price development and also describes risks and uncertainty relating to gold.

2.1 A historical and modern perspective of Gold

There is famous quoted line relating to gold which is describing gold very well: ”The beauty of gold is, it loves bad news.” This sentence is originally mentioned in John Updike’s novel Rabbit is Rich. According to Bhanja and Dar (2015), this sentence means that gold maintains value as well in situations that are harmful in market or riskier. Gold has historically played a crucial role as financial asset in the global financial system (Alimukhamedov, 2024). People have been using gold for a long time in different ways. It served as a currency in numerous different civilizations such as Ancient Greece, Rome, and Egypt. Nowadays, gold is still having very significant role in the global financial system, acting as hedging tool and reserve asset for central banks (Alimukhamedov, 2024).

Gold has long been considered as a valuable asset during periods of uncertainty. Historically it has delivered positive long-term returns regardless of whether economic conditions were good or there was a time a market shock. Gold serves a dual purpose. First one is that it is an investment for being a hedging tool for protecting and growing wealth over time. Second one is that gold can be a consumer good for jewellery and technology sector (World Gold Council, 2024b).

There are many ways to invest in gold, such as buying physical gold, investing in gold-tracking exchange-traded funds (ETFs), or buying shares in gold mines. Physical gold bars and coins provide tangible ownership, while a gold ETFs and shares enable easier liquidity and lower storage costs. Gold prices are affected by many factors, such as geopolitical tensions, exchange rate changes and interest rate fluctuations (World Gold Council, 2024b).

2.2 Gold as a commodity, a monetary asset and the wealth protection

Gold is a precious metal that is classified as both a commodity and a monetary asset. For centuries, it has functioned as a versatile metal with similar properties to money; it serves as a tool for the custodian of value and as an exchange tool (Baur & McDermott, 2010; Solt & Swanson, 1981). Moreover, gold is used in various industries, including dentistry and jewellery, as well as being an investment asset and as a reserve asset. Central banks and financial institutions that invest in gold maintain large gold reserves (Tully & Lucey, 2007, p. 317). Overall, gold's enduring value and versatility underscore its critical role in both historical and contemporary financial systems.

During economic downturns, such as recessions, more people are more attracted to invest in gold due to its reliable value (World Gold Council, 2024b). Often seen as a safe haven asset, gold attracts investors during periods of market turbulence (Alfaro, 2021). When the returns on bonds, stocks, and real estate are expected to decline or actually do, interest in gold increases, leading to a rise in its price (Folger, 2023). Gold acts as a hedge against economic challenges like currency devaluation and inflation. Additionally, it is considered a protective investment during times of political instability.

Jaffe (1989) has proved that the value of gold changes very independently, so gold does not correlate with other investments in the portfolio. By allocating a portion of your investment in gold, it is possible to further reduce the risk of a diversified portfolio. During military conflicts and natural disasters, the value of gold remains excellent compared to other investments, but volatility is high, and risks are high (Jaffe, 1989, p. 57). Gold has been also considered a safe haven if there have been major declines on the capital markets and dollar is weak (Reboredo & Rivera-Castro, 2014). Additionally, gold has the potential to protect its investment portfolio from inflation (Chua & Woodward, 1982).

2.3 The Gold production

The monetary value of gold is significantly influenced by the costs associated with its production. It is important to consider and account for these costs when assessing the value of gold. The supply of gold consists of mining (67 %) and recycling (33 %). The average annual supply and demand has been around 4300 tons over the years 2008-2017. In the year 2023 there exist a total of mined gold over 200 000 tons of which in jewelleries 45 %, owned by private investors and held by investment instruments 22%, held by the official sector as central banks 17 % and at other locations 15% (World Gold Council, 2024a).

Global gold production influences the price of gold, illustrating the principle of supply and demand. Gold mine production was around 3,000 metric tons in 2023, down from a peak of around 3,300 metric tons per in 2018 and 2019 (Statista, 2024). Despite the increase over the past decade, gold mining production has remained relatively stable since 2016. Gold mining has become more costly because the easily accessible reserves have been exhausted, forcing miners to dig deeper and face greater hazards and environmental impacts (Folger, 2023). As a result, it costs more to extract less gold, driving up production costs and sometimes leading to higher gold prices.

2.4 Investing in Gold

Investing in gold can be done in many different ways. Gold can be purchased in physical form, but investing is also possible through financial instruments such as exchange-traded funds (ETFs). In the following subchapters, a comprehensive overview of different investment methods is presented. Also, examining how each investing method operates, and evaluating their respective advantages and disadvantages.

2.4.1 Physical Gold

The simplest way to invest in gold is to buy gold bars or coins. The value of gold is just in metal itself, which you can feel in your own hands, brings a sense of security and stability that is not found in other form of gold investment. The physical gold has been found to retain its value most reliably in all economic situations (Baur & McDermott, 2010, p. 1888). However, owning physical gold often leads to storage costs, and issues related to insurance and taxes can also arise (Niskanen, 2020). Investment-grade physical gold, also known as gold bullion, can be bought at the spot price. This price includes the cost of raw, unprocessed gold plus any additional fees, which may differ from seller to seller (Goetz, 2023). The downside of physical gold is also that the sale prices of gold bars and coins can differ greatly from the purchase price (Niskanen, 2020). While these costs may not impact investors aiming to allocate a small portion of their portfolio to gold, they can be prohibitive for those seeking larger exposure.

Many investors prefer acquiring physical gold over gold exchange-traded funds (ETFs) because they want to physically own and manage their gold (Goetz, 2023). Especially in crises, physical gold can be melted down and reshaped as needed, providing owners with flexibility and assurance during potentially challenging market conditions. On other hand, physical gold can pose liquidity challenges and may incur higher costs when selling. In comparison, gold ETFs provide a more liquid and cost-efficient option (Alfaro, 2024). When acquiring physical gold, it is important to be careful about where it is obtained. Trusted suppliers offer certified investment-grade gold with clear markings of the manufacturer, weight, and purity, ensuring investors high quality and transparency (Goetz, 2021).

2.4.2 Other investment options

Exchange Traded Funds (ETF) are funds that are listed on a stock exchange. They are a cost-effective way to own paper gold and their buying and selling take place on the stock exchange and there are no safety issues with gold storage (Dhawan, 2023). ETFs are a preferred form of investment as their spreads and management fees are usually low (Niskanen, 2020). Another good aspect is that pricing in transparent and close to the real price of gold (Dhawan, 2023). When choosing a gold ETF, there are guaranteed funds available that own physical gold, as well as non-guaranteed ones that invest in gold derivatives. At the international level, the guaranteed funds are more popular than the not guaranteed ones (Niskanen, 2020). However, the investor of ETF does not receive gold in physical form, which can evoke a sense of uncertainty.

People can also invest in gold with various derivatives, which are options, futures, and swaps. Derivatives can be bought and sold through your book-entry account at low cost. While there are risks involved in investing in derivatives, they also have potential to generate significant returns (Niskanen, 2020). Futures are derivatives that allow for speculation on the future price of gold or, for example, hedging the value of physical gold against market price fluctuations (Niskanen, 2020). However, investing in futures involves a substantial amount of risk, so they are not recommended for beginners. Options offer investors a safer approach to trading gold derivatives compared to futures (Niskanen, 2020). When investing with options, only the person selling the option undertakes to execute the option if necessary. The buyer of an option only has the right to use the option he bought. According to Alimukhamedov (2024), there are various options for investment purposes to protect gold positions with different derivative instruments forwards, futures, and options and also gold swaps.

2.5 The price development

The price of gold is governed by the law of supply and demand. Its price is really volatile, which means it has varied greatly throughout the history (Lehto-Isokoski, 2014). That's why the long-term predictability of the price of gold is challenging. The price of gold is influenced by several key factors: its dollar-denominated nature means a stronger U.S. dollar tends to depress prices, while weaker dollar values typically push prices higher; fluctuations in real and expected inflation rates also play a significant role; central bank gold purchases impact prices, as does global demand for gold in jewellery and technology (Folger, 2023). The property of gold as a store of value increases its attractiveness as a portfolio risk factor to minimize the risk when the dollar is weak (Reboredo & RiveraCastro, 2014). The value of gold can drop significantly if a large amount of gold suddenly enters the market (Lehto-Isokoski, 2014). These reasons are important to consider when investing in gold and choosing the timing of the investment.

Comparing to stocks or bonds, gold investment does not generate regular income like dividends. Some investors may see this as a drawback of gold but however what gives more value to gold investment is that gold doesn't have credit risk or counter-party risk. Investors are dependent on price appreciation to receive value on owning gold. Luckily, gold has statistically generated positive return on long-term in both good market situations and during market crises. Also, gold has performed better comparing many other asset classes between different investment horizons (World Gold Council, 2024b). According to World Gold Council (2024b), gold has outperformed US Aggregate bonds and US equities during most of crisis that have occurred between 2020 to 2022. This highlights gold's capability to maintain positive returns even during times of crises and also showing its likelihood to be promising hedging and diversification tool against risks happening in market turmoil.

2.6 The risk and uncertainty of Gold

Gold prices are affected by exchange rates, economic growth, market uncertainty, mine production and demand shocks (Shafiee & Topal, 2010, p. 178). Due to these diverse factors driving the supply and demand of gold, its price does not strongly correlate with changes in other prices. The price of gold has developed steadily since the beginning of the 19th century for more than 150 years, and it was not until 1980 that there was a sharp rise in price, and another rise began in 2008 (Shafiee & Topal, 2010, p. 180). The situation in global economy affects changes in the price of gold, so that in a downturn when stock prices and bond markets are volatile, companies protect themselves from inflation and high oil prices by investing in gold (Shafiee & Topal, 2010, p. 180).

Gold-investing ETFs have made it easier to invest in gold because they can be traded on the stock exchange like ordinary shares, but it must be borne in mind that shares of gold mining companies do not offer the same diversification benefits as the real physical gold bullions. The gold shares follow more directly the performance of normal stock indices and other stocks and have the same risks (Chua et al., 1990, p. 79). The gold market is relatively simple and quite easy to understand and evaluate. In times of uncertainty, such properties are valuable. As a physical precious metal, the supply of gold is relatively inelastic and the demand for gold varies (Baur & McDermott, 2010). These properties reinforce the theory that gold acts as a store of value and a safe haven in times of market uncertainty (Baur & McDermott, 2010). The value of gold does not depend on income and does not involve credit risk.

Gold mining has significantly influenced the economic development and stability of many countries. However, this activity generates and releases toxic wastes that have significant and profound impacts on the ecosystem (Fashola et al., 2016). For this reason, it is crucial to invest in sustainability in the gold mining industry. According to World Gold Council (2024b), sustainable gold mining is substantially important to reduce environmental impacts and, also to minimize different risks. Responsible gold miners must follow strict regulations that ensure local economic development by paying wages, improving infrastructure and providing access to health care. Gold mining industry are also committed to the United Nations Sustainable Development goals. When investing to gold industry which is doing sustainable gold mining can reduce the climate risks of investment portfolios and decrease the carbon footprint. Investors are also able to benefit gold's diversification and hedging benefits at the same time. (World Gold Council, 2024b)

3 The theory of Bitcoin

This chapter aims to deliver an in-dept analysis of Bitcoin, focusing on its properties as a digital currency and its role in the modern economy. Bitcoin is a digital and decentralized currency that is not based on a value guaranteed by any government or legal entity, and it is not possible to be converted into gold or other physical assets. Its reliability is based on peer-to-peer networks and cryptographic methods that guarantee both security and transparency of operations (Grinberg, 2012).

The first part of this chapter examines the basics of the virtual currency concept and compares it to traditional currencies. Also impact on the international financial system is described. The second subsection focuses on high level how Bitcoin transactions work including how transactions are initiated and processed on the blockchain and how this technology works. After this, next subsection provides an overview of Bitcoin mining process in briefly, the process where new bitcoins are created, and transactions are confirmed. Finally, the following subsection analyses the factors that affect Bitcoin's value creation, such as market demand and technological innovation. Bitcoin price fluctuations and market dynamics are also explained. After this, also risks and uncertainty relating to Bitcoin are demonstrated briefly. This thesis focuses to explore the hedging capabilities with green bond and gold against Bitcoin market. Consequently, it is also relevant to present a concise theory and overview of the fundamental principles relating to Bitcoin.

3.1 Virtual currency

Virtual currencies are digital form of money which are often using blockchain technology for secure, transparent, and fast transactions. The first recognizable virtual currency was Bitcoin, but in 2018 there were already lots of different virtual currencies, approximately more than 1,500. Virtual currencies are globally operated currencies which means that people are able to purchase them in different places disregarding national borders (Dabrowski & Janikowski, 2018). Another definition for virtual currency is a digital currency which is used as a medium of exchange and store of value, but it is not having legal tender status and is not guaranteed by any government (FATF, 2014). In the beginning of 2020, there was already over 5,100 different crypto currencies with a total market capitalisation over 250 billion US dollars which also indicate their high demand (Houben & Snyers, 2018).

The European Central Bank (2012, p. 13) defines Bitcoin as a virtual currency, a form of digital money that is unregulated and controlled by developers. Bitcoins are generally kept in digital wallets, which are vulnerable to hacking. Consequently, Bitcoin is characterized by higher volatility compared to traditional fiat currencies and is more likely to experience speculative bubbles (Grinberg, 2012). Conversely, Bitcoin offers its users protection and anonymity through cryptographic pseudonyms, because virtual transactions are nearly anonymous (Mardi & Howlader, 2022). Bitcoin is also sharing some similar features comparing to gold as both of them are having maxing amount which is available and both of them have the absence of counterparty risk (Baur et al., 2017). However, Bitcoin ecosystem is substantially different comparing to gold as Bitcoin's regulatory system is different. Also, Bitcoin is having lower liquidity and much higher and stronger volatility when comparing to gold (Bridgewater, 2021).

3.2 Bitcoin transactions

Nakamoto (2008) wanted to create an online payment system that would completely eliminate a trusted third-party in the transaction. Before Bitcoin, direct virtual transactions between two parties were not possible without involving a trusted third party, typically a payment service, to prevent double spending (Brito & Castillo, 2013). Bitcoin uses an automatic algorithm and therefore do not need any bank services (Reid & Harrigan, 2013). Using the blockchain technology it was solved the so-called double-spending problem (Brito & Castillo, 2013). This means that the recorded entry, which has been successfully posted to the blockchain, cannot be used twice in the payment. The history is stored on a Peer-to-Peer network and can be downloaded by anyone. When using Bitcoin, the record of the past transactions serves as the only method for verifying whether a previous transaction has taken place or not (Reid & Harrigan, 2013).

The key purpose of Bitcoin is to offer its users the ability to transfer a payment directly from one party to another irrevocably and without the involvement of the financial institution and thus reduce the transaction costs included in the fee in e-commerce (Nakamoto, 2008; Reid & Harrigan, 2013). In cross-border payments in particular, the speed and cost-effectiveness of virtual currencies have been highlighted (He, 2018, p. 14). Ultimately, payment becomes so-called cross border, only when the virtual currency entry is exchanged for FIAT-money in the destination country. Because Bitcoin is not issued through central government and its protection does not make it possible to collect taxes, it lacks one factor that stabilize the value of the currency and prevents the escape of deposits (Dwyer, 2015).

Bitcoin’s current goal is to act as a custodian of the payment system and value (Floyd, 2024). In blockchain technology, the foundation of transaction record-keeping lies in the Public Key Infrastructure (Keskitalo, 2022, p. 48). The public key specifies the address of the account where the transactions associated with that individual or account are recorded. Additionally, each blockchain involves a private key, which grants the authority to modify the transaction records linked to the corresponding public key (Keskitalo, 2022, p. 48). Bitcoin ownership is confirmed through a digital signature that relies on the owner's private key, proving their control over the Bitcoin. When the ownership of bitcoin currency is transferred to another, the previous owner digitally signs the transaction details, including information about the prior transaction and the new owner. This signed information is then added to the coin's transaction history. (Nakamoto, 2008). The recipient has the ability to authenticate the signatures to confirm the complete history of ownership. Due to the digital signature the sender does not need to give private key to other users (Reid & Harrigan, 2023). This establishes the basis for two separate network structures: the transaction network, which tracks the movement of Bitcoins between transactions over time, and the user network, which shows the transfer of Bitcoins between users over the same time period (Reid & Harrigan, 2013).

3.3 Mining of Bitcoin

Bitcoin are produced by a process called mining. Mining allows new transactions to be added to the to the block chain and at the same time produce new bitcoins. New bitcoins are formed through mining, which means solving computationally challenging puzzles (Newman, 2017). Mining takes place on the user`s powerful computers that solve mathematically challenging problems (Frankenfield, 2021). These problems cannot be solved by hand, and they require a lot of resources even from the most efficient computers. The task is to create bitcoins and make the Bitcoin network reliable and secure by accepting transaction information (Frankenfield, 2021).

Bitcoin mining process can be compared to gold mining as there is also limited supply of Bitcoin (Bouri et al., 2020). In mining the certification of a new block in the block chain gets a block premium. The block premium is halved every four years. The maximum supply of Bitcoin is limited and should not exceed 21 million units (Newman, 2017). The blockchain's decentralized ledger contains all the transactions performed over the network or in the blockchain it can't happen relevant transfer operations between the parties unless they are recorded in the block chain. In practice, this means that every miner, who is an involved with a block chain, has the contents of the entire blockchain database recorded, from the first entry (Hazen, 2019).

3.4 The value formation of Bitcoin

The market value of Bitcoin is determined by supply and demand (Brito and Castillo 2013, p. 4). Additionally, Bitcoin's exchange and value formation are enhanced by its global accessibility, enabling anyone to buy it and conduct transactions of any size, from very large to extremely small (Brito & Castillo, 2013, p. 5). This makes Bitcoin trading flexible, and its value can fluctuate significantly. Unlike physical assets, Bitcoin's value is not derived from anything tangible, making it resistant to prevention, destruction, or seizure (Ammous, 2018). A currency is considered functional if it can maintain its value over time (Kelleher, 2021). The characteristics of a functional currency include scarcity, divisibility, acceptability, portability, durability, and uniformity (Hill, 2013). Bitcoin’s volatility has been stronger than that of regular currencies, making it difficult to consider Bitcoin as a stable currency and preventing it from meeting the economic definition of money (Yermack, 2013, p. 2).

Bitcoin's supply is predetermined and limited, which is why it has the potential to serve as a store of value (Ammous, 2018). Bitcoin has also demonstrated authorities' inability to alter its supply schedule. While Bitcoin was originally designed to act as a means of payment and a store of value, its practical use often leans towards investment purposes (Spithoven, 2019, p. 385-386). In addition, 10 million users hold a significant amount of bitcoin as a speculative financial asset (Hileman & Rauch, 2017). Nevertheless, Bitcoin's primary feature lies in its ability to foster trust without centralized management (Huberman et al., 2017). Huang (2020) writes that, Bitcoin has been described as a surprisingly stable investment especially during political and economic crises. This partially resembles the gold standard. Bitcoin has also been referred as virtual gold by Dyhrberg (2016). The protective effect of the portfolio of gold and also Bitcoin is supported by the fact that central banks do not control the production of gold or Bitcoin (Dyhrberg, 2016, p. 142). Bitcoin and gold are also linked by the fact that they are both limited in quantity and the mining of both is slowing down the closer they get the roof (Reid & Harrigan 2013).

