

The Eligibility of Green Bonds as Safe Haven Assets: A Systematic Review

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Abstract: This study follows Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to examine the existing literature on the connectedness of green bonds with other markets as an attempt to highlight the effectiveness of green bonds in risk management and the benefits associated with incorporating green bonds in investment portfolios. An extensive search of relevant research papers to the scope of the review led to the identification of 31 articles published by February 2022. Our analysis traces the evolution of studies on green bonds' interactions with other markets, the methodologies and data frequencies used for cross-market relations analysis, and the role of green bonds in portfolio risk management (diversifier, hedge, and safe-haven) in normal and extreme market conditions. The study reports several interesting findings. First, green bonds can be a strategic safe-haven avenue for investors in stocks, dirty energy stocks, and the foreign exchange market in the US and China in extreme market downturns. Second, green bonds demonstrated hedging properties against spillovers from Bitcoin, forex, soft commodities, and CO₂ emission allowance. Third, the role of green bonds in the markets of natural gas, industrial metals, and crude oil is limited to a portfolio diversifier in different investment horizons. Fourth, green bonds had no diversification or hedge benefits for investors in conventional bonds. Fifth, the interrelationships between green bonds and most markets' understudy were influenced by macroeconomic and global factors such as the COVID-19 pandemic, economic policy uncertainty, OVX, and VIX. Our review of the literature also facilitated identification of future research topics. The outcome of the review offers insightful information to investors in green bonds in risk management and assets allocation. Policy makers can benefit from this review in effective policy legislation for the advancement of the green bonds market and acceleration of a smooth transition to a net zero emission economy.



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Keywords: green bonds; safe haven; diversification; hedge; risk management

1. Introduction

The study of financial crisis enhances our understanding of the deficiencies in our financial systems and the exposure of financial markets to idiosyncratic and external risks, which threaten businesses, markets, and the overall economy to delve into spirals of economic recession. With the transformation of the world's economy into an increasingly financially integrated system, the severity of a crisis is highly unlikely to be region- or market-specific. In fact, a crisis in one market is anticipated to be transmitted in a synchronized way over different markets or even the entire global financial system, triggering contagion or spillover effects. A case in point is the global financial crisis of 2007–2008, which emerged in a developed country and spread worldwide. This phenomenon could potentially cripple the foundations of financial systems, induce markets to crash, and force businesses and corporates to shut down.

History is a good place to trace the aftermath of crises on financial markets, learn from past mistakes, and construct a proactive roadmap of risk mitigation for upcoming crises to limit their virulence and ferocity. In the event of a crisis outbreak, a key challenge facing investors is searching for ways to mitigate uncertainties in their portfolios. One way to

do so is by investing in safe-haven assets capable of shielding portfolios from incurring significant losses. A safe-haven asset has the potential to compensate investors for the losses endured in a depreciating asset through the appreciation in the value of another asset. The relentless quest of searching for a hedge and safe-haven assets is vital when crisis strikes.

From an academic perspective, crises have the potency to stimulate research in a certain field. Particularly, research in cross-market interactions tends to gain momentum post a crisis outbreak. Islamic banking, for example, earned global recognition after the 2007–2008 crisis [1,2]. The promising signs of shock resilience demonstrated by Islamic banks was the perfect pitch for Islamic banks to penetrate the financial system globally. While investors are on a hunt for safe-haven assets during crises for risk management purposes, academia is intrigued to explore markets' relations to understand markets' interdependence, capture channels of risk transmission, spot favorable investment opportunities, and guide investors to profitable investments. The outcome of these studies facilitates policy legislation to promote a safer financial system and avert future crises.

With the emergence of green bonds to decarbonize investment portfolios, ethical investors are fascinated by the mandate and mission green bonds thrive to achieve. Thereby, the green fixed-income asset can be considered as a vehicle targeting ecological goals. As a multifacet asset, green bond hedge and safe-haven properties became apparent with extreme market volatilities and the outbreak of the COVID-19 pandemic. The negative and low correlations between green bonds [3–5] and other assets (e.g., stocks and crude oil) positioned green bonds as strategic risk–reward investments during crises such as the COVID-19 pandemic. Research in green bonds' cross-market relations has increased significantly in recent years. The focus of these studies was mainly on risk transmission behavior from and to green bonds. This step allowed researchers to test the ability of green bonds to offer shelter to price oscillation in other markets and ultimately classify the role of green bonds across different markets into diversifier, hedge, and safe-haven asset. These studies offer investors insightful information about the incorporation of green bonds in investment portfolios for risk management purposes.

Against this backdrop, researchers have used various econometric methodologies to comprehensively explore green bonds' connectedness with other markets over different investment horizons. The findings of these studies, however, remain inconclusive and contradictory. Therefore, it is important to carry out a systematic literature review of studies examining green bonds' interaction with other markets to understand the relationship between green bonds and the respective markets. This study attempts to answer four research questions:

1. How did the literature on green bonds' interaction with other assets evolve?
2. What are the prominent data frequencies and methodologies used in the literature of green bonds' relationship with other markets?
3. How are green bonds used in cross-market interactions?
4. What are the implications of the research outcomes and the future trends?

The significance of this study lies in its contribution to delineate a holistic overview of green bonds' relations with other asset classes as an attempt to validate the capacity of green bonds in risk management as diversifiers, hedges, or safe havens in bullish and bearish market conditions. The outcome of the review serves as a pathway for the identification of future research trends and lay policy recommendations. To the best of our knowledge, a systemic literature review of markets' interactions between green bonds and other assets has not been conducted. This study attempts to fill this gap in the literature.

The rest of the paper is organized as follows. Section 2 sets the outline for data inclusion and methodology. Section 3 presents the results of the study by illustrating a theoretical background for the most important concepts used in this review, demonstrates the evolution of the research topic, discusses data frequency and prominent methodologies used by the articles under study to examine cross-market relations, and explores the relationship between green bonds and selected assets from the existing literature. Section 4

identifies future research trends in the scope of green bonds' interaction with other assets. The study is concluded in Section 5 and proposes policy recommendations in Section 6.

2. Materials and Methods

A systematic literature review uses transparent, organized, and replicable procedures to locate and synthesize research that addresses specific questions [6,7]. A Systematic literature review is an insightful tool to delineate a thorough overview of the scientific evidence of an area of interest as an attempt to single out research gaps in the literature and new research directions via the identification and evaluation of research trends and existing studies in a research topic [8]. Systematic literature reviews come in different forms, ranging from bibliometric reviews [9], meta-analysis reviews [10], theory-based reviews, structured reviews [11], and framework-based reviews [12], among others.

This review draws upon existing studies in the scope of green bonds' connectedness with other asset classes to present a landscape of the academic literature in the respective fields of research. This review adopts a four-step process for the identification and selection of research papers relevant to our study, as shown in Figure 1. We initiated this study in March 2022 by extracting research papers from the Scopus database relevant to the scope of our research domain. Scopus and Web of Science are well-known high-quality disciplinary literature databases [13,14]. Second, we identified an initial search