As said above the supply of Bitcoin is limited, as the total amount of Bitcoins will never exceed the 21 million units, projected to be reached in 2140 (Hayes, 2024). Bitcoin’s rapid appreciation has made it more widely known to investors as a speculative investment target (Hileman & Rausch, 2017). Baur et al. (2018, p.178) examine Bitcoin's use, suggesting that it serves mainly as an alternative currency or as a speculative investment instrument. Their study show that reason is mostly driven by Bitcoin’s high volatility and potential for substantial returns. Bitcoin had invested up to 1,39 trillion dollars' worth of money (Reif, 2024). In early 2021, Bitcoin broke the all-time high record on several occasions and tripled its value from where it had peaked (Edwards, 2024). In early 2024 did it again with 69,1919.95 dollars partly because of the approval of spot bitcoin ETFs (Nquyen, 2024). After that the exchange rate has fallen to around 55,860.29 US dollars and is now increased to 64,794.97 US dollars on 15 of July 2024 (CoinDesk, 2024). This also tells how volatile and rapidly changing investment instrument Bitcoin is. Furthermore, some institutional investors have also started to invest in crypto assets, especially to Bitcoin. Typically, these investors have higher risk tolerance and a long investment horizon. However, institutional investors share of all Bitcoin investments are still relatively small, approximately 5 percent of total issued Bitcoin. (Karniol-Tambour et al., 2022)

3.5 The risk and uncertainty of Bitcoin

The one main uncertainty and risk associated with Bitcoin is relating to its value formation. According to Baur and Dimpfl (2021) Bitcoin is having difficulties to use as currency due to its very high volatility. The significant price fluctuations make its effectiveness as stable medium of exchange. Their study demonstrates that because of Bitcoin's excess volatility Bitcoin is challenging instrument to use as a risk-diversifier in portfolios. Bitcoin's uncertainty is also significantly affected by whether it is used as an alternative currency or speculative investment (Baur et al., 2017). Their study results indicate that Bitcoin is primarily used as a speculative investment and reason is mostly attributed to its significant volatility and potential for substantial returns.

Bitcoins means of avoiding panic are also associated with the safety of Bitcoin exchange. Bitcoin exchanges are themselves responsible for any security system and the source code of the software they use. The poor security of trading venues has allowed hackers to steal bitcoin over the years (Mcmillan, 2014). Up to 1.1 million bitcoins have been stolen in the five-year period 2013-2017 (Grobys, 2020). The lack of regulation and enforcement may have attracted scammers and miscreants (Maume, 2020). Hileman and Rausch (2017, p. 37) indicate that around 73% of cryptocurrency exchanges retain control over the private keys of their clients, rendering them potential targets for cyberattacks. To mitigate such risks, nearly 90% of exchanges employ cold storage methods, where private keys are maintained offline. This makes it harder for potential cybercriminals to access the keys.

Blockchain technology has evolved significantly since Bitcoin was introduced in 2008 (Koksal, 2019). Greater transparency, increased efficiency, improved security, and improved traceability are blockchain technology’s greatest benefits. However, alongside these advantages, new risks also appear. According to Kethineni and Cao (2019), also many criminals, including drug traffickers and extortionists, use bitcoin as they allow hiding behind privacy and anonymity. Evidence from studies shows that nearly a quarter of users and nearly half of all Bitcoin transactions are associated with illicit activities. (Foley et al., 2019).

4 Green Bond

Green bonds are financial instruments specially designed to support projects which are beneficial to the environment and the climate. This chapter aims to offer a comprehensive overview of key aspect of green bond and its role in the field of sustainable finance. The chapter begins with examine the urgency of the global challenge of climate change and how green bonds can act as solutions for mitigating the climate crisis. Additionally, some other relevant aspects are mentioned briefly. The second subsection focuses on the Paris Climate Agreement, which is an international agreement dedicated to limit global temperature rise and climate change. The aim is also to give high level overview of the Paris Climate Agreement and how it is linked to green bonds. This is important aspect as the popularity of green bonds has also increased after signing and the implementation of the Paris Climate Agreement (Quinson & Benhamou, 2021).

The third subsection focus on the principles of sustainable and responsible investing (SRI). The chapter is presenting the framework relating to sustainable finance and how possible environmental, social and governance (ESG) matters are considered in investment choices. Additionally, the discussion also covers the role of climate bonds in this context. After this next part of chapter is relating to the historical development of green bonds and their position in the financial market and their impact on the market. Also, in this subsection is provided more in-depth information on the principles of green and social bonds briefly. Moreover, the last subsection is focusing to describe in high level some risks and uncertainties which are associated with green bond.

4.1 Climate change

The impact of human activities on global warming is one of the greatest global crises, adversely affecting people and the environment around us (WWF.fi, 2024). Climate change and environmental deterioration have been identified as critical concerns by governments and international institutions. Over the last 15 years, there has been a collective effort by national governments, international organizations, and various sectors to implement cleaner and more efficient production practices to mitigate greenhouse gas (GHG) emissions (Yahya et al., 2020). For this reason, considerable financial resources have been allocated to cleaner energy solutions, which has led to the development of a significant new industry focused on sustainable energy. The primary strategies of mitigating climate change are the abandonment of fossil fuels, the use of sustainable renewable energy sources, energy efficiency, the electrification of transport, halting, deforestation, increasing natural carbon sinks and sustainable production and consumption of imports (WWF.fi, 2024).

Climate change has become a huge concern among everybody. Consumers increasingly prefer environmentally friendly products and services, driving businesses to prioritize sustainability (Schaltenbrand et al., 2018). In today's business landscape, corporate environmental investments are monitored and judged by many stakeholders. As a result, companies must pay attention to these concerns. Top management has been found to play a significant role in how companies make green investments (Schaltenbrand et al., 2018, p. 1144). That emphasise the importance of leadership in fostering sustainable practices within organizations. The eligible Green Projects encompass a diverse range of categories aimed at promoting sustainability and environmental responsibility (ICMA, 2021). Key categories include renewable energy projects, such as production and transmission, as well as energy efficiency efforts, like building refurbishments, energy storage, and smart grid development.

4.2 The Paris Climate Agreement

The Paris Climate Agreement, adopted on December 12, 2015, is a global agreement, aimed at slowing down climate change. The European Union has set a goal, supported by its member countries, to achieve climate neutrality across its economy and society by 2050 as first continent in the world (European Commision, 2024a).

The goal of the Paris Climate Agreement is to rapidly lower global greenhouse gas emissions. The agreement aims to ensure that human-caused greenhouse gas emissions and the sinks that absorb these emissions in the latter half of this century (Ministry of the Environment, 2024). In 2020, the EU presented its long-term emission reduction strategy and updated climate plans (European Commision, 2024a). The EU is committed itself in the Paris Climate Agreement to reducing CO2 emissions by at least 40%, increasing renewable energy by at least 33% and increasing energy efficiency by at least 32,5 % by the year 2030 (Europe Commission, 2024b). All parties to the agreement are expected to take even more ambitious and stricter actions over time to lower emissions, adapt to climate impacts, and improve both operational effectiveness and transparency (Ministry of the Environment, 2024). For example, water, wind, ocean and solar energy are alternative renewable energy sources to fossil fuels. Green investment in renewable energy, public transport, sustainable construction, energy efficiency and waste management are one of the key factors in addressing climate change (Europe Commission, 2018).

These bonds have the crucial role in supporting the financial mechanisms which are required to fulfil the targets established by the Paris Climate Agreement. According to Tolliver et al. (2019) green bond market is substantially growing, and more investors' money is allocated to them. Increasing amount of investments are allocated to renewable energy and clean water which are supporting the goal of the Paris Climate Agreement and sustainable development. This is also helping with low-carbon transportation. However, in the recent past it was more popular to favour fossil fuel industry investments comparing to green projects. According to Quinson and Benhamou (2021) from 2014 to 2020 green project did not receive so much financing comparing to the fossil fuel industry. After signing of The Paris Climate Agreement, the share of green projects started to rise quickly and finally in 2021 their amount was bigger. This also highlight synergy between green finance, particularly green bonds, and the Paris Climate Agreement. Green bonds are providing a structured and appealing approach for investors to fund climate-positive projects which is at the same time helping to reach the goal of The Paris Climate Agreement.

4.3 Sustainable responsible investing

One of the most widely accepted definitions of sustainable development comes from the Brundtland Commission (1987). They defined it as progress that satisfies current needs without undermining the capacity of future generations to meet their own (the Brundtland Report, 1987). Sustainable financing plays a significant role in climate change and sustainable development. Sustainable financing is about financial instruments that emphasize perseverance and environmental, social and the involvement of administrative factors in investment decisions (Brinkman, 2009, p. 136-137). It has been found that economic growth and sustainable are closely related for as the economy grows, so do emissions. The purpose of sustainable financing aims to promote economic growth in a sustainable way by reducing greenhouse gas, emissions, and pollutions, minimizing waste of striving for better resource efficiency (EuroSIF, 2018).

The growing importance of sustainability is prompting investors to shift towards green investments. In the light of research data, green and responsible investing appears to be a profitable option that does not require compromising returns (Bodhanwala and Bodhanwala, 2019). Silvola and Landau (2019) highlights the demand from corporate shareholders as a significant driver of responsibility and green investment. They are now forming portfolios that include eco-friendly companies (Dutta et al., 2020a, p. 1). Silvola and Landau (2019, p. 21) conclude that responsible investments tend to perform better in the long term and has a lower risk. Numerous academic studies have examined the correlation between clean energy stocks and various financial assets, including crude oil and other markets (Dutta et al., 2020a). These firms, known for producing and supporting environmentally friendly goods and services, are gaining popularity. Green investments or environmental assets have become of paramount interest to market participants (Dutta et al., 2020a, p. 1). When a company is listed on an exchange, an environmentally responsible company is valued higher. Moreover, investing in ESG-rated companies has been shown to yield excess returns (Silvola and Landau, 2019). Schaeffer et al. (2012) argue that eco-friendly firms have recently garnered significant attention from investors, policymakers, and society for their green services.

Due to rising environmental concerns, numerous eco-friendly investment opportunities have emerged, such as green and climate bonds (Dutta et al., 2021). Climate bonds are particularly attractive to long-term institutional investors who prioritize a low-carbon economy. These investors are less likely to liquidate their climate bond holdings during market turbulence, suggesting that climate bonds are resilient during periods of economic uncertainty, such as the COVID-19 outbreak (Dutta et al., 2021). This resilience indicates their potential as effective diversifiers and hedges against the downside risks of stock and commodity markets during market turmoil periods. Climate bonds differ from green bonds, which are designed to fund both environmental and climate-friendly projects (Dutta et al., 2021). Climate bonds encompass a broader range of investments but follow stricter selection criteria. They can include climate-aligned bonds that are not labelled “green” but are issued by companies generating over 95% of their revenues from climate-aligned projects (Dutta et al., 2021).

4.4 The history of Green Bond

The concept of green bonds and the idea of the green bonds was initiated by a number of Swedish pensions funds in late 2007, seeking to invest in climate-friendly projects (World Bank Group, 2019). They approached SEB Bank, which took over the matter together with the World Bank. In November 2008, the World Bank and SEB were the first institutions in the world to issue a green bond. The bond raised funds from fixed-income investors to finance loans for projects focused on addressing climate change (World Bank Group, 2019). Norwegian CICERO provided an independent evaluation, and this practice laid the foundation for the principles of green bonds. The first green bonds issued by companies were published in 2014, and at the same year was introduced the Green Bond Principles, currently supervised by ICMA (Reichelt & Keenan, 2017).

Early research considers a notable “green premium” or “greenium”, in green bonds compared to conventional bonds (Ehlers & Packer, 2017). Later studies have explored the relationship between green bonds and financial markets to glean insights into their potential for portfolio diversification and hedging. However, the academic literature on the relationship between climate bonds and financial markets remains underdeveloped (Dutta et al., 2021). As climate bond become increasingly popular among environmentally conscious investors, there is significant potential to enhance and expand this field of research.

4.4.1 The Green and Social Bond Principles

Green Bond Principles (GBP) were established by the International Capital Market Association in 2014. GBP is a voluntary and self-regulatory statute that issuers of green bonds may choose to comply with. The Green and Social Bond Principles have established the global benchmark for a $5 trillion market, representing the primary source of financing dedicated to sustainability and climate transition. These principles are followed internationally by corporations, financial institutions, and governments (ICMA, 2024). In 2024, these principles have been referenced in approximately 98% of sustainable bonds issued worldwide (ICMA, 2024). The market comprises four distinct categories of green bonds: Standard Green Use of Proceeds Bond, Green Revenue Bond, Green Project Bond, and Green Securitized Bond (The Green Bond Principles, 2021).

The Green Bond Principles (GBP), along with the Social Bond Principles (SBP), the Sustainability Bond Guidelines (SBG) and the Sustainability-Linked Bond Principles (SLBP) are regulated by the ICMA and are known as “the Principles” (The Green Bond Principles, 2021). These voluntary frameworks aim to enhance the role of global debt markets in advancing environmental and social sustainability. The mission and vision of the Principles are to promote the use of debt capital markets to finance sustainable development initiatives worldwide. Green Bonds are financial instruments where the capital raised is allocated fully or partially to the financing or refinancing of new or existing green projects that meet specific eligibility criteria in accordance with the principles established by the GBP (The Green Bond Principles, 2021). The Green Bond Principles (GBP) provide a set of voluntary guidelines designed to enhance transparency and disclosure, aiming to promote integrity the credibility of the Green Bond market by establishing a structured approach to Green Bond issuance.

4.4.2 The Green Bond market and investments

When gold has been valued for millennia, green bonds in their current form were first issued by the World Bank and SEB in 2008, the same year that Bitcoin was released (World bank Group, 2019; Bouri et al., 2017b). Green Bonds are classified as bonds to finance projects that contribute to environmental and climate goals (Dutta et al., 2021). The green bond market has surged from less than $4 billion in 2012 to nearly $600 billion in 2023. Investor interest in social and sustainability-linked bonds has significantly increased this expansion, pushing total global green bond issuance to over $871.6 billion (Climate Bonds Initiative, 2024). Despite its growth, green finance remains just a small part of the overall global finance market (TheCityUk, 2022). Green bond indices allow investors to easily evaluate the performance of green bonds in relation to other financial investments (Climate Bonds Initiative, 2017). Introduced in 2014, the Bloomberg Barclays MSCI Global Green Bond Index was designed to provide a reliable reference point for the green bonds market (Statista Research Department, 2024).

Green bonds have gained significant global attention from issuers and investors due to the rising interest in environmentally sustainable projects (Bouri et al., 2021, p. 1). Although they carry credit risks similar to conventional bonds, studies like Ehlers and Packer (2017) indicates the presence of a “green premium” associated with green bonds. Green bonds show resilience during times of market stress for several reasons. First, the market mainly includes long-term institutional investors, including pension funds and international organizations like the European Investment Bank (Ehlers & Packer, 2017). These investors typically hold green bonds until maturity rather than selling them during market crises (Bouri et al., 2021, p. 2). Additionally, the demand for green bonds from environmentally driven funds offers extra protection against market sell-offs. Lastly, many green bond issuers are large, financially stable organizations with strong governance, which enhances their resilience during market crises. Unlike conventional bonds, green bonds are rarely issued by industries like oil, which are particularly vulnerable during financial market downturns (Bouri et al., 2021, p. 2).

4.5 The risk and uncertainty of Green Bond

In a green bond, as in a traditional bond, the primary risk and uncertainty can be considered in credit risk and the possibility that the issuer will not repay the invested capital back to the investor. Green bonds issued in the local currency of countries or companies with high credit ratings are considered as the most secure (Vaihekoski, 2020, p. 14). The Green Bond Principles (2021) emphasizes the importance of transparency and openness in the green bond market. They recommend that issuer use an external and independent evaluator to verify the bond's green credentials. Companies such as Morningstar Sustainalytics and CICERO, as well as credit rating agencies including Moody's and Standard & Poor's, provides evaluations for green bonds. The Climate Bond Standard certification is the only classification that is fully in line with the Paris Climate Agreement (Climate Bonds Initiative, 2024). To minimize risk, investors can rely on these ratings and certifications, which provide critical assurance and confidence for investors in the green bond market.

As the clean energy sector expand, the demand for raw materials needed to manufacture clean energy solutions increases accordingly (Gustafsson et al., 2022). This heightened demand may lead to cause significant changes in the price and overall market dynamics of these energy metals, impacting their relationship with clean markets. Understanding this relationship is essential for mitigating the risks associated with clean energy investments. Since clean energy stocks represent a relatively recent addition to the varieties of asset classes, they often exhibit substantial market volatility (Gustafsson et al., 2022). Therefore, it is essential for environmentally conscious investors to learn how to diversify and hedge the potential risk associated with clean energy indices (Ahmad et al., 2018).

The rapid expansion of the green bond market has increased its vulnerability to "greenwashing" (Dutta et al., 2021). The variability in definitions of environmental responsibility and wide scope of interpretation can expose green bonds to the risk, potentially diminishing investor confidence. As the green bond market has rapidly grown and attracts diverse types of issuers, one of the significant risks for investors and sustainable finance is greenwashing. Greenwashing occurs when companies are reporting positively about their environmental activities, while their actual environmental performance is poor (Delmas & Burbas, 2011). These practises can mislead investors and consumers, highlighting the importance of relying on robust certifications and evaluations to ensure the authenticity of green bonds.

5 Volatility estimation

Since understanding volatility is essential to many sectors of the economy, financial research has looked at its significance in great detail. Volatility, for instance, is a crucial component that influences decision-making in risk management and option pricing. Because of the close connection between volatility and the unpredictability of the financial markets, investors and corporate executives must have a thorough understanding of the concept of volatility and how volatility acts in various markets (Poon & Granger, 2002). In this study main focus area is in understanding the volatility and hedging properties between gold, green bond and bitcoin so it becomes essential to establish a basic understanding of volatility estimation. At first, it is crucial to understand the fundamental ideas and procedures behind the idea of measuring volatility. This chapter also seeks to clarify these core principles and techniques to provide a comprehensive understanding of the subject.

Economic research has consistently identified several key characteristics in the volatility of financial markets. Notable features include the tendency for volatility to cluster in specific periods, its mean-reverting behaviour, and the presence of heavy-tailed distributions. Unlike financial returns, which are relatively straightforward, volatility follows a stochastic and less predictable process. Hull (2015, p. 521) highlight that the intraday fluctuations in volatility are substantially high because of the stochastic movement, and this influence becomes even large following market turbulence and bad news. Nevertheless, academics have successfully estimated volatility when used a short enough observation frequency and a robust dataset. (Poon & Granger, 2002).

In this chapter first original ARCH model is explained in detail. Following this, the chapter transitions to discussing the GARCH model, with a brief mention of the related extensions and variants of GARCH models. Also, relevant equations are presented and explained. These presented ARCH and GARCH models are giving the foundation level for the used methodology which is explained in the upcoming chapter.

5.1 ARCH models

One of the earliest formal propositions to measure and model volatility in time series is ARCH model which refers to autoregressive conditional heteroskedastic process. Engle (1982) initially introduced the ARCH model in his study. In the ARCH process, financial time series are modelled with the assumption that the mean, μ, remains constant over time, while the variance of the returns, σ^2, is the key variable. The return, in this framework, is characterized in the next presented way.

$$r_t = \mu + \varepsilon_t, \tag{1}$$

In formula r_t represents the return at time t, which is defined by a constant mean μ and a stochastic error term or a shock parameter ε_t. The error term is presented as following way

$$\varepsilon_t = \sigma_t z_t \qquad z_t \sim i.i.d\ (0,1) \tag{2}$$

In this formula, Z_t denoted as IID, refers to an independent and identically distributed standard normal variable, $Z_t \sim (0, 1)$ and σ_t are representing a time-varying standard deviation that scales the innovation Z_t. This structure described in the formula enables the ARCH model to respond to the impact of new information or shocks on the return process the variability of $\sigma_{t.}$ Last mentioned parameter refers to stochastic. The conditional volatility of the time series is represented by the ARCH process using the formula below

$$\sigma_t^2 = \omega + \Sigma_{i=1}^{q}\ \alpha_i\ \varepsilon_{t-i}^2 \tag{3}$$

Parameter σ_t^2 represents at time t the conditional variance, while ω is a constant ensuring a positive long-term variance, and α_i is coefficient which is quantifying the impact of squared residuals from earlier periods. Every coefficient αi is defined to be non-negative ($\alpha i \geq 0$) and the number of lag error terms in the model is indicated by the parameter q.

By examining the relationship between current volatility and historical return and error levels, the ARCH(q) model, presented in equation 3, effectively captures the evolving nature of volatility. This model highlights how past information influences the dynamic changes in volatility that occur over different periods of time. This same model differentiates between the usual, baseline volatility and the increased volatility affected by shock up to q number of lags, allowing for precise predictions of future volatility from historical data. As mentioned, the ARCH model provides a robust framework of tool for predicting future volatility based on the history series of observed past financial information, offering insights for financial risk management and trading strategies. Next subsection is presenting the GARCH model which is built upon the foundation of the ARCH model.

5.2 GARCH models

After groundbreaking ARCH-model by Robert F. Engle (1982) more advanced models have been published to diminish some limitation which occurred in ARCH-model. Bollerslev (1986) presented generalized autoregressive conditional heteroskedasticity (GARCH) model, providing broader and a more comprehensive framework for analysing financial time series data and expanded the scope of volatility modelling. One significant finding from GARCH model is including lagged conditional variances and also considering the lagged squared residuals. For GARCH model, it is possible to capture more complicated and longer-lasting volatility patterns because of this feature. This allows GARCH-model to be more flexible to use and realistic model for analysing financial time series where volatility shocks can have a longer-lasting effect or have volatility clustering. The GARCH model, often called the GARCH(p,q) model, allows for the analysis of both past conditional volatility and past squared residuals. While the return regressions in the earlier mentioned ARCH(q) and the GARCH(p,q) models are the same, the GARCH(p,q) model is described by the following mathematical formula.

$$\sigma_t^2 = \omega + \Sigma_{t=1}^{q} \alpha_j \varepsilon_{t-1}^2 + \Sigma_{t=1}^{\mathrm{p}} \beta_j \, \sigma_{t-1}^2, \tag{4}$$

Where the parameters ω, α_j and β_j are limited by the rule ω > 0, α_j ≥ 0, β_j ≥ 0 and α_j + β_j ≤ 1. Parameter q symbolize how many past squared residuals are included in the model, while p denotes the number of lagged variances included in the model. When p = 0, the model simplifies to the ARCH(q) model. Additionally, β_j describes how past conditional variances affect the volatility observed in future periods.

This described model has been broadly used and adopted in both academic researchers and practical applications by institutions because of its capability in analysing financial market dynamics. The GARCH is known for its capability to model both positive and negative financial shocks. What makes this more difficult to analyse in detail level is that conventional GARCH-model understand these shocks symmetrically without regard to their directional impact. This model is only estimating the magnitude of effects from positive and negative shocks and fails to identify the sign of shocks (Brooks, 2014). This finding has urged further research for different kind of extended GARCH models address the deficiencies of the original model. For instance, Nelson (1991) introduced the exponential GARCH (EGARCH), which makes easier the modelling of the logarithm of variance, thereby enhancing the model’s response rate for asymmetric shocks. Additionally, Engle and Ng (1993) developed the quadratic GARCH-model (QGARCH). This model has many useful features comparing to the conventional GARCH. Its significant capabilities are not only relating to capture the asymmetric effects of conditional variance but also include higher moments such as kurtosis, thereby benefit financial time series analysis. The QGARCH model extends this highlighted approach also to be used to both univariate and multivariate scenarios and could provide more details in volatility analysis. Another approach is the threshold GARCH (TGARCH) model discovered by Zakoian (1994) This model’s benefit comparing to the standard GARCH model is broader volatility equation to include an additional parameter that could capture the asymmetric impact of negative shocks. This can be achieve using an indicator function that can divide positive and negative shocks.

There are plenty of significant extensions and variants of GARCH models that are relevant in financial econometrics. Sometimes some variants address same fundamental issue but are slightly different and named differently by their inventor. Another approach of GARCH model is the GJR-GARCH model which was developed by Glosten et al. (1993). That model is similar to the TGARCH model, but it's made slightly different formulas relating to the leverage effect and uses of the indicator function. Additional relevant application of GARCH model is in analysing how volatility is transmitted between different markets. This means understanding how news and shocks in one market can create volatility which can also induce volatility in other markets. There are also specific GARCH-models which can evaluate both the impact and the extent of this volatility transmission effect. This effect refers to the phenomenon where fluctuations in volatility from one financial market or asset are transferring to another. For instance, for methodology of this thesis is the dynamic conditional correlation GARCH-model (DCC-GARCH) used. A more comprehensive examination of the DCC-GARCH model will be provided in the chapter data and empirical methodology. Other useful GARCH-models which are capable to determine volatility transmission effects are for example BEKK-GARCH and VAR-GARCH. BEKK-GARCH was originally proposed by Engle and Kroner (1995), and it was developed from Baba et al. (1990) earlier work. This method is another way to capture volatility spillovers and also estimate time-varying covariances and correlations among different time series. Like these methods, also the vector autoregressive GARCH (VAR-GARCH) is multivariate GARCH-model and can model interdependencies of volatilities and covariances between different financial markets. The concept of VAR-GARCH was elaborated by Engle and Kronor (1995) but properly developed later by Ling and McAleer (2003). However, for this study's methodology DCC-GARCH is used due to computational efficiency and hedging effectiveness of DCC-GARCH comparing to these other models (Lin et al., 2014; Dutta et al., 2021)

6 Data and empirical methodology

The forthcoming sections of this thesis will conduct an empirical analysis of the performance of green bond, gold and Bitcoin. This approach will highlight the financial behaviours and market dynamics of each of these instruments. First, these assets daily price movements are presented and their summary statistics for price series with relevant parameters. After that, same assets daily returns are shown from the same time period including also summary statistics for logarithmic return series. These results are tested with Augmented Dickey-Fuller and Philips-Perron and also with Jarque-Bera stationarity tests to indicate if findings are reliable and accurate. Moreover, in this chapter definitions for the used data and used methodology are clarified with many required equations. Also, all equation's parameters are explained in detail. Equations are relating to e.g. logarithmic return, mean, volatility, volatility transmission and also to dynamic conditional correlation between specific assets.

6.1 Data description

The empirical analysis in this study comprises daily price data for MSCI green bonds, gold, and Bitcoin. These daily prices are converted into logarithmic returns to measure the changes in the value of an asset over a time. The primary sample period spans from January 2, 2015, to March 24, 2022. Another sample is including only COVID-19 period and excluding pre-COVID period, so this period begins on 3rd February 2020 and ends on 24th March 2022. In this thesis data samples are presented in the following way:

The main sample population I: The whole data period (1/2015 - 3/2022)
Sample population II: COVID-19 period (2/2020 - 3/2022)

In the whole data set, there are 1813 daily observations per instruments. The idea for this data set is to observe different movements from these instruments from longer time period. It is consisting also COVID-19 crisis period and also the beginning of Ukraine war. Sample population II contains 540 data observations per every instrument and excluding pre-COVID-19 period. Idea to use two different data sets is to observe two data sets and compare is there differences between their DCC-GARCH models and ADCC-GARCH models and try to analyze if there are possible differences. Sample population II is used only for DCC-GARCH and ADCC-GARCH model tables and otherwise the main sample population I is used. Figure 1 illustrates the price developments of MSCI green bond price, gold instrument price and Bitcoin instrument price over the observation time period.

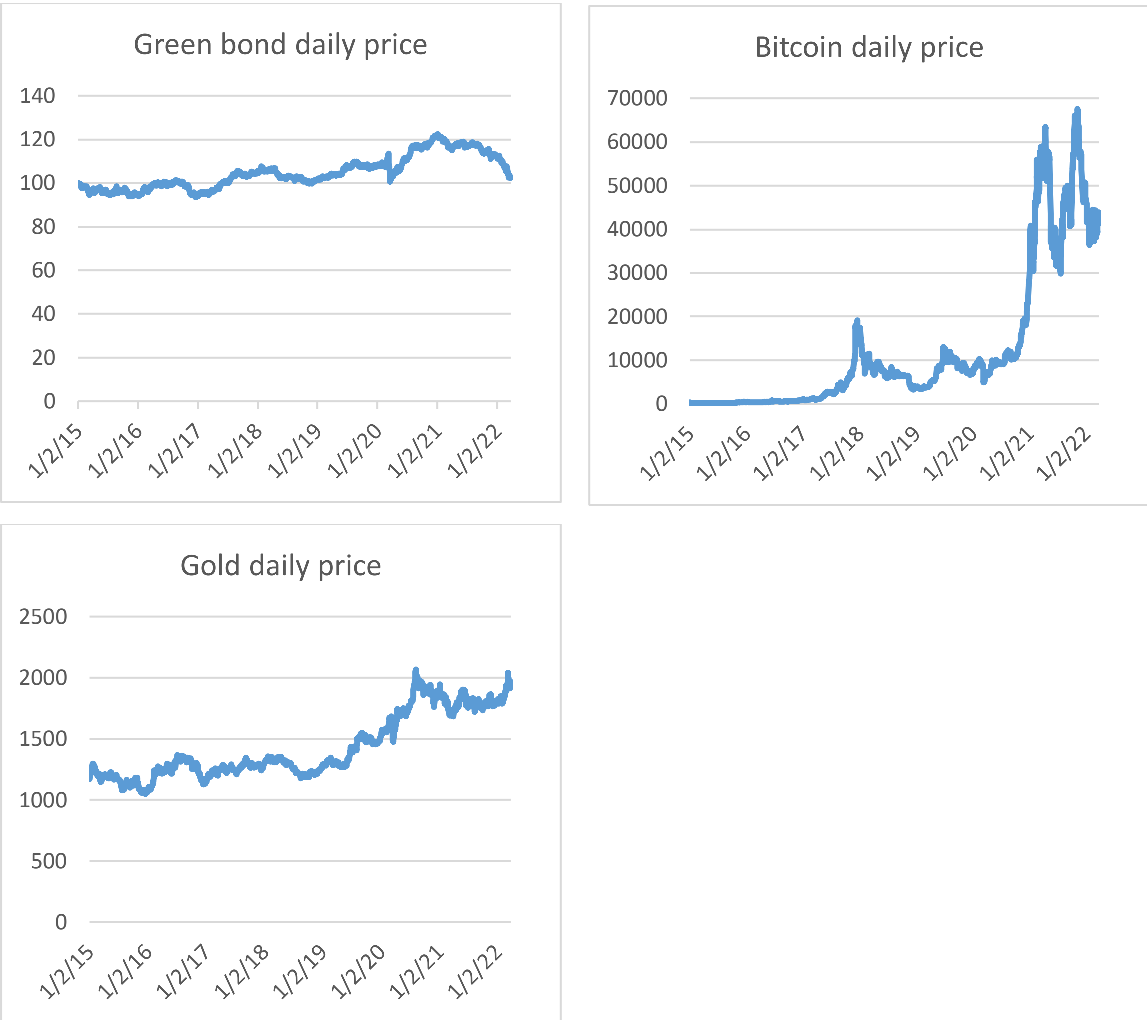

Figure 1: Price development of Green Bond, Bitcoin and Gold daily prices.

As illustrated in figure 1, the data reveals that throughout the years covered in this study, we can notice that the daily return of green bond have remained relatively consistent across the observation period. This sounds logical, because it is understandable that the green bond instrument behaves like this, and it shows only small changes in the daily return. Next, when we are looking for changes in gold daily return, we can observe slightly larger changes during the entire review period, but still quite moderate changes. This is explained by the fact that the price changes in gold daily return are also usually quite low. When we next observe the changes in the daily return of Bitcoin, we can notice significant changes. At the end of 2017, the value of Bitcoin increased to nearly $20,000 before a beginning a downward trend. The high volatility in the price of Bitcoin can also be seen when its price surged to nearly $69,000 in November 2021, followed by a sharp decline. From these three tables, it can be noted that the prices of these instruments vary greatly among them.

The summary statistics for green bond, gold and Bitcoin relating to their price series are included in the table 1 below for the whole data period (1/2015-3/2022). Comparing these different standard deviation values, Bitcoin is much more volatile than gold or green bond. This sounds reasonable as Bitcoin is known for its highly volatile nature, characterized by rapid price fluctuations over short periods. The daily price series for all these instruments exhibit positive skewness, indicating that each distribution has a long right-hand tail. Among these, Bitcoin's skewness is strongest when comparing the results. This means that there are many high price observations in data that are pulling the mean towards the right side of the distribution. This cause distribution highly asymmetrical. Green bond and gold have a negative kurtosis value which mean that the distribution of green bond price and gold price are flatter than a normal distribution. Bitcoin has positive kurtosis which suggests that the distribution of Bitcoin prices has heavier tails and sharper peak comparing to a normal distribution. To further assess the normality of the distributions, Jarque-Bera tests were performed. For all three assets, the Jarque-Bera test results indicate that all assets are following non-normality distribution pattern. Bitcoin's Jarque-Bera test result is substantially higher comparing to others, suggesting that the distribution of Bitcoin prices significantly deviates from a normal distribution. This result is consistent with the high skewness and kurtosis values relating to Bitcoin which is indicating the non-normality of Bitcoin's price distribution.

Table 1. Summary statistics for price series of Green Bond, Bitcoin and Gold.

Price	Green bond	Bitcoin	Gold
Mean	104.79	12141.02	1428.60
Median	103.53	6580.63	1308.35
Standard Deviation	7.53	16512.93	264.34
Kurtosis	-0.76	1.67	-1.01
Skewness	0.544	1.708	0.689
Minimum	93.55	178.10	1049.40
Maximum	122.31	67566.83	2067.15
Jarque-Bera	133.00 (0.00)***	1091.64 (0.00)***	220.76 (0.00)***

*Notes: The primary descriptive statistics for the daily price series across the full data period are provided in this table. In parentheses, the p-values are shown. Statistical significance at the 1% level is indicated by ***.*

Moreover, observing the volatility connections between green bond, Bitcoin and gold prices with DCC-GARCH model it requires deriving a logarithmic return from the daily price series. The logarithmic return is calculated using equation presented below:

$$R_{i,t} = \ln\left(\frac{P_t}{P_{t-1}}\right), \tag{5}$$

In this equation $R_{i,t}$ denotes the the logarithmic return of variable i at time t, where P_t signifies the price of the variable at time t, P_{t-1} denotes the price of the variable from the previous period. In figure 2, the logarithmic returns for green bond, Bitcoin and gold during the sample data period are presented. When examining the graphs more closely, it can be seen that all these logarithmic return series have very high values and also volatility clustering. This means that high return periods are typically followed by subsequent high return periods. Conversely, low return periods tend to be followed by additional time periods of low returns. This indicates the volatility clustering for these indexes. In other words, periods of calm or stability and high returns in the market tend to persist during some time.

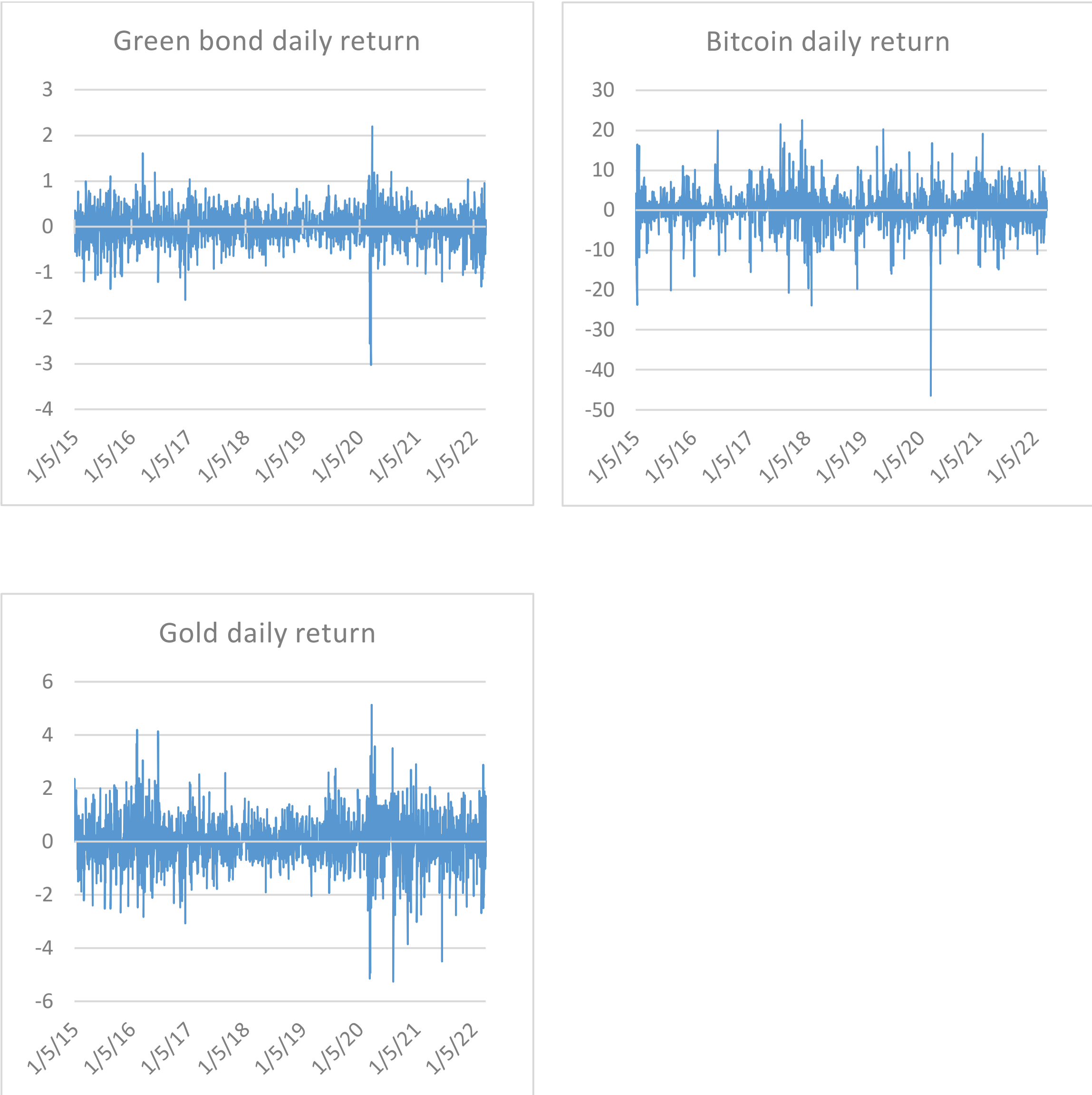

Figure 2: Logarithmic returns of Green Bond, Bitcoin, and Gold.

The summary statistics for logarithmic return green bond, gold and Bitcoin are presented in the table 2 below. When examining the table more closely, it can be seen that logarithmic returns derived from all observed instruments shows high values as minimum and maximum values exhibit greater separation, but differences can be observed. Especially Bitcoin shows the highest volatility among these other assets, as can be noticed by its significantly larger standard deviation and wider range comparing to minimum and maximum returns. Especially in Bitcoin these values are extremely high. This means that

Bitcoin investments produce higher risk comparing to green bonds and gold. Moreover, green bond has the lowest volatility, with a quite small standard deviation and also a narrower range of returns when comparing minimum and maximum compared to Bitcoin and gold. If investors are seeking stability and lower risk, they might find green bond very attractive.

Bitcoin has the highest mean return which indicates the potential for higher average returns compared to green bond and gold. Gold has the lowest mean return but exhibits a quite balanced distribution with its median close to the mean. This means that there might be available a more stable and predictable return profile compared to Bitcoin. From the table can be seen that all three instruments have negative skewness which means that the distributions of their returns are slightly skewed to the left. Because of this observation, extreme negative returns are less likely than extreme positive returns, they are still more common comparing to the situation in a perfectly symmetric distribution. Furthermore, the kurtosis values for each logarithmic return series exceed three, indicating that the data follows leptokurtic distributions rather than a normal distribution. It can be also seen that Bitcoin has the highest kurtosis. This is indicating a distribution with heavier tails and sharper peak when comparing to green bond and gold. This means that Bitcoin return is more prone to outliers than the other two instruments. The Jarque-Bera statistical test was also performed again to identify more information about these assets and verified possible non-normality. Results are very similar comparing to results got from summary statistics for price series table. Jarque-Bera results are now higher but still Bitcoin has the highest results indicating a much greater deviation from normality. This could be due to high kurtosis and high volatility of Bitcoin. The Jarque-Bera test suggests that logarithmic return series conform non-normal distribution also from gold and green bond including Bitcoin, which was already mentioned.

Table 2. Summary statistics for logarithmic return series of Green Bond, Bitcoin and Gold.

Returns	Green bond	Bitcoin	Gold
Mean	0.001	0.273	0.028
Median	0.005	0.237	0.004
Standard Deviation	0.372	4.621	0.907
Kurtosis	5.339	9.292	3.801
Skewness	-0.577	-0.710	-0.148
Minimum	-3.031	-46.473	-5.265
Maximum	2.198	22.512	5.133
Jarque-Bera	2254.2357 (0.00)***	6674.5839 (0.00)***	1098.3131 (0.00)***

*Notes: The primary descriptive statistics for the daily return series across the full data period are provided in this table. In parentheses, the p-values are shown. Statistical significance at the 1% level is indicated by ***.*

Next, table 3 provides the outcomes of the augmented Dickey-Fuller and Philips-Perron stationarity tests conducted over the whole data period. The purpose of this test is to estimate whether a time series is stationary or non-stationary, based on the concept of unit root testing. It is important to test if time series are stationary or non-stationary as stationarity is a key property that is able to ensure if the statistical properties of a time series, for example variance and mean, are constant over time period. The following table illustrates that the augmented Dickey-Fuller and Phillips-Perron tests produce comparable outcomes. Both tests consistently indicate non-stationarity in the price series of Bitcoin, green bond, and gold. This can be noticed from high p-values in both tests suggesting that these results are not fulfil the stationarity demand. However, both tests confirm that the logarithmic return series for Bitcoin, green bond and gold are stationary, and results are significant with low p-values. This is crucial that logarithmic return series is fulfilling the stationarity demand because stationary data is essential for GARCH models to verify accurate volatility forecasting and risk management. For this reason, it is recommendable to utilise logarithmic return series data in the GARCH model.

Table 3. Stationarity test outcomes: Philips-Perron and Augmented Dickey-Fuller.

	Price			Returns		
	Green bond	Bitcoin	Gold	Green bond	Bitcoin	Gold
Dickey-Fuller	-1.052 (0.93)	-1.9483 (0.60)	-2.6131 (0.32)	-12.469 (0.01)***	-10.741 (0.01)***	-11.724 (0.01)***
Philips-Perron	-6.8838 (0.73)	-7.9661 (0.67)	-9.8866 (0.56)	-1675.5 (0.01)***	-1889.5 (0.01)***	-1787 (0.01)***

*Notes: The results of the Augmented Dickey-Fuller and Phillips-Perron tests for the full data period are presented in this table. The p-values are shown in parentheses. Statistical significance at the 1% level is indicated by ***.*

6.2 Empirical methodology

This study aims to explore the safe haven properties of green bond and gold in relation to the Bitcoin which is very volatile financial instrument. Specifically, the study aims to analyse volatility transmission effects, return dynamics and time-varying correlation between Bitcoin and green bond and also between Bitcoin and gold. This thesis adopts the methodology presented by Dutta et al. (2020b) and Dutta (2018). In this first mentioned paper, Dutta et al. (2020b) used a bivariate dynamic conditional correlation GARCH-model to investigate the dynamic relationships and fluctuations in correlations over time between variables such as oil, Bitcoin, and gold. Several equations for the methodology of this thesis were also adapted from a second study where the author used a multivariate DCC-GARCH model to analyse the interconnections between emissions and biodiesel feedstock prices.

The DCC-GARCH model, first introduced by Engle (2002), builds upon Bollerslev's (1990) constant conditional correlation (CCC) GARCH model. While the CCC-GARCH model presupposes that asset correlations remain constant over time, the DCC-GARCH model allows for these correlations to fluctuate, thereby proving a robust framework for analysing the variable correlations between assets. Additionally, The DCC-GARCH model's flexibility makes it especially effective in capturing the volatility of financial time series, offering a straightforward and efficient approach for estimating models that involve a large number of variables. The efficacy of the DCC-GARCH model in capturing the dynamics of multivariate volatility has been affirmed in multiple studies by various researchers. For instance, Chevallier (2012) demonstrated DCC-GARCH models superiority in modelling dependencies among gas, oil and carbon prices. Additionally, according to Basher and Sadorsky (2016) The DCC-GARCH model is discovered for capturing persistence in volatility and correlation, which are important for creating hedging strategies. Further, Saeed et al. (2020) also highlights that DCC-GARCH framework is suitable when exploring the relationships between green bonds and dirty energy investments and its use enables to assess the hedging effectiveness and time-varying correlations of green bonds against dirty energy investments.

Next, relevant equations for DCC-GARCH model is presented. In this thesis the core components of the DCC-GARCH model, including the volatility and DCC parameters, are described using several mathematical formulas. GB indicates green bond, and B indicates Bitcoin and one option in this thesis would be present G, gold part of equations instead of green bond. The mean equation of the bivariate framework is also relevant part of DCC-GARCH formula and that is demonstrated by equations 6 and 7:

$$R_t = L + \tau R_{t-1} + \varepsilon_t, \tag{6}$$

$$\varepsilon_t = H_t^{1/2} \xi_t \ , \tag{7}$$

In which, R_t denotes a matrix that incorporates the returns for green bond and Bitcoin prices. L designates a matrix of constant parameters, while τ is a matrix of coefficients that reflects the impact of both self-transmission and cross-transmission effects and ε_t represents the shock component. In the equation 7, $H_t^{1/2}$ indicates to the matrix of conditional volatilities of green bond and Bitcoin, whereas ξ_t signifies a matrix of independently and identically distributed (IID) innovations.

Additionally, the parameter $H_t^{1/2}$ from equation 7 which incorporates volatilities of green bond, bitcoin and gold is subsequently broken down as follows:

$$H_t = D_t R_t D_t, \quad (8)$$

$$D_t = diag\left(\sqrt{h_t^{GB}}, \sqrt{h_t^{B}}\right), \quad (9)$$

$$R_t = diag(Q_t)^{-1/2} Q_t diag(Q_t)^{-1/2}, \quad (10)$$

$$Q_t = (1 - \alpha - \beta)\bar{Q} + \alpha \varepsilon_{t-1} \varepsilon'_{t-1} + \beta Q_{t-1}. \quad (11)$$

The conditional covariance structure is depicted in equation 9. This equation is diagonal matrix in which each diagonal element represents time-varying standard deviations. These diagonal values are denoted here as h_t^{GB} and h_t^{B} which are corresponding to the conditional volatilities of green bond and Bitcoin. Within the DCC-GARCH framework, the correlation matrix, here represented as R_t is permitted to change over time. Additionally, in equation 11, Q_t explicates the formation of the time-varying covariance matrix. In this same formula, the non-negative parameters α and β are essential as they play a critical role in shaping the equation's behaviour. Specifically, these parameters must satisfy the condition $\alpha + \beta < 1$, a requirement that ensures the model exhibits mean-reversion. This mean-reverting characteristic implies that, after a shock to the returns, the dynamic correlation steadily returns to its long-term average.

When the condition α + β = 0 is present, the model simplifies to a constant conditional correlation framework, where the correlations between green bond and Bitcoin prices remain stable over time, despite external shocks. The parameters α and β specifically measure different effects: α captures the impact of historical shocks on the current conditional correlations between green bond and Bitcoin prices, while β reflects the influence of historical dynamic conditional correlations on the present correlations between these two financial instruments.

Equation 9 presents the parameters h_t^{GB} and h_t^B which are relating to the conditional volatilities of green bond and bitcoin prices, respectively. To analyse both intra-asset and inter-asset volatility effects in volatility transmission, the conditional volatility equations are structured in the following manner:

$$h_t^{GB} = d_{GB}^2 + \beta_{11}^2 h_{t-1}^{GB} + \beta_{21}^2 h_{t-1}^B + \alpha_{11}^2 \varepsilon_{GB,t-1}^2 \, \alpha_{21}^2 \varepsilon_{B,t-1}^2 \, , \tag{12}$$

$$h_t^B = d_B^2 + \beta_{12}^2 h_{t-1}^{GB} + \beta_{22}^2 h_{t-1}^B + \alpha_{12}^2 \varepsilon_{GB,t-1}^2 \, \alpha_{22}^2 \varepsilon_{B,t-1}^2 \, , \tag{13}$$

The equations present effects of past volatilities and impacts of prior shocks for each market. Specially, equation 12 represents green bond volatility based on its historical volatility ($\beta_{11}^2 h_{t-1}^{GB}$), the past volatility of Bitcoin prices ($\beta_{21}^2 h_{t-1}^B$), and the impacts of past shocks and news relating green bonds ($\alpha_{11}^2 \varepsilon_{GB,t-1}^2$) and Bitcoin ($\alpha_{21}^2 \varepsilon_{B,t-1}^2$). Similarly, equation 13 illustrates the volatility of Bitcoin which is incorporating influences from its own historical volatility ($\beta_{22}^2 h_{t-1}^B$) and the past volatility of green bond prices ($\beta_{12}^2 h_{t-1}^{GB}$), including also the responses to past shocks and news in green bond ($\alpha_{12}^2 \varepsilon_{GB,t-1}^2$) and Bitcoin ($\alpha_{22}^2 \varepsilon_{B,t-1}^2$).

The β parameters in these equations quantify the own and intermarket impacts of past variances on current market volatilities for both green bond and Bitcoin. On the other hand, α parameters gauge the impact of past shocks and news, capturing both own market-specific and cross-market influences on the volatility dynamics of green bond and Bitcoin. This framework provides deeper understanding into the dynamics and interactions between green bond and Bitcoin markets and make it possible to compare these markets volatility transmission.

Another option to illustrate the dynamic conditional correlation between certain assets is to use following equation presented by Dutta et al. (2021)

$$\rho_t = \frac{h_t^{GBB}}{\left(\sqrt{h_t^{GB}}\sqrt{h_t^B}\right)} \, , \tag{14}$$

In which, ρ_t represents the dynamic conditional correlation at time t between the returns on green bond and Bitcoin. This parameter can quantify the degree to which the returns on the two assets under study move in tandem. h_t^{GBB} denotes the conditional covariance between the returns of the green bond and Bitcoin at the same time point. This captures the degree of linear relationship, could be strong or weak, among the variances in returns of the green bond and Bitcoin from their specific expected values at the same time point t. h_t^{GB} and h_t^{B} denote the conditional variances of the green bond and Bitcoin, respectively, again at time t. These parameters provide insight capturing the risk or volatility associated with these assets in time t.

7 Empirical results

This chapter is presenting estimated results from chosen empirical modelling methods. First, the DCC-GARCH estimation results are presented, focusing on the direction, intensity, and potential volatility transmission effects between Bitcoin and green bond markets and also between Bitcoin and gold markets. Variance equations and DCC parameters will be explained and also compared to previous studies. After this, time-varying correlation between Bitcoin and green bond markets and between Bitcoin and gold markets are presented and comparing how correlation is evolving through time. Thirdly, hedging effectiveness is calculated between these explained markets to have a more detailed understanding of possible hedging benefits between assets. Lastly, robustness analysis is assessed using asymmetric DCC-GARCH-model (ADCC-GARCH). With ADCC-GARCH idea is to confirm DCC-GARCH results and check if results are robust and accurate. Also, The ADCC-GARCH model and the associated findings on hedging effectiveness and time-varying correlations have been thoroughly analysed and compared with results from prior research. Additionally, the results from both the DCC-GARCH model and the ADCC-GARCH model have been examined separately from the whole data period (1/2015 - 3/2022) and from additional sample population II (2/2020 - 3/2022), with a comparative analysis conducted between both of these data samples. This approach aims to evaluate whether the market crisis impacted by COVID-19 affects the research outcomes regarding green bond and gold hedging properties against Bitcoin.

In this chapter, previous studies are comprehensively reviewed in order to compare previous results related to hedging properties of green bond and gold with the results of this thesis. The aim is to make it easier for the reader to evaluate the findings of this thesis in comparison with the broader academic literature. The results of previous studies regarding green bond and gold have been extensively discussed in order to make the empirical part more qualitative and comprehensive. The purpose of this approach is to ensure that empirical findings are better contextualized and justified in light of previous research.

7.1 DCC-GARCH estimation

7.1.1 Variance equations and DCC parameters

Following presented tables are describing DCC-GARCH model results. First presented table illustrates the results from the DCC-GARCH model relating to green bond and Bitcoin assets and second table is presenting the same results from the DCC-GARCH model relating to gold and Bitcoin assets during the whole data period. In the table 4, first are variance equations presented. $\varepsilon^{GB}{}_{t-1}$ and $\varepsilon^{B}{}_{t-1}$ are the squared error terms which are indicating how past shocks and innovations in green bond and in Bitcoin assets is affecting the current volatility. The error terms are the crucial components in GARCH model to capture the unpredictable part of returns. Next, $h^{GB}{}_{t-1}$ and $h^{B}{}_{t-1}$ parameters are showing how past volatility and variance of green bond and Bitcoin affects current volatility. Finally, the dynamic conditional correlation parameters are denoted as θ_1 and θ_2 which are crucial for understanding the time-varying correlations between these assets returns.

Table 4. Results from DCC-GARCH model on Green Bond and Bitcoin during the whole data period.

Ind. Var.	Green bond	Bitcoin
Variance equation		
$\varepsilon^{GB}{}_{t-1}$	0.0640*** *(0.00)*	2.0778*** *(0.00)*
$\varepsilon^{B}{}_{t-1}$	0.0002*** *(0.00)*	0.1235*** *(0.00)*
$h^{GB}{}_{t-1}$	*0.9059**** *(0.00)*	-1.6095*** *(0.00)*
$h^{B}{}_{t-1}$	-0.0003*** *(0.00)*	0.8074*** *(0.00)*
DCC parameters		
θ_1	-0.0072 *(0.32)*	
θ_2	0.7111 *(0.11)*	
LL	17424.75	

*Notes: The estimates for the DCC-GARCH model applied to the green bond-Bitcoin pair are detailed in this table. $\varepsilon^{GB}{}_{t-1}$ and $\varepsilon^{B}{}_{t-1}$ represent the influence of market shocks or news within the green bond and Bitcoin markets. Similarly, $h^{GB}{}_{t-1}$ and $h^{B}{}_{t-1}$ measure the volatility spillover effects between these markets. P-values are provided in parentheses, with statistical significance at the 1% level denoted by ***.*

Findings from table 4 indicates that both the green bond and Bitcoin markets are significantly impacted by their own past shocks or news and volatilities. In addition, Bitcoin market sends volatility to the green bond market and vice-versa. Hence, it can be concluded that there exists a bidirectional volatility connection between these two assets. Bitcoin's past innovations (ε^{B}_{t-1}) finding is also significant and its impact both Bitcoin and green bond volatilities. As already mentioned, this is suggesting strong intermarket volatility effects.

Further examination of these two markets indicate also that they have an inverse relationship through the volatility cross-effects. These findings suggests that green bond can serve as a hedge against Bitcoin volatility (the parameter estimate is -0.0003) and also the potential for green bond to diversify risk in Bitcoin investments (the parameter estimate is -1.6095). In this case, investors should include green bond asset in their Bitcoin portfolio to increase possible hedging opportunities.

Table 5. Results from DCC-GARCH model on Gold and Bitcoin during the whole data period.

Ind. Var.	Gold	Bitcoin
Variance equation		
ε^{G}_{t-1}	0.0243*** *(0.00)*	-0.2362*** *(0.00)*
ε^{B}_{t-1}	0.0002*** *(0.00)*	0.1357*** *(0.00)*
h^{G}_{t-1}	*0.9686**** *(0.00)*	-0.5647*** *(0.00)*
h^{B}_{t-1}	-0.0003*** *(0.00)*	0.8117*** *(0.00)*
DCC parameters		
θ_1	0.0114 *(0.75)*	
θ_2	-0.0499 *(0.98)*	
LL	11714.34	

Notes: *The estimates for the DCC-GARCH model applied to the gold-Bitcoin pair are detailed in this table. ε^{G}_{t-1} and ε^{B}_{t-1} represent the influence of market shocks or news within the gold and Bitcoin markets. Similarly, h^{G}_{t-1} and h^{B}_{t-1} measure the volatility spillover effects between these markets. P-values are provided in parentheses, with statistical significance at the 1% level denoted by ***.*

Findings from table 5 relating to DCC-GARCH model for gold and Bitcoin markets are indicating similar results comparing to table 4. All variance equations are again significant but beside similarities there is also some differences. The gold market is substantially influenced by past news or shocks and volatility, similar to the green bond market. Past innovations in the gold market (ε^{G}_{t-1} is 0.0243) have a significant positive impact on its own current volatility. Also, it can be noticed that there exists a bidirectional volatility connection between gold and Bitcoin like table 4 indicated same kind of results between green bond and Bitcoin.

Moreover, there are hedging opportunities to be indicated when combining gold to bitcoin portfolio. There are again possible to identify that gold and Bitcoin have an inverse relationship through volatility transmission effects. This means that the inverse relationship between gold's past volatility and Bitcoin returns (the parameter h^{G}_{t-1} estimate is -0.5647) verify gold's possibility to be a hedge against Bitcoin volatility. Also, Bitcoin's past volatility negatively affects gold returns (h^{B}_{t-1}) which is also indicating opportunities for hedging as it was also indicated from the previous table 4.

Overall, the DCC-GARCH model indicates that gold could provide effective hedging benefits against Bitcoin due to its significant inverse volatility relationship. When comparing findings presented in table 4 and table 5, both assets, green bond and gold indicate potential for providing hedging benefits against Bitcoin volatility. Both green bond and gold show strong persistence in their own volatilities which is reflected in the significant positive parameters of h^{GB}_{t-1} and h^{G}_{t-1}. Both green bond and gold seems to have significant interactions with Bitcoin regarding to past shocks and volatilities and also providing intermarket effects which is making them essential hedging tools for Bitcoin. However, DCC parameters results from tables 4 and 5 are non-significant. These DCC results are showing some evidence against hedging benefits indicating that the dynamic correlations are not so strongly affected by past shocks or past correlations. For this reason, more evidence is required to achieve more accurate results also in terms of DCC parameters.

Following table 6 and table 7 are presenting results from DCC-GARCH model for the COVID-19 pandemic period (2/2020 – 3/2022) where is excluded pre-COVID-19 period (1/2015 – 1/2020). Idea is to confirm is DCC-GARCH results staying at the same level or is it possible to recognize some changes during significant stress test like COVID-19.

Table 6. Results from DCC-GARCH model on Green Bond and Bitcoin during the COVID-19 period.

Ind. Var.	Green bond	Bitcoin
Variance equation		
ε^{GB}_{t-1}	0.1085***	0.0536***
	(0.00)	*(0.00)*
ε^{B}_{t-1}	0.0001***	0.0441***
	(0.00)	*(0.00)*
h^{GB}_{t-1}	*0.8200****	0.0782**
	(0.00)	*(0.03)*
h^{B}_{t-1}	-0.0015***	0.5200***
	(0.00)	*(0.00)*
DCC parameters		
θ_1	-0.0090***	
	(0.00)	
θ_2	0.0069***	
	(0.00)	

Notes: The estimates for the DCC-GARCH model applied to the green bond-Bitcoin pair are detailed in this table. ε^{GB}_{t-1} *and* ε^{B}_{t-1} *represent the influence of market shocks or news within the green bond and Bitcoin markets. Similarly,* h^{GB}_{t-1} *and* h^{B}_{t-1} *measure the volatility spillover effects between these markets. P-values are provided in parentheses, with statistical significance at the 1% level and 5% level denoted by *** and **,* respectively.

Table 6 indicates that both periods have significant impacts from past shocks. During COVID-19 period, the impact of green bond's past shocks on itself is even stronger. Also, past volatility seems to be also significant and almost at the same level comparing to the whole data period 2015-2022, although during COVID-19 period the impact of Bitcoin's past volatility on green bond is even stronger. A bigger difference can be noticed from DCC parameters. During COVID-19 period, both θ_1 and θ_2 results are significant which is suggesting a change in a dynamic correlation structure. This increased significance of DCC parameters shows a stronger interdependence which means that green bond can provide potentially a more substantial hedge against Bitcoin volatility during time periods of market stress like observed COVID-19 pandemic.

Table 7. Results from DCC-GARCH model on Gold and Bitcoin During the COVID-19 period.

Ind. Var.	Gold	Bitcoin
Variance equation		
ε^{G}_{t-1}	0.0669*** *(0.00)*	0.7107*** *(0.00)*
ε^{B}_{t-1}	-0.0004 *(0.38)*	0.1287*** *(0.00)*
h^{G}_{t-1}	*0.7734**** *(0.00)*	-1.5282*** *(0.00)*
h^{B}_{t-1}	-0.0063*** *(0.00)*	0.8164*** *(0.00)*
DCC parameters		
θ_1	0.0151*** *(0.00)*	
θ_2	0.9807*** *(0.00)*	

Notes: *The estimates for the DCC-GARCH model applied to the gold-Bitcoin pair are detailed in this table.* ε^{G}_{t-1} *and* ε^{B}_{t-1} *represent the influence of market shocks or news within the gold and Bitcoin markets. Similarly,* h^{G}_{t-1} *and* h^{B}_{t-1} *measure the volatility spillover effects between these markets. P-values are provided in parentheses, with statistical significance at the 1% level denoted by ***.*

Table 7 shows that findings from DCC-GARCH model for the COVID-19 period with gold-Bitcoin pair portfolio is mostly similar but also significantly different comparing to the whole data period. In both time periods, gold's past shocks and volatility stay at significant level and in addition the impact is even stronger during the COVID-19 period. This indicates that gold's performance in past had a stronger influence on volatility in future during the COVID-19 pandemic. Another important observation from table 7 is related to DCC parameters. During the COVID-19 period, both θ_1 and θ_2 results seems to be significant which is indicating a change in a dynamic correlation structure between gold and Bitcoin. This observation defines that the hedging effectiveness of gold against Bitcoin is stronger during the COVID-19 pandemic, indicating better hedging benefits when using gold instrument.

During the COVID-19 pandemic, it can be noticed that both green bond and gold show high evidence from better hedging properties against Bitcoin due to the significant changes in their dynamic conditional correlation. This is interesting finding for possible investors demonstrating that both of these hedging tools could provide even more stable and stronger diversification benefits during the market stress like COVID-19. However, when comparing green bond and gold it seems that green bond shows a stronger positive intermarket volatility effect on Bitcoin which highlights green bond to be even more essential hedging tool. Gold is also showing good hedging benefits against Bitcoin and DCC-GARCH model is provide also significant level of DCC parameters, so these results highlight gold's traditional role as a safe-haven asset.

Previous studies have also shown similar results and are highlighting some of these results. Moreover, there are also several previous studies relating to how gold or green bond can act as a hedging tool. For example, Mensi et al. (2023) used DCC-GARCH model to identify what would be the optimal portfolio weigh and what is the hedge ratio for short-term and long-term hedging strategies. They noticed stronger diversification benefits when using a mixed portfolio where one of the used assets is gold or green bond. Moreover, green bond and gold provide good hedging benefits also against extreme negative stock price movements during the COVID-19 period. Gao et al. (2023) also used DCC-GARCH model to investigate different hedging benefits between various assets e.g. gold and different green bond instruments. They discovered that it is possible to use different low-carbon green bond instruments during the market stress situation and also gain at least some hedging power.

In addition, Creti et al. (2013) used the dynamic conditional correlation GARCH method to analyse time changes of correlations between the commodity and stock markets. Their study highlights gold role as a strong safe-haven asset as gold's correlations with stock returns showed mostly negative. Similar results relating to green bond when using DCC-GARCH model was also found from other studies. Reboredo (2018) examines the co-movement and hedging features of green bonds in financial markets. The results indicate that green bonds can offer good diversification benefits for investors if they want to protect their stock or energy market portfolio where may happen larger price fluctuations. These findings are significant and also provide useful information where DCC-GARCH model is used and also emphasise green bond and gold assets hedging properties.

7.1.2 Time-varying correlation

Beyond exploring the dynamics of return and risk transmission, the DCC-GARCH model also allows for the examination of how the correlation between assets develop over time. Figure 3 shows the movement of the correlation between Bitcoin and green bond and how it has been evolved during the years under review. The graph indicates that the DCC correlation does vary over time. It can be also notice that it remains positive during the sample period under study. Interesting observation from the figure 3 is that the maximum correlation happened during the COVID-19 outbreak where the correlation spike was almost three times higher comparing to the mean correlation. Moreover, the mean correlation is close to zero, implying that there is a possibility for hedging.

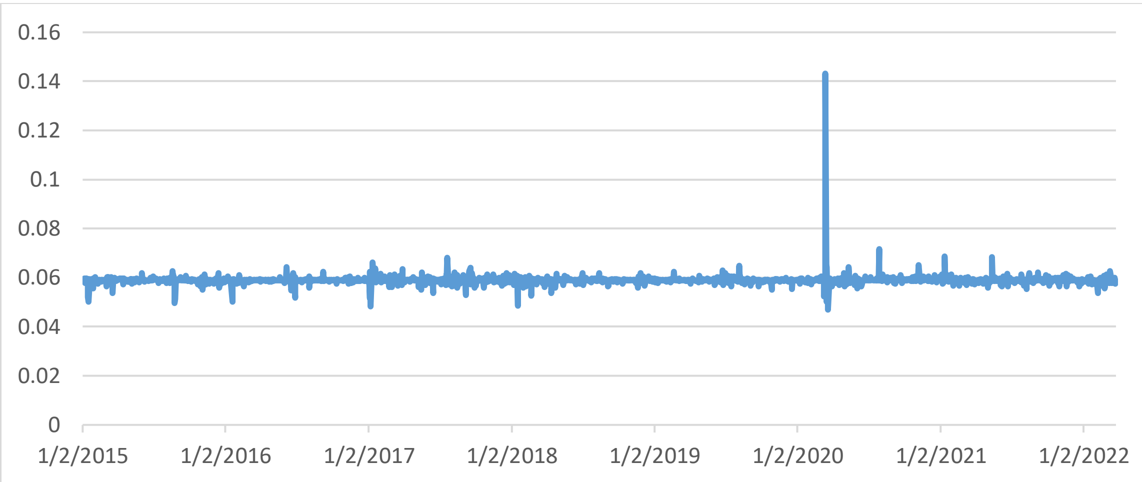

Figure 3: Time-varying conditional correlation between Bitcoin and Green Bond.

Table 8 indicates the results of the summary statistics on the dynamic correlations between Bitcoin and green bond. The mean correlation is relatively low at 0.058977, with a modest standard deviation of 0.002402. This shows a quite weak and stable correlation during the sample period under study. This finding tells that Bitcoin price changes are not strongly reflected in green bond movements and vice versa. In addition, the range between the maximum and minimum correlations is not wide and they are relatively close each other, indicating that significant fluctuations are not common.

Table 8. Summary statistics of time-varying correlation between Bitcoin and Green Bond

Minimum	Maximum	Mean	Standard deviation
0.046964	0.143189	0.058977	0.002402

Notes: The primary summary statistics for the time-varying correlation between Bitcoin and green bond during the whole data set are detailed in the table.

Figure 4 reveals that the correlation between Bitcoin and gold also evolves over time. It is also observed that it swings between positive and negative regions. Besides, the maximum correlation occurs during the COVID-19 pandemic, consistent with the earlier graph depicting the correlation relationship between Bitcoin and green bond. The maximum correlation spike during the observation years is almost 7.5 times higher comparing to the mean correlation which means that the maximum correlation is significantly higher. It can be also noted that the mean correlation exceeds 0, but not high. Hence, there exists a good possibility for hedging.

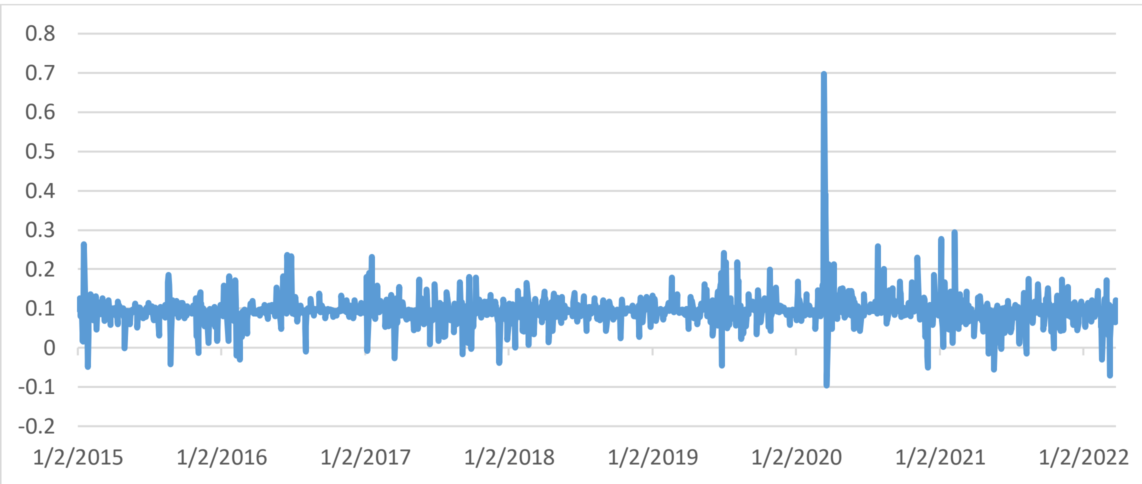

Figure 4: Time-varying conditional correlation between Bitcoin and Gold.

Table 9 provide more insights from time-varying correlation between Bitcoin and gold. The mean correlation is 0.094545 which is higher comparing to table 8. It is also relatively weak correlation but indicates a little bit more significant relationship comparing to between Bitcoin and green bond. However, the standard deviation is significantly higher

(0.034878) comparing to that between Bitcoin and green bond's standard deviation. Moreover, the range between the maximum and minimum correlations is quite broad caused mostly by COVID-19 spike. This tells that possible correlation between Bitcoin and gold might change rather dramatically under certain market conditions.

Table 9. Summary statistics of time-varying correlation between Bitcoin and Gold.

Minimum	Maximum	Mean	Standard deviation
-0.096360	0.697340	0.094545	0.034878

Notes: The primary summary statistics for the time-varying correlation between Bitcoin and gold during the whole data set are detailed in the table.

Overall, both of these time-varying correlations are giving same kind of results. Although Bitcoin-gold pair has broader and stronger correlation however it acts same way comparing to Bitcoin-green bond pair. Both of these has stronger correlation spikes which could be indicated during the COVID-19 pandemic which was a significant stress test for financial markets globally. From a hedging perspective, it is beneficial when asset pairs have weaker correlation relationship. This indicates that assets don't move in tandem and can provide diversification benefits.

These findings are in line with some prior findings. Saeed et al. (2020) compared clean energy stocks-crude oil pair and green bond-crude oil pair and noticed that green bond provides a weaker correlation compared to others. Their study shows that risk relating to crude oil can be more diversified if crude oil portfolio is combined with green bond in this same portfolio. Nguyen et al. (2021) study shows that combining green bond with stock or commodity market portfolio it will give low or even negative correlation which indicates good diversification and hedging benefits. Also, Dutta et al. (2021) study provides similar type of findings regarding the hedging properties of climate bond. The study demonstrates a low correlation between climate bond and WTI oil prices, indicating that climate bond could potential have hedging benefits for oil market participants. All these findings are highlighting green bonds hedging opportunities. Additionally, Ui Haq et al. (2021) findings highlight that green bonds show negative correlation with economic policy uncertainty also during COVID-19 period. This also verify green bonds superior hedging properties in times of market turmoil.

7.2 Hedging effectiveness

Time-varying correlation and DCC-GARCH results indicates that possible hedging benefits between assets might exist. Further examine is needed to understand even better whether including green bond assets or gold assets in a portfolio with Bitcoin asset helps to mitigate the overall risk of the combined investment. Hedging effectiveness (HE) analysis is used as another analysis method for further analysis purposes. It is important to note that a higher HE value signifies a more effective risk mitigation strategy. One way to present hedging effectiveness is to use the time-varying hedge effectiveness (TVHE) method like Dutta et al. (2021) have use it with the following formula:

$$TVHE_t = \beta_t^2 \frac{h_t^{GB}}{h_t^B}, \tag{15}$$

In this formula, if $TVHE_t$ is equal to 1, that describes a perfect hedge situation, whilst if equation is equal to 0, that means a total lack of hedging effectiveness. In this formula GB indicates green bond (or might be also G which would indicate gold) and B indicates bitcoin.

Another way to present HE formula is to use following formula from Ku et al. (2007):

$$HE = \frac{Var_{unhedged} - Var_{hedged}}{Var_{unhedged}}, \tag{16}$$

In this equation, $VAR_{unhedged}$ describes the variance of a portfolio which is solely comprised of Bitcoin, without any hedging instrument. Moreover, VAR_{hedged} includes the equivalent the variance of the hedged portfolio which is including both Bitcoin and green bond or instead of green bond using gold. A higher hedging effectiveness ratio indicates a stronger risk reduction. VAR_{hedged} can be present as following way:

$$Var_{hedged} = (\omega_t^{GBB})^2 h_t^{GB} + (1 - (\omega_t^{GBB})^2) h_t^B + 2\omega_t^{GBB}(1 - \omega_t^{GBB}) h_t^{GBB}\ , \quad (17)$$

In above equation h_t^B and $h_t^{GBB}$are the conditional volatilities of Bitcoin and green bond (could be also h_t^G where G present gold) which are defined in equation 12 and 13. These parameters are indicating how much the price of Bitcoin or price of green bond fluctuates over time. The conditional covariance between green bond and Bitcoin are described with parameter h_t^{GBB}. It is possible to measure with covariance, how much two assets change together. This is showing the relationship between the price movements of Bitcoin and green bond. Another important parameter here is ω_t^{GBB} which is representing the optimal weight of green bond in the portfolio, defining how much of the portfolio should be allocated to green bond comparing to Bitcoin to minimize risk. The optimal weight $\omega_t^{GBB}$is calculated with the following equation:

$$\omega_t^{GBB} = \frac{h_t^{GB} - h_t^{GBB}}{h_t^{GB} - 2h_t^{GBB} + h_t^B}\ , \quad (18)$$

This equation 18 numerator $h_t^{GB} - h_t^{GBB}$ is describing the difference between the volatility of green bond and the covariance between green bond and Bitcoin. A higher difference between these two parameters indicates that the volatility of green bond is much higher compared to the extent to which Bitcoin and green bond prices move in tandem. Moreover, equation's denominator $h_t^{GB} - 2h_t^{GBB} + h_t^B$ is showing the part that is combining the volatilities of Bitcoin and green bond while at the same time adjusting for their covariance. In other words, it is reflecting the overall risk when taking into account both individual volatilities and their combined movement. $\omega_t^{GBB}$is indicating the fraction of the portfolio that is right amount to be invested in green bond to achieve the lowest possible risk when combining this instrument with Bitcoin. Next, it is presented what kind of hedging effectiveness results were obtained in this study:

Table 10. Results from hedging effectiveness analysis during the whole data period.

Portfolio ↓	Var (Unhedged)	Var (hedged)	HE (%)
Gold/Bitcoin	0.1767	0.1251	29.20
Green bond/Bitcoin	0.1742	0.1109	36.33

Notes: In this table, it is provided the variance of unhedged and hedged portfolios and also hedging effectiveness percentage between Bitcoin and each of the two instruments under study which are gold and green bond. The sample includes 1813 daily observations which are from the whole data period.

Table 10 above presents HE analysis results from gold-Bitcoin pair and green bond-Bitcoin pair combinated portfolios from the whole data period. The results obtained in the study indicate that green bond/Bitcoin and gold/Bitcoin combinated portfolios have higher hedging effectiveness meaning that both asset pairings provide significant hedging opportunities. The hedging effectiveness is 29.20 % with gold and Bitcoin asset portfolio and 36.33 % with green bond and Bitcoin portfolio. While both green bond and gold can act as hedging tools, green bond appears to be more effective in hedging Bitcoin risk. These percentages show the reduction of variance between Var (Unhedged) and Var (hedged). Both of these hedging effectiveness percentages are relatively high although the mean correlations are quite weak, suggesting that even with weak correlation green bond and gold can provide substantial hedging benefits. This means that both green bond and gold could provide substantially variance reduction which can underscore the value of including assets like green bond and gold in a diversified portfolio. It is also good to mention one notable finding that even with generally low correlation both green bond and gold can provide good hedging benefits which highlight their role in absorbing shocks when other markets may be in turmoil with significant stress test like COVID-19. Hence, investors holding asset in crypto markets should include more green assets in their portfolio to hedge the downside risk as green bond provided even higher hedging effectiveness percentage comparing to gold.

Overall, hedging effectiveness analysis confirmed results indicated with time-varying correlation and DCC-GARCH that there are possible hedging benefits exits including green bond-Bitcoin pair portfolio or gold-Bitcoin pair portfolio. However hedging benefits in crypto markets are more effective when using green bond as hedging tool.

There are also some previous studies relating to hedging effectiveness and even using similar type of assets. Dutta et al. (2021) used the time-varying hedge effectiveness method and noticed that climate bond provided best hedge for US equities. However, they noticed also that hedge effectiveness may vary a lot over time regarding of market situation. Mezghani et al. (2023) study highlight the role of green bond in portfolio when mitigating risks with diversification during COVID-19. Their study indicates that using green bond-stock pair or green bond-commodity pair allows higher hedging effectiveness for all financial markets before and during COVID-19. However, they also noticed that hedging effectiveness was higher in the short-term comparing to the long run, but still green bond provided great diversification benefits. Mensi et al. (2023) study also indicate that both green bond and gold can act as safe haven assets for investors, but they also highlighted that it is important to understand that hedging effectiveness may vary over time and be event dependent.

Arif et al. (2022) study reveal interesting finding relating to green bonds safe-haven capabilities. Their study show that green bonds can provide significant diversification benefits and be safe-haven assets for currency and commodity investments even during medium and long-term equity investors. These findings cover also benefits which commodity and currency investors may use to hedge downside risk. Arif et al. (2022) highlight also that COVID-19 type of crisis reveals an enhanced short- and medium-term lead-lag correlation between traditional investment and green bond index returns. This indicates inefficient hedging benefit in some cases for short and medium-term investors. However, their longer-term finding is significant and may help investors to choose more often green bond as a hedging tool and this way use sustainable safe haven option. Also, Ui Haq et al. (2021) study demonstrate that green bond can act as a strong safe haven asset against the US and UK economic policy uncertainty. On the other hand, study by Akhtaruzzman et al. (2021) demonstrate gold's function as a hedge or safe-haven asset during different time periods of the COVID-19 period. Their study shows that gold act as a safe-haven asset for stock market in the beginning of COVID-19 period but lost its safe-haven capability. This indicates that the timing can significantly impact whether an asset can act as a hedging tool. Timing is affected by several variables, such as market conditions and changes in hedging costs. These previous research findings complement the hedging effectiveness results of this thesis. In addition, findings highlight that green bonds might have better hedging properties comparing to gold during times of market crisis. All in all, green bond hedging effectiveness results are significant based on this thesis and also based on previous studies, which is a substantial observation.

7.3 Robustness check

To understand more accurately the observations and to test reliance of them robustness check is conducted. When using more robust estimators it can estimate more accurate forecasts and conclusions which are based on the empirical results (Brooks, 2014). In this study, the robustness check of DCC-GARCH is conducted using an asymmetric variant (ADCC-GARCH), following methodology by Dutta et al. (2020) and Dutta et al. (2021). Cappiello et al. (2006) originally presented the ADCC-GARCH model which extends the symmetric DCC-GARCH framework by incorporating asymmetric effects into the correlation dynamics.

This asymmetric DCC-GARCH model differs from DCC-GARCH model by incorporating asymmetry element in the correlation dynamics which allows it to respond differently to positive and negative market shocks. ADCC-GARCH also provides a more accurate result of movement in stress conditions or volatile environments. Due to these capabilities, ADCC-GARCH model offers improved risk management and can be well used for financial market data which appears often non-linear by nature.

When comparing ADCC-GARCH model with DCC-GARCH model it can be noticed that the mean equation and the conditional volatility formula are formulated similarly. Difference between these models comes from the time-varying conditional dependence formula Q_t. In asymmetric modelling time-varying dependence can be formulate in the following way:

$$Q_t = (1-\theta_1-\theta_2)\bar{Q} + \theta_3\bar{Z} + \theta_1\xi_{t-1}\xi'_{t-1} + \theta_2 Q_{t-1} \ + \theta_3 \ z_{t-1}z'_{t-1}, \quad (19)$$

Idea is to explain the main ideas of this equations. In the equation 19, $\bar{Q}$ is presenting the unconditional covariance matrix of standardized residuals. The first part of the equation means a weighted constant that contains the long-term average dependence between green bond or gold and Bitcoin. Next, $\theta_3\bar{Z}$ adds an asymmetric component to the equation capturing the different impacts of positive and negative shocks on the dependence structure. Moreover, $\theta_1\xi_{t-1}\xi'_{t-1}$ term idea is to determine past shocks in the dependence structure and ξ_{t-1} are the standardized residuals. $\theta_2 Q_{t-1}$ describes a persistence term that brings past conditional dependence matrix. And finally, $\theta_3 \ z_{t-1}z'_{t-1}$ idea is to capture the asymmetric effects of past shocks and to ensure that the ADCC-GARCH model can differentiate and act to the nature of the shocks. In this formula θ_3 indicates the different correlations from different sign shocks which refers to positive and negative shocks. In addition to the time-varying conditional dependence matrix Q_t, ADCC-GARCH model also involves conditional volatilities h_t^{GB} and h_t^{B}. The formulation follows the same principles as those used in the symmetric DCC-GARCH model described earlier. This approach provided by this equation can help to have a more detailed understanding of the dynamic relationship between gold and Bitcoin and also between green bond and Bitcoin under various market conditions.

Tables below describes the estimation results from ADCC-GARCH models. First table 11 is presenting ADCC-GARCH model from green bond and Bitcoin combination portfolio from the whole data period (1/2015-3/2022). First, focusing on the variance equation it can be noticed that green bond and also Bitcoin results are both significant like results was significant in the DCC-GARCH table earlier relating to green bond and Bitcoin. This tells that their own past news, and volatilities significantly effect on green bond and bitcoin market. In other words, this finding indicates that historical price movements and volatilities are relevant for future expectations in both Bitcoin and green bond markets.

Next, focusing DCC parameters and first specially θ_1 and θ_2 which are ADCC-GARCH model's asymmetric terms in these next two tables. Asymmetric component could highlight possible different impacts of positive versus negative shocks between markets. θ_2 (Bitcoin asymmetric component) is significant that suggests it has predictive power over market under consideration. This finding means that Bitcoin market is affecting the volatility of the green bond market. Analysing more h^{GB}_{t-1} and h^{B}_{t-1} components results show significant negative coefficient for Bitcoin's past volatility which is affecting to green bond volatility. This suggests an inverse relationship, where increases in Bitcoin volatility could decrease green bond volatility and cause a good potential hedging effect. Same type of significant negative coefficient for green bond's past volatility can be noticed and it's impacting to Bitcoin's volatility which is indicating also inverse relationship. This means that higher volatility in the green bond market could reduce Bitcoin's volatility.

When comparing DCC parameters between earlier DCC-GARCH table and this ADCC-GARCH table we can notice that θ_3 and θ_4 are insignificant in both tables but θ_2 is significant in ADCC-GARCH table, so it needs to be evaluated more closely. When analysing asymmetric parameters from green bond and Bitcoin ADCC-GARCH table, it can be noticed that θ_2 value is significant which tells that there is indeed asymmetric effect in the data. This also indicates that there could be a time-varying positive conditional correlation between the returns of Bitcoin and green bond. This also tells that green bond and Bitcoin reacts differently to market shocks. Overall, some results are not significant from the table but however, investors could use relatively stable green bond to balance the volatility of Bitcoin, and this way reduce overall portfolio risk. Green bond offer good diversification benefits and one aspect could be if sustainability is a key consideration relating to chosen investing instruments.

After these the whole data ADCC-GARCH tables there are presented ADCC-GARCH tables from COVID-19 period where are excluded pre-COVID-19 time. Reason is to analyse more variance equations but especially DCC parameters and try to confirm is it possible to identify changes from significancy level between these different time periods.

Table 11. Results from ADCC-GARCH model on Green Bond and Bitcoin during the whole data period.

Ind. Var.	Green bond	Bitcoin
Variance equation		
ε^{GB}_{t-1}	0.0677*** *(0.00)*	2.0221*** *(0.00)*
ε^{B}_{t-1}	0.0002*** *(0.00)*	0.1166*** *(0.00)*
h^{GB}_{t-1}	*0.9065**** *(0.00)*	-1.5408*** *(0.00)*
h^{B}_{t-1}	-0.0003*** *(0.00)*	0.8064*** *(0.00)*
DCC parameters		
θ_1	-0.0064 *(0.10)*	
θ_2	0.0139** *(0.02)*	
θ_3	-0.0071 *(0.35)*	
θ_4	0.7100 *(0.12)*	
Log Likelihood	17425.02	

Notes: *The estimates for the ADCC-GARCH model applied to the green bond-Bitcoin pair are detailed in this table.* ε^{GB}_{t-1} *and* ε^{B}_{t-1} *represent the influence of market shocks or news within the green bond and Bitcoin markets. Similarly,* h^{GB}_{t-1} *and* h^{B}_{t-1} *measure the volatility spillover effects between these markets. P-values are provided in parentheses, with statistical significance at the 1% level and 5% level denoted by *** and **,* respectively.

Next, table 12 below is presenting ADCC-GARCH model from gold and Bitcoin combination portfolio from the whole data period (1/2015-3/2022). First, focusing again on the variance equation it can be noticed that gold and also Bitcoin results are both significant like results was significant in the symmetric DCC-GARCH table earlier relating to gold and Bitcoin. Results indicates impact of past news and volatility. This tells that also their own past news, and volatilities significantly effect on gold and bitcoin market. In other words, this observation indicates that historical price movements and volatilities are relevant for future expectations in both Bitcoin and gold markets. h^{G}_{t-1} indicates gold past volatility which has significant negative coefficient in Bitcoin section. This points an inverse relationship and could suggests gold to be good risk stabilizer with Bitcoin and tells about hedging opportunities. This means that the historical volatility of gold is having a strong positive influence on its own volatility.

When analysing DCC parameters, it can be noticed that same parameters are significant and same parameters are insignificant in this ADCC-GARCH table and earlier presented symmetric DCC-GARCH table relating to gold and Bitcoin. θ_1 and θ_2 coefficients are asymmetric parameters and can reveal if gold and Bitcoin can react differently to market shocks. θ_1 is significant so it needs to be evaluated more closely. θ_1 parameter has significant negative coefficient indicating that gold's correlation with Bitcoin may decrease under specific conditions. This highlight gold's role as a hedging instrument during the times of increased Bitcoin volatility.

Overall, some results are not significant from the table but however, investors could benefit using gold in their portfolio and utilise gold's hedging characteristics. These findings are highlighting opportunities for investors that they could balance the volatility of Bitcoin and the overall portfolio risk when using gold as hedging tool.

Table 12. Results from ADCC-GARCH model on Gold and Bitcoin during the whole data period.

Ind. Var	Gold	Bitcoin
Variance equation		
ε^{G}_{t-1}	0.0343*** *(0.00)*	-0.0910*** *(0.01)*
ε^{B}_{t-1}	0.0003*** *(0.00)*	0.1398*** *(0.00)*
h^{G}_{t-1}	*0.9635**** *(0.00)*	-0.9305*** *(0.00)*
h^{B}_{t-1}	-0.0004*** *(0.00)*	0.8063*** *(0.00)*
DCC parameters		
θ_1	-0.0154*** *(0.00)*	
θ_2	-0.0069 *(0.31)*	
θ_3	0.0131 *(0.73)*	
θ_4	-0.0500 *(0.98)*	
Log Likelihood	11715.51	

Notes: *The estimates for the ADCC-GARCH model applied to the gold-Bitcoin pair are detailed in this table.* ε^{G}_{t-1} *and* ε^{B}_{t-1} *represent the influence of market shocks or news within the gold and Bitcoin markets. Similarly,* h^{G}_{t-1} *and* h^{B}_{t-1} *measure the volatility spillover effects between these markets. P-values are provided in parentheses, with statistical significance at the 1% level denoted by ***.*

Most of the DCC parameters are appearing to be insignificant also in the gold and Bitcoin's ADCC-GARCH table for the whole data set. These insignificant DCC parameters indicates a quite stable relationship with Bitcoin, but it is not so strongly influenced by past asymmetric effects. This also means that past shocks and volatilities do not have clear dynamic effect on the correlation between these assets properly. Also, these findings might affect the precision of the model in proving hedging strategies during some market situations. Next, tables 13 and 14 are presenting ADCC-GARCH models from the COVID-19 period relating to green bond-Bitcoin pair portfolio and gold-Bitcoin pair portfolio. Idea is to identify is there changes in variance equations and DCC parameters when changing time period.

Table 13. Results from ADCC-GARCH model on Green Bond and Bitcoin during the COVID-19 period.

Ind. Var.	Green bond	Bitcoin
Variance equation		
ε^{GB}_{t-1}	0.1080*** *(0.00)*	10.4002*** *(0.00)*
ε^{B}_{t-1}	0.0001*** *(0.00)*	0.0408*** *(0.00)*
h^{GB}_{t-1}	*0.8197**** *(0.00)*	-15.1289*** *(0.00)*
h^{B}_{t-1}	-0.0003*** *(0.00)*	0.9500*** *(0.00)*
DCC parameters		
θ_1	-0.0202*** *(0.00)*	
θ_2	-0.0231*** *(0.00)*	
θ_3	-0.0089*** *(0.00)*	
θ_4	0.7546** *(0.05)*	

Notes: *The estimates for the ADCC-GARCH model applied to the green bond-Bitcoin pair are detailed in this table.* ε^{GB}_{t-1} *and* ε^{B}_{t-1} *represent the influence of market shocks or news within the green bond and Bitcoin markets. Similarly,* h^{GB}_{t-1} *and* h^{B}_{t-1} *measure the volatility spillover effects between these markets. P-values are provided in parentheses, with statistical significance at the 1% level and 5% level denoted by *** and **,* respectively.

Table 13 above presents results from ADCC-GARCH model for the COVID-19 period with green bond-Bitcoin pair portfolio. Results are mainly similar with the whole data period ADCC-GARCH model but there are also substantial differences. First, the effect of past green bond shocks on its own volatility is now increased significantly during the COVID-19. Same effect relating to Bitcoin is now slightly changed at a reduced level. Past green bond volatility is still having a strong positive influence on its own volatility during the COVID-19 period although with a little bit reduced level. Also, Bitcoin's past volatility influence on green bond returns to stay at negative and significant level.

During the COVID-19 period, all DCC parameters seems to be at a significant level which are the biggest difference comparing to the ADCC-GARCH table for the whole data set. DCC parameters significant level is indicating much stronger dynamic conditional correlations when comparing to the whole data set time period. DCC parameters suggest for example a strong negative impact from past shocks (θ_1, θ_2, θ_3) during COVID-19 for green bond and Bitcoin which means that past news and information are strongly effected green bonds and Bitcoin's correlation. Another finding is that highly significant and more positive θ_4 parameter during the COVID-19 period indicates even better hedging features when comparing to the whole data set from the 2015-2022 time period. Overall, these DCC parameter findings indicate increased interconnectedness and higher potential for hedging and could provide insightful information to the investors.

Table 14. Results from ADCC-GARCH model on Gold and Bitcoin during the COVID-19 period.

Ind. Var	Gold	Bitcoin
Variance equation		
ε^G_{t-1}	0.0742*** *(0.00)*	-0.0566 *(0.74)*
ε^B_{t-1}	0.0036*** *(0.00)*	0.0523*** *(0.00)*
h^G_{t-1}	*0.9520**** *(0.00)*	4.0597*** *(0.00)*
h^B_{t-1}	-0.0052*** *(0.00)*	0.6929*** *(0.00)*
DCC parameters		
θ_1	-0.0774*** *(0.00)*	
θ_2	0.2032*** *(0.00)*	
θ_3	0.0154*** *(0.00)*	
θ_4	0.9789*** *(0.00)*	

Notes: *The estimates for the ADCC-GARCH model applied to the gold-Bitcoin pair are detailed in this table.* ε^G_{t-1} *and* ε^B_{t-1} *represent the influence of market shocks or news within the gold and Bitcoin markets. Similarly,* h^G_{t-1} *and* h^B_{t-1} *measure the volatility spillover effects between these markets. P-values are provided in parentheses, with statistical significance at the 1% level denoted by ***.*

When comparing table 14 results to earlier presented the whole data set ADCC-GARCH table 12 the first finding is that now the influence of past gold shocks on its own volatility is significantly increased during the COVID-19. Also, Bitcoin's influence on its own volatility stays significant. Moreover, the past volatility findings are also strongly significant but stays the closely at the same level comparing to the earlier the whole data set table.

In the COVID-19 period, all of the DCC parameters are at the statistically significant level and most of these DCC parameters (θ_2, θ_3, θ_4) was insignificant during the whole data set table. θ_1 parameter was significant during the both time periods but however, during the COVID-19 period there was a stronger negative value which tell a stronger negative impact of past shocks. This significant negative number signifies that gold provides a more hedging benefit against Bitcoin volatility because increased volatility in Bitcoin is more associated with declining volatility in gold. The positive and significant θ_2 suggests that past news have a substantial positive impact on current conditional correlation indicating a dynamic relationship between gold and Bitcoin. θ_3 is also significant meaning that past volatilities have stronger positive effect on the current correlation comparing to the whole data set there this was insignificant. θ_4 is now positive and significant which is highlighting better hedging properties during the COVID-19 period. It is also showing the strong influence of past correlations between gold and Bitcoin highlighting a robust interconnectedness during this time period. In overall, these findings indicates that gold could provide more robust hedging benefits against Bitcoin during the market stress stage like the COVID-18 period when comparing to the more stable period. This highlights gold's role as a safe haven asset.

The ADCC-GARCH analysis during the COVID-19 period shows that there are stronger dynamic conditional correlations for green bond and Bitcoin and also for gold and Bitcoin which means enhanced hedging capabilities in this type of volatile market conditions. Green bond seems to have even better capabilities as results are stronger and significant. Relating to green bond, significant negative impacts from past shocks indicates that past news are heavily influenced these correlations. Although gold's results indicate weaker dynamic correlation and hedging, gold asset are also proving relatively good results and can act as a hedging tool. Both of these ADCC-GARCH table results from COVID-19 period are very similar comparing to the DCC-GARCH models results from the same time period.

This finding means when comparing both empirical frameworks that original DCC-GARCH results regarding capturing dynamic correlations, volatility spillovers and hedging benefits can be considered to be relatively robust.

Asymmetric DCC-GARCH model has been used in many studies. It is possible to capture asymmetric effect and compare the results with symmetric results to see are results robust. Basher and Sadorsky (2016) also used ADCC-GARCH model alongside the DCC-GARCH and a generalized OGARCH model. They noticed that e.g. hedging effectiveness was different when comparing all these models giving useful information because HE was better in most cases when using ADCC-GARCH. Moreover, Raheem et al. (2023) also used same variants of the multivariate GARCH framework (DCC, ADCC and GO-GARCH) to examine green energy market and they used as hedging tool different so called brown assets e.g. gold, oil and bond. They noticed that ADCC results complement DCC results and make their study results more insightful when they used variants of different GARCH models. ADCC-GARCH models can provide many different kinds of benefits and results may vary comparing to DCC-GARCH like they were in this thesis. Elsayed and Helmi (2021) decided to use ADCC-GARCH to measure the dynamic return co-movements and also volatility clustering, time variation and asymmetric volatility. Additionally, Wang et al. (2022) used also ADCC-GARCH model to examine the evolving correlations between Bitcoin and 14 major financial assets. One finding was that the correlation coefficients between Bitcoin and every asset have significant time variability and ADCC-GARCH model made it possible to capture the dynamic correlation between every asset and Bitcoin.

Joo and Park (2024) explored the use of four different commodity futures to hedge against Bitcoin. In their analysis, they utilised different GARCH models, specifically DCC-GARCH and ADCC-MGARCH, to find conditional correlations and time-varying optimal hedge ratios. This made their findings more reliable and robust. Similar to this thesis, which also employed two different GARCH models, their approach included the use of multiple models to ensure comprehensive and reliable results. Their results indicated that DCC-GARCH model produces higher hedging effectiveness, and incorporating the ADCC-

MGARCH model also proved beneficial for a comprehensive analysis. Their findings closely align with this thesis, suggesting that to minimize portfolio risk and hedge against unexpected events in financial markets, it is recommend using an optimal combination of cryptocurrencies and commodities. BenSaïda's (2023) research further supports the findings of this thesis, demonstrating that the ADCC-GARCH model effectively captures asymmetric effects. Additionally, his study highlights the model's capability to more accurately reflect financial market behaviour during periods of stress, such as the COVID-19 pandemic. All in all, ADCC-GARCH model compliment symmetric DCC-GARCH model highlighting this thesis hedging tools, green bond and gold, hedge properties during the different time periods. Findings are also suggesting that green bond have better hedging properties comparing to gold, especially during the market turmoil.

8 Conclusions

The investment landscape has been changing dramatically in past years. Popularity among investors in Bitcoin has been increased substantially during its existing. Good example of Bitcoin's rising popularity is that according to Bouri et al. (2017) Bitcoin had a market capitalization of $6.5B in the end of 2015 but according to coinmarket.com (2024) Bitcoin's market capitalization has risen to as much as $1.25T on 15 of July 2024. Bitcoin, as a leading cryptocurrency, provides potential for high rewards but investments come with significant volatility. Bouri et al. (2017) indicate that Bitcoin does not serve as a sufficient hedging tool, but it can act an effective diversifier when used in portfolio. In a hedging perspective, Bouri et al. (2020) show that gold have still good hedging properties and Bitcoin should not be used just in that purpose. However, their study shows that Bitcoin is having very promising features and when comparing these assets together, gold is not a strong safe-haven asset during the COVID-19 period. According to BenSaïda (2023), the traditional safe-haven asset gold has a much stronger hedging effectiveness compared to Bitcoin both during the times of market stability and times of crises.

This thesis examines different aspects of hedging Bitcoin using traditional hedging tool gold and also green bond which popularity has been risen due to increasing environmental awareness and the shift towards sustainable finance. In this study idea is to focus on two different periods that partially overlap: the main sample period from January 2015 to March 2022, consisting of 1813 observations per instrument, and the specific COVID-19 pandemic period from February 2020 to March 2022, with 813 observations per instrument. By utilizing DCC-GARCH and ADCC-GARCH models, idea was to analyse the dynamic relationships between these assets to find out their potential as hedging tools during periods of market stress. Also, other research methods were used, which complement the whole study and enrich the thesis. Hedging effectiveness and time-varying correlations was also presented to capture how these relationships change over time. This is also important information for managing risk in volatile markets. Additionally, summary statistics for logarithmic return series and price series of these assets to offer a more detailed view of their volatility and performance.

This study shows that green bonds and gold has significant hedging benefits against Bitcoin, especially during periods of market stress like COVID-19 pandemic. The DCC-GARCH results indicate that past news and volatilities substantially influence current correlations, which emphasizes green bonds' potential as a hedge in both normal and market stress periods. In the same way, gold demonstrates significant dynamic relationships although its hedging effectiveness is different compared to green bond. Results validates gold to be a reliable hedge during the COVID-19 period, but gold is providing less effective hedge comparing to green bond in the normal periods. This finding is crucial for investors who want to diversify their portfolio and use effective hedging tools for very volatile portfolios during market turmoil. Overall, green bond has better diversification and hedging benefits when comparing results from both time periods.

The ADCC-GARCH model results from the main sample period (2015-2022) and the COVID-19 period highlight strong dynamic relationships between green bond and Bitcoin and also between gold and Bitcoin. For the main sample period, the ADCC-GARCH results show that green bond demonstrates a more persistent hedging potential compared to gold, especially in the presence of asymmetric shocks. This can be seen from the higher coefficients from green bond indicating stronger past volatility effecting on the conditional correlations. When analysing ADCC-GARCH results in the COVID-19 period, it can be noticed that green bond-bitcoin pair have even stronger hedging effectiveness which means that green bond can provide better protection against market fluctuations and turmoil compared to gold. The comparison to DCC-GARCH reveal that ADCC-GARCH models not only align closely with the DCC-GARCH findings but also improve the robustness and accuracy by taking account asymmetric responses to market shocks. These results verify also efficient hedging and safe haven properties for green bond over gold also during volatile market stress periods.

When analysing this thesis time-varying correlation results between green bond and Bitcoin, as well as gold and Bitcoin, it is possible to compare insights between their dynamic relationships. Findings indicate a relatively stable and steadily low positive correlation between green bond and Bitcoin during the main sample period. Green bond can be more reliable hedge against Bitcoin, making it an interesting option for investors when thinking different options to mitigate risks. Correlation results show that gold's hedging benefits against Bitcoin is less consistent and also fluctuating substantially during different market conditions. This result is similar comparing to GARCH models findings in this thesis and makes green bond attractive option especially during unstable market periods like the COVID-19 pandemic. Moreover, this study also highlights the higher hedging effectiveness of green bond over gold when paired with Bitcoin. This indicates that green bond can provide a higher level of risk reduction compared to gold when using them as a hedge tool against Bitcoin. This thesis results indicate rejection of the null hypothesis and acceptation of rest of main hypotheses. All of these findings highlight that investors who are aiming for both diversification and sustainable investments should consider green bond as a more favourable hedging tool over gold. Furthermore, green bond can act as a stronger hedging tool also during extreme market conditions.

Green investing, which aim to environmentally sustainable investment strategies, has gained substantial attraction as nowadays there are more awareness of climate change and environmental preservation. Deschryver and De Mariz (2020) mentioned that green bonds and climate bonds have received enormous traction over the recent years because they have helped with the transition towards a low-carbon economy. Arif et al. (2022) also highlights that due to a low-carbon economy transition in different countries there are high interest of using green financial assets as a diversification and hedging tool. Mensi et al. (2023) demonstrate that green bond and gold can have good safe haven features during the COVID-19 period. Their results also indicate good diversification benefits. Nguyen et al. (2020) study highlights also green bonds hedging benefits over conventional bonds. Green bonds help to increase environmental protection and also sustainable side of portfolio, but they can also provide very strong diversification and hedging benefits. Their study shows low or negative correlation of green bonds-stock or green bonds-commodity pair portfolio meaning that green bond is able to provide good diversification benefit and decrease possible portfolio volatility. Furthermore, Ui Haq et al. (2021) study also shows that green bond has strong hedging properties and can act as a strong safe haven asset during economic policy uncertainty, especially against market turmoil such as COVID-19 period.

All these findings enrich and complement this thesis findings in a way that green bond is really a superior hedging tool. Although green bond's hedging properties are changing over time it is still able to provide sufficient benefit for risk-averse investors who are also seeking possible ways to increase socially responsible investments in their portfolios. Also, gold shows relatively good hedging properties over time although overall benefit when using green bond as a hedging tool are higher regarding of this thesis results. Moreover, according to Akhtaruzzman et al. (2021) gold's hedging properties may change dramatically over time and gold is not capable to be safe haven asset during all time periods of market stress. In addition, previous studies indicate mostly similar results regarding of green bond's better hedging properties.

The idea of this study was to present relevant literature review and show key findings on sustainable finance and cryptocurrency by proving empirical evidence on the hedging benefits of green bond and gold against Bitcoin. The growing importance of sustainable investing also led to matter to explore what kind of hedging and diversification benefits green bond could provide against the highly volatile Bitcoin. Moreover, comparing green bonds and gold's hedging properties revealed significant insights from the point of view of whether a green bond could offer as good or even better hedging features comparing to traditional safe haven gold against Bitcoin. As this study is able to verify a significant benefit for using green bond as a hedging tool during different market situations the thesis could provide motivation for additional research regarding hedging and volatility transmission effect.

There are many options to explore in future research. First, researchers could investigate the hedging benefits and volatility connection of green bond-Bitcoin pair and gold-Bitcoin pair during other high volatility market situations, such as the 2008 financial crisis or recent geopolitical events. This could provide deeper understanding from the consistency and reliability of these assets as hedging tools. Another useful option would be to utilise different GARCH models. Basher and Sadorsky (2016) and also Raheem et al. (2023) used GO-GARCH together with DCC-GARCH and ADCC-GARCH to compare the hedging and diversification results produced by different GARCH models. Researchers have developed a variety of GARCH models, many of them will probably remain in empirical use across different fields in the future according to Bollerslev (2023).

Additionally, one option for future research would be to examine the hedging benefits of green bonds from specific industries against Bitcoin. With industry-specific analysis it could be possible to investigate if certain types of green bonds offer more efficient hedging properties. Another idea for future studies could be to include other hedging tools and compare them with green bond. It's important to notice that hedging benefits may change over time so in this case it might be useful to investigate short-term and longer-term hedging benefits separately. Another matter to consider is the hedging costs which may rise a lot in the long term. Additionally, like in this thesis, the main subject was to investigate, whether there are hedging properties against very volatile Bitcoin. One future research option would be to investigate the hedging features of green bonds or other green instruments against other cryptocurrency or major stock indices like S&P500. In the end, this thesis highlights the significance of flexible and diversified investment methods. Green bonds prove to be a valuable asset for enriching risk management and providing portfolio diversification when markets are volatile.

References

Ahmad, W., Sadorsky, P. & Sharma A. (2018). Optimal hedge ratios for clean energy equities. *Economic Modelling*, 72, 278-295. https://doi.org/10.1016/j.econmod.2018.02.008

Akhtaruzzaman, M., Boubaker, S., Lucey, B. M. & Sensoy, A. (2021). Is gold a hedge or a safe-haven asset in the COVID–19 crisis? *Economic Modelling,* 102. https://doi.org/10.1016/j.econmod.2021.105588

Alfaro, I. P. (2024, 28. July). *The Most Affordable Way to Buy Gold: Physical Gold or ETFs?* Investopedia. Retrieved 2024-07-28 from https://www.investopedia.com/articles/investing/031913/most-affordable-way-buy-gold-physical-gold-or-etfs.asp

Alimukhamedov, K. (2024). *Gold Investing Handbook For Asset Managers.* The World Bank. https://documents1.worldbank.org/curated/en/099610302282427760/pdf/IDU136aee178198b114722197d515b4a9f9ef84a.pdf

Ammous, S. (2018). *The Bitcoin Stardard: The Decentralized Alternative to Central Banking.* John Wiley & Sons.

Ammous, S. (2018). Can cryptocurrencies fulfill the functions of money? *The Quarterly Review of Economics and Finance*, 70, 38–51. https://doi.org/10.1016/j.qref.2018.05.010

Arif, M., Naeem, M. A., Farid, S., Nepal, R. & Jamasb, T. (2022). Diversifier or More? Hedge and Safe Haven Properties of Green Bonds During COVID-19. *Energy Police,* 168. https://doi.org/10.1016/j.enpol.2022.113102

Baba, Y., Engle, R. F., Kraft, D. F. & Kroner, K. F. (1990). *Multivariate Simultaneous Generalized ARCH*. MIMEO, Department of Economics, University of California, San Diego.

Basher, S. A. & Sadorsky, P. (2016). Hedging emerging market stock prices with oil, gold, VIX, and bonds: A comparison between DCC, ADCC and GO-GARCH. *Energy Economics*, 54, 235-247. https://doi.org/10.1016/j.eneco.2015.11.022

Baur, D. G., Dimpfl, T. (2021). The volatility of Bitcoin and its role as a medium of exchange and a store of value. *Empirical Economics,* 61, 2663–2683. https://doi.org/10.1007/s00181-020-01990-5

Baur, D., Hong, K. & Lee, A. D. (2018). Bitcoin: medium of exchange or speculative assets? *Journal of International Financial Markets, Institutions and Money*, 54, 177–189. https://doi.org/10.1016/j.intfin.2017.12.004

Baur, D. G., & Lucey, B. M. (2010). Is gold a hedge or a safe haven? An analysis of stocks, bonds and gold. *Financial Review*, 45(2), 217–229. https://doi.org/10.1111/j.1540-6288.2010.00244.x

Baur, D. G. & McDermott, T. K. (2010). Is gold a safe haven? International evidence. *Journal of Banking & Finance*, 34(8), 1886–1898. https://doi.org/10.1016/j.jbankfin.2009.12.008

BenSaïda, A. (2023). Safe haven property of gold and cryptocurrencies during COVID-19 and Russia–Ukraine conflict. *Annals of Operations Research.* https://doi.org/10.1007/s10479-023-05517-w

Bhanja, N. & Dar, A. B. (2015). “The beauty of gold is, it loves bad news”: evidence from three major gold consumers. *Economic Change and Restructuring*, 48, 187–208. https://doi.org/10.1007/s10644-015-9160-z

Bodhanwala, S. and Bodhanwala, R. (2019). Relationship between sustainable and responsible investing and returns: a global evidence. *Social Responsibility Journal*, 16(4), 579-594. https://doi.org/10.1108/SRJ-12-2018-0332

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, 31(3), 307-327. https://doi.org/10.1016/0304-4076(86)90063-1

Bollerslev, T. (1990). Modelling the Coherence in Short-Run Nominal Exchange Rates: A Multivariate Generalized Arch Model. *The Review of Economics and Statistics,* 72(3), 498-505. https://doi.org/10.2307/2109358

Bollerslev, T. (2023). The story of GARCH: A personal odyssey. *Journal of Econometrics,* 234, 96-100. https://doi.org/10.1016/j.jeconom.2023.01.015

Bouri, E., Gupta, R., Tiwari, A.K. & Roubaud, D. (2017a). Does bitcoin hedge global uncertainty? evidence from wavelet-based quantile-in-quantile regressions.

Finance Research Letters, 23(November), 87–95. https://doi.org/10.1016/j.frl.2017.02.009

Bouri, E., Lucey, B. & Roubaud, D. (2020). Cryptocurrencies and the downside risk in equity investments. *Finance Research Letters,* 33. https://doi.org/10.1016/j.frl.2019.06.009

Bouri, E., Molnár, P., Azzi, G., Roubaud, D. & Hagfors, L. I. (2017b). On the hedge and safe haven properties of Bitcoin: Is it really more than a diversifier? *Finance Research Letters,* 20, 192–98. https://doi.org/10.1016/j.frl.2016.09.025

Bridgewater. (2021). Inside the research engine: assessing the gold market with the world gold council. Westport, CT: Bridgewater Associates.

Brière, M., Oosterlinck, K. & Szafarz, A. (2015). Virtual currency, tangible return: Portfolio diversification with bitcoin. *Journarl of Asset Management,* 16, 365–373. https://doi.org/10.1057/jam.2015.5

Brinkman, M. (2009). *Incentivizing Private Investment in Climate Change Mitigation*. In: Climate Finance. Ed. By R. Stewart, B. Kingsbury and B Rudyk. New York University Press.

Brito, J. & Castillo, A. (2013). *Bitcoin: A Primer for Policymakers.* Mercatus Center at George Mason University, Arlington, VA.

Brooks, C. (2014). *Introductory Econometrics for Finance*. 3rd Edition, Cambridge University Press.

Brundtland Report. (1987, 20. March). *Our Common Future.* Retrieved 2024-06-28 from https://www.are.admin.ch/are/en/home/media/publications/sustainable-development/brundtland-report.html

Cappiello, L., Engle, R. F., & Sheppard, K. (2006). Asymmetric dynamics in the correlations of global equity and bond returns. *Journal of Financial econometrics,* 4(4), 537-572. https://doi.org/10.1093/jjfinec/nbl005

Chevallier, J. (2012). Time-varying correlations in oil, gas and CO2 prices: an application using BEKK, CCC and DCC-MGARCH models. *Applied Economics,* 44(32), 4257-4274. https://doi.org/10.1080/00036846.2011.589809

Chua, J. H., Sick, G. & Woodward, R. S. (1990). Diversifying with Gold Stocks. *Financial Analysts Journal,* 46(4), 76-79. http://www.jstor.org/stable/4479351

Chua, J. H. & Woodward, R. S. (1982). Gold As An Inflation Hedge: A Comparative Study of Six Major Industrial Countries. *Journal of Business Finance & Accounting,* 9(2), 191-197. https://doi.org/10.1111/j.1468-5957.1982.tb00985.x

Climate Bonds Initiative. (2017). *The role of exchanges in accelerating the growth of the green bond market.* Retrieved 2024-07-01 from https://www.climatebonds.net/files/files/RoleStock%20Exchanges.pdf

Climate Bonds Initiative. (2024, 2. May). *Sustainable debt global state of the market 2023.* Retrieved 2024-06-28 from https://www.climatebonds.net/files/reports/cbi_sotm23_02h.pdf

CoinDesk. (2024). *Bitcoin.* Retrieved 2024-07-18 from https://www.coindesk.com/price/bitcoin

CoinMarketCap.com (2024). *All Cryptocurrencies.* Retrieved 2024-5-13 from https://coinmarketcap.com/all/views/all/

Creti, A., Joets, M. & Mignon, V. (2013). On the links between stock and commodity markets' volatility. *Energy Economics,* 37, 16-28. https://doi.org/10.1016/j.eneco.2013.01.005

Dabrowski, M. & Janikowski, L. (2018). *Virtual currencies and central banks monetary policy: challenges ahead.* European Parliament. Retrieved 2024-06-02 from https://www.europarl.europa.eu/cmsdata/149900/CASE_FINAL%20publication.pdf

Dawar, I., Dutta, A., Bouri, E. & Saeed, T. (2021). Crude oil prices and clean energy stock indices: Lagged and asymmetric effects with quantile regression. *Renewable Energy*, 163, 288-299. https://doi.org/10.1016/j.renene.2020.08.162

Delmas, M. A. & Burbano, V. C. (2011). The Drivers of Greenwashing. *California Management Review*, 54(1), 64–87. https://doi.org/10.1525/cmr.2011.54.1.64

Deschryver, P. & De Mariz, F. (2020). What Future for the Green Bond Market? How can Policymakers, Companies and Investors Unlock the Potential of the Green Bond

Market? *Journal of Risk and Financial Management,* 13(3). https://doi.org/10.3390/jrfm13030061

Dhawan, S. (2023, 20. April). *Different ways to buy and invest in gold.* The Economic Times. Retrieved 2024-06-27 from https://economictimes.indiatimes.com/wealth/invest/different-ways-to-buy-and-invest-in-gold/articleshow/64568785.cms?from=mdr.

Dutta, A. (2018). A note on the implied volatility spillovers between gold and silver markets. *Resources Policy,* 55, 192-195. https://doi.org/10.1016/j.resourpol.2017.11.017

Dutta, A., Bouri, E. & Noor, H. (2021). Climate bond, stock, gold, and oil markets: Dynamic correlations and hedging analyses during the COVID-19 outbreak. *Resources Policy*, 74. https://doi.org/10.1016/j.resourpol.2021.102265

Dutta, A., Bouri, E., Saeed, T. & Vo, X. V. (2020a). Impact of energy sector volatility on clean energy assets. *Energy,* 212, 1-11. https://doi.org/10.1016/j.energy.2020.118657

Dutta, A., Das, D., Jana, R. K. & Vo, X. V. (2020b). Covid-19 and oil market crash: Revisiting the safe haven property of gold and bitcoin. *Resources Policy*, 69. https://doi.org/10.1016/j.resourpol.2020.101816

Dwyer, G. P. (2015). The economics of Bitcoin and similar private digital currencies. *Journal of Financial Stability,* 17, 81-91. https://doi.org/10.1016/j.jfs.2014.11.006

Dyhrberg, A. H. (2016). Hedging Capabilities of bitcoin. Is it the virtual gold? *Finance Research Letters,* 16, 139 – 144. https://doi.org/10.1016/j.frl.2015.10.025

Edwards, J. (2024. 26. May). *Bitcoin's Price History.* Investopedia. Retrieved 2024-06-12 from https://www.investopedia.com/articles/forex/121815/bitcoins-price-history.asp

Ehlers, T. & Packer, F. (2017, 17. September). Green Bond Finance and Certification. BIS Quarterly Review September 2017. Retrieved 2024-07-05 from https://ssrn.com/abstract=3042378

Elsayed, A. H. & Helmi, M. H. (2021). Volatility transmission and spillover dynamics across financial markets: the role of geopolitical risk. *Annals of Operations Research,* 305, 1-22. https://doi.org/10.1007/s10479-021-04081-5

Engle, R. F. (1982). Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation. *Econometrica*, 50(4), 987-1007. https://doi.org/10.2307/1912773

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. https://www.jstor.org/stable/1392121

Engle, R. F. & Kroner, K. (1995). Multivariate Simultaneous GARCH. *Econometric Theory*, 11(1), 122-150. http://dx.doi.org/10.1017/S0266466600009063

Engle, R. F., & Ng, V. (1993). Measuring and testing the impact of news of volatility. *Journal of Finance*, 48, 1749-1478. https://doi.org/10.2307/2329066

European Comission. (2018). *Financing a sustainable European economy.* Retrieved 2024-07-15 from https://finance.ec.europa.eu/system/files/2018-01/180131-sustainable-finance-final-report_en.pdf

European Comission. (2024a). *European Climate Law.* Retrieved 2024-07-23 from https://climate.ec.europa.eu/eu-action/european-climate-law_en

European Comission. (2024b). Renewable energy targets. Retrieved 2024-07-23 from https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en

EuroSIF. (2018). *European SRI Study 2018.* Retrieved 2024-06-28 from https://www.eurosif.org/wp-content/uploads/2021/10/European-SRI-2018-Study.pdf

Fashola, M. O., Ngole-Jeme, V. M. & Babalola, O. O. (2016). Heavy Metal Pollution from Gold Mines: Environmental Effects and Bacterial Strategies for Resistance. International Journal of Environmental Research and Public Health, 13(12), 1-20. https://doi.org/10.3390/ijerph13111047

FATF. (2014). *Virtual Currencies - Key Definitions and Potential AML/CFT Risks.* Retrieved 2024-05-28 from https://www.fatf-gafi.org/content/dam/fatf-gafi/reports/Virtual-currency-key-definitions-and-potential-aml-cft-risks.pdf

Floyd, D. (2024, 13. June). *How Bitcoin Works.* Investopedia*. Retrieved 2024-07-16 from* https://www.investopedia.com/news/how-bitcoin-works/

Foley, S., Karlsen, J. R. & Putniņš, T. J. (2019). Sex, drugs, and Bitcoin: How much illegal activity is financed through cryptocurrencies? *The Review of Financial Studies*, 32(5), 1798–1853. https://doi.org/10.1093/rfs/hhz015

Folger, J. (2023, 17. December). *What drives the price of Gold?* Investopedia. Retrieved 2024-06-05 from https://www.investopedia.com/financial-edge/0311/what-drives-the-price-of-gold.aspx

Frankenfield, J. (2024). *Bitcoin Mining.* Investopedia. Retrieved 2024-06-28 from https://www.investopedia.com/terms/b/bitcoin-mining.asp.

Gao, L., Guo, K. & Xianhua, W. (2023). Dynamic relationships between green bonds and major financial asset markets from the perspective of climate change. *Frontiers in Environmental Science,* 10. https://doi.org/10.3389/fenvs.2022.1109796

Glosten, L. R., Jagannathan, R. & 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(5), 1779-1801. https://doi.org/10.1111/j.1540-6261.1993.tb05128.x

Goetz, L. (2023, 27. July). *How Do You Purchase Physical Gold Bars?* Investopedia. Retrieved 2024-07-01 from: https://www.investopedia.com/articles/investing/072316/how-do-you-purchase-physical-gold-bars.asp

Granger, C. W. J. & Poon, S. (2002, 18. September). Forecasting Volatility in Financial Markets: A Review. http://dx.doi.org/10.2139/ssrn.331800

Grinberg, R. (2012). Bitcoin: An Innovative Alternative Digital Currency. *Hasting Science and Technology Law Journal*, 4(1). https://repository.uchastings.edu/hastings_science_technology_law_journal/vol4/iss1/3

Grobys, K. (2020). When Bitcoin has the flu: on Bitcoin's performance to hedge equity risk in the early wake of the COVID-19 outbreak. *Applied Economics Letters,* 28(10), 860-865. https://doi.org/10.1080/13504851.2020.1784380

Gustafsson, R., Dutta, A. & Bouri, E. (2022). Are energy metals hedges or safe havens for clean energy stock returns? *Energy*, 244(A). https://doi.org/10.1016/j.energy.2021.122708

Haq, I. U., Chupradit, S. & Huo, C. (2021). Do green bonds act as a hedge or a safe haven against economic policy uncertainty? evidence from the USA and China. *International Journal of Financial Studies*, 9(3), 1-18 https://doi.org/10.3390/ijfs9030040

Hazen, T. L. (2019). Tulips, Oranges, Worms, and Coins – Virtual, Digital, or Crypto Currency and the Securities Laws. *North Carolina Journal of Law & Technology,* 20(4), 493-528. https://scholarship.law.unc.edu/ncjolt/vol20/iss4/3

Hayes, A. (2024, 13. March). *What Happens to Bitcoin After All 21 Million Are Mined?* Investopedia. Retrieved 2024-06-06 from https://www.investopedia.com/tech/what-happens-bitcoin-after-21-million-mined/

He, D. (2018). Monetary Policy in the Digital Age: Crypto assets may one day reduce demand for central bank money. *Finance & Development (IMF),* 55(2), 13-16. https://www.imf.org/external/pubs/ft/fandd/2018/06/pdf/fd0618.pdf

Hileman, G. & Rausch, M. (2017). *Global Cryptocurrency Benchmarking Study.* Cambridge University, Cambridge Center for Alternative Finance: Cambridge. https://ssrn.com/abstract=2965436

Hill, A. T. (2013). *Functions and Characteristics of Money.* Federal Reserve Bank of Philadelphia. Retrieved 2024-06-06 from https://www.philadelphiafed.org/-/media/frbp/assets/institutional/education/lesson-plans/functions-and-characteristics-of-money-lesson.pdf

Houben, R. & Snyers, A. (2018). *Cryptocurrencies and blockchain: Legal context and implications for financial crime, money laundering and tax evasion*. European

Union. Retrieved 2024-07-15 from https://data.europa.eu/doi/10.2861/280969

Huang, R. (2020, 18. May). *Bitcoin vs. Inflation.* Forbes. Retrieved 2024-06-28 from https://www.forbes.com/sites/rogerhuang/f2020/05/18/bitcoin-vs-inflation/?sh=4ac6641f1c07

Huberman, G., Leshno, J. D. & Moallemi, C. (2017). Monopoly without a monopolist: An economic analysis of the bitcoin payment system. *Bank of Finland Research Discussion Papers*, 27. https://urn.fi/URN:NBN:fi:bof-201709051593

Hull, J. (2015). *Options, futures and other derivatives* (9th ed.). Pearson Prentice Hall.

ICMA. (2024, 25. June). *The Principles announce guidance for green enabling projects and guidelines for Sustainability-Linked Loan financing Bonds (SLLB) alongside other important updates.* Retrieved 2024-07-28 from https://www.icmagroup.org/News/news-in-brief/the-principles-announce-guidance-for-green-enabling-projects-and-guidelines-for-sustainability-linked-loan-financing-bonds-sllb-alongside-other-important-updates/

Jaffe, J. F. (1989). Gold and Gold Stocks as Investments for Institutional Portfolios. *Financial Analysts Journal,* 45(2), 53 – 59. http://www.jstor.org/stable/4479205

Joo, Y. C. & Park, S. Y. (2024). Hedging Bitcoin with commodity futures: An analysis with copper, gas, gold, and crude oil future. *The North American Journal of Economics and Finance,* 72. https://doi.org/10.1016/j.najef.2024.102127

Karniol-Tambour, K., Ross, T., Tsarapkina, D., Sondheimer, J. & Barnes, W. (2022, 14. January). *The Evolution of Institutional Investors' Exposure to Cryptocurrencies and Blockchain Technologies.* Bridgewater. Retrieved 2024-07-15 from https://www.bridgewater.com/research-and-insights/the-evolution-of-institutional-investors-exposure-to-cryptocurrencies-and-blockchain-technologies

Kelleher, J. (2024, 10. April). *Why Do Bitcoins Have Value?* Investopedia. Retrieved 2024-06-16 from https://www.investopedia.com/ask/answers/100314/why-do-bitcoins-have-value.asp

Keskitalo, K. (2022). *Suomen rahan sääntelyn oikeushistoria – raha oikeudellisena maksuvälineenä ennen ja nyt* [väitöskirja, Helsingin yliopisto]. Helsingin yliopisto. http://urn.fi/URN:ISBN:978-951-51-7897-8

Kethineni, S. & Cao, Y. (2019). The rise in popularity of cryptocurrency and associated criminal activity. *International Criminal Justice Review*, 30(3), 325–344. https://doi.org/10.1177/1057567719827051

Koksal, I. (2019, 23. October). *The Benefits Of Applying Blockchain Technology In Any Industry*. Forbes. Retrieved 2024-06-28 from https://www.forbes.com/sites/ilkerkoksal/2019/10/23/the-benefits-of-applying-blockchain-technology-in-any-industry/?sh=493d900749a5

Ku, Y. H. H., Chen, H. C., & Chen, K. H. (2007). On the application of the dynamic conditional correlation model in estimating optimal time-varying hedge ratios. *Applied Economics Letters,* 14, 503-509. http://doi.wiley.com/10.1080/13504850500447331

Lehto-Isokoski, H. (2014, 18. November). *Sijoituskulta säihkyy arvaamattomasti.* Taloustaito. Retrieved 2024-06-28 from https://www.taloustaito.fi/Rahat/Sijoituskulta-saihkyy-arvaamattomasti/#7aa1bf73

Lin, B., Wesseh, P. K. & Appiah, M. O. (2014). Oil price fluctuation, volatility spillover and the Ghanaian equity market: Implication for portfolio management and hedging effectiveness. *Energy Economics*, 42, 172-182. https://doi.org/10.1016/j.eneco.2013.12.017

Ling, S. & McAleer, M. (2003). Asymptotic Theory for a Vector ARMA-GARCH Model. *Econometric Theory*, 19(2), 280-310. http://www.jstor.org/stable/3533354

Mardi, D. & Howlander, J. (2022). Anonymous Bitcoin transaction: A solution using secure multiparty computation. *Security and privacy,* 5(4). https://doi.org/10.1002/spy2.232

Maume, P. (2019). Initial Coin Offerings and EU Prospectus Regulation. *European Business Law Review,* 31, 185-208. https://ssrn.com/abstract=3317497

Mensi, W., Vo, X. V., Ko, H. & Kang, S. H. (2023). Frequency spillovers between green bonds, global factors and stock market before and during COVID-19 crisis. *Economic Analysis and Policy*, 77, 558-580. https://doi.org/10.1016/j.eap.2022.12.010

Mezghani, T., Hamadou, F. & Boujelbene-Abbes, M. (2023). Network connectedness and portfolio hedging of green bonds, stock markets and commodities. *International Journal of Emerging Markets.* https://doi.org/10.1108/IJOEM-02-2023-0160

Ministery of the Environment. (2024). *Pariisin ilmasto-sopimus.* Retrieved 2024-07-23 from https://ym.fi/pariisin-ilmastosopimus

Mcmillan, R. (2014, 3. March). *The Inside Story of MT. Gox, Bitcoin´s $460 Million Disaster.* Wired. Retrieved 2024-06-20 from https://www.wired.com/2014/03/bitcoin-exchange/

Nakamoto, S. (2008). *Bitcoin: A Peer – to – Peer Electronic Cash System.* Bitcoin. Retrieved 2024-06-05 from http:// bitcoin.org/bitcoin.pdf

Newman, C. (2017). *Bitcoin from beginner to expert: the ultimate guide to cryptocurrency and blockchain*. Independently published.

Nelson, D. B. (1991). Conditional heteroskedasticity in asset returns: A new approach. *Econometrica,* 59, 347-370. https://doi.org/10.2307/2938260

Nguyen, T. T. H., Naeem, M. A., Balli, F., Balli, H. O. & Vo, X. V. (2020). Time-frequency comovement among green bonds, stocks, commodities, clean energy, and conventional bonds. *Finance Research Letters,* 40. https://doi.org/10.1016/j.frl.2020.101739

Niskanen, V. (2020). *Kultaa sijoittaminen eri sijoitustuotteilla?* Lynx. Saatavissa: https://www.lynxbroker.fi/sijoitusblogi/etf/kultaan-sijoittaminen/

Platanakis, E. & Urquhart, A. (2020). Should Investors Include Bitcoin in Their Portfolios? A Portfolio Theory Approach. *British Accounting Review*, 52(4), 1-42. https://doi.org/10.1016/j.bar.2019.100837

Poon, S. H. & Granger, C. W. J. (2002). Forecasting volatility in financial markets: A Review. *Journal of Econometric Literature*, 41(2), 679-682. https://doi.org/10.1257/002205103765762743

Quinson, T. & Benhamou, M. (2021, 19. May). *Banks Always Backed Fossil Fuel Over Green Projects - Until This Yeart.* Bloomberg. Retrieved 2024-07-02 from https://www.bloomberg.com/graphics/2021-wall-street-banks-ranked-green-projects-fossil-fuels/?embedded-checkout=true

Raheem, I. D., Akinkugbe, O., Yusuf, A. H. & Asl, M. G. (2022). Hedging strategies among financial markets: the case of green and brown assets. *Empirical Economics,* 65, 831-873. https://doi.org/10.1007/s00181-023-02358-1

Reboredo, J. C. (2018). Green bond and financial markets: Co-movement, diversification and price spillover effects. *Energy Economics,* 74, 38–50. https://doi.org/10.1016/j.eneco.2018.05.030

Reboredo, J. C. & Rivera-Castro, M. A. (2014). Gold and exchange rates: Downside risk and hedging at different investment horizons. *International Review of Economics and Finance,* 34, 267-279. https://doi.org/10.1016/j.iref.2014.07.005

Reihcelt, H. & Keenan, C. (2017, December). *The Green Bond Market: 10 years later and looking ahead.* The World Bank. Retrieved 2024-07-05 from https://thedocs.worldbank.org/en/doc/460121522347658092-0340022018/original/publicationpensionfundservicegreenbonds201712.pdf

Reid, F. & Harrigan, M. (2013). *An Analysis of Anonymity in the Bitcoin System.* In: Altshuler, Y., Elovici, Y., Cremers, A., Aharony, N., Pentland, A. (eds), Security and Privacy in Social Networks (pp. 197–223). Springer, New York, NY. https://doi.org/10.1007/978-1-4614-4139-7_10

Reif, N. (2024, 10. April). *How Much of All Money Is in Bitcoin?* Investopedia. Retrieved 2024-06-14 from https://www.investopedia.com/tech/how-much-worlds-money-bitcoin/

Saeed, T., Bouri, E. & Tran, D. K. (2020). Hedging strategies of green assets against dirty energy assets. *Energies,* 13(12). https://doi.org/10.3390/en13123141

Saeed, T., Bouri, E. & Alsulami, H. (2021). Extreme return connectedness and its determinants between clean/green and dirty energy. *Energy Economics,* 96. https://doi.org/10.1016/j.eneco.2020.105017

Schaeffer, R., Borba, B. S.M.C., Rathmann, R., Szklo, A. & Castelo Branco, D. A. (2012). Dow Jones sustainability index transmission to oil stock market returns: A GARCH approach. *Energy*, 45(1), 933-943. https://doi.org/10.1016/j.energy.2012.06.066

Schaltenbrand, B., Foerstl, K., Azadegan, A. & Lindeman, K. (2018). See What We Want to See? The Effects of Managerial Experience on Corporate Green Investments. *Journal of Business Ethics*, 150(4), 1129–1150. https://doi.org/10.1007/s10551-016-3191-x

Shafiee, S. & Topal, E. (2010). An Overview of Global Gold Market and Gold Price Forecasting. *Resources policy,* 35(3), 178-189. https://doi.org/10.1016/j.resourpol.2010.05.004

Silvola, H. & Landau, T. (2019). *Vastuullisuudesta ylituottoa sijoituksiin.* Alma Talent.

Solt, M. E. & Swanson, P. J. (1981). On the efficiency of the markets for gold and silver. *Journal of Business*, 54(3), 453–478. http://dx.doi.org/10.1086/296140

Spithoven, A. (2019). Theory and Reality of Cryptocurrency Governance. *Journal of Economic Issues*, 53(2), 385-393. https://doi.org/10.1080/00213624.2019.1594518

Statista. (2024). *Mine production of gold worldwide from 2010 to 2023.* Retrieved 2024-24-05 https://www.statista.com/statistics/238414/global-gold-production-since-2005/

Statista Research Department. (2024, 21. August). *Annual development of the Bloomberg Barclays MSCI Global Green Bond Index 2016-2021.* Retrieved 2024-08-21 from https://www.statista.com/statistics/1109189/bloomberg-barclays-msci-global-green-bond-index-development/

Tully, E. & Lucey, B. M. (2007). A power GARCH examination of the gold market. *Research in International Business and Finance*, 21(2), 316–325. https://doi.org/10.1016/j.ribaf.2006.07.001

Vaihekoski, M. (2020). *Sijoittajan korko-opas*. Suomen Pörssisäätiö. Retrieved 2024-07-05 from: https://www.porssisaatio.fi/app/uploads/2023/12/Sijoittajan-korko-opas-2020.pdf

TheCityUk. (2022, 31. March). *Accelerating growth for global green finance.* Retrieved 2024-07-01 from https://www.thecityuk.com/news/accelerating-growth-for-global-green-finance/

The European Central Bank. (2012). *Virtual currency schemes.* Retrieved 2024-05-28 from https://www.ecb.europa.eu/pub/pdf/other/virtualcurrencyschemes201210en.pdf?941883c8460133b7758f498192a3ed9e

The Green Bond Principles. (2021, June). *Voluntary Process Guidelines for Issuing Green Bonds.* Retrieved 2024-07-05 from https://www.icmagroup.org/assets/documents/Sustainable-finance/2022-updates/Green-Bond-Principles-June-2022-060623.pdf

Tolliver, C., Keeley, A. R. & Managi, S. (2019). Green bonds for the Paris agreement and sustainable development goals. *Environmental Research letters,* 14, 1-14. https://doi.org/10.1088/1748-9326/ab1118

Wang, P., Liu, X. & Wu, S. (2022). Dynamic Linkage between Bitcoin and Traditional Financial Assets: A Comparative Analysis of Different Time Frequencies. *Entropy,* 24. https://doi.org/10.3390/e24111565

World Bank Group. (2019, 18. March). *10 Years of Green Bonds: Creating the Blueprint for Sustainability Across Capital Markets.* Retrieved 2024-07-05 from https://www.worldbank.org/en/news/immersive-story/2019/03/18/10-years-of-green-bonds-creating-the-blueprint-for-sustainability-across-capital-markets

World Gold Council. (2024a, 28. March). Gold Demand Trends Full Year 2023. Retrieved 2024-05-15 from https://www.gold.org/goldhub/research/gold-demand-trends/gold-demand-trends-full-year-2023

World Gold Council. (2024b, 28. March). *Gold as a strategic asset: 2024 edition.* Retrieved 2024-05-15 from https://www.gold.org/goldhub/research/relevance-of-gold-as-a-strategic-asset/golds-key-attributes-1-return

WWF (World Wildlife Fund). (2022). *Ilmastonmuutos.* Retrieved 2024-06-28 from https://wwf.fi/uhat/ilmastonmuutos/

Yahya, M., Ghosh, S., Kanjilal, K., Dutta, A. & Uddin, G. S. (2020). Evaluation of cross-quantile dependence and causality between nonferrous metals and clean energy indexes. *Energy, 202, 1-14. https://doi.org/10.1016/j.energy.2020.117777*

Yermack, D. (2013). Is Bitcoin a Real Currency? *NBER Working Paper Series,* 19747. https://doi.org/10.1016/B978-0-12-802117-0.00002-3

Zakoian, J. M. (1994). Threshold heteroskedastic models. *Journal of Economic Dynamics and Control*, 113(488), 931-944. http://doi.wiley.com/10.1111/1468-0297.13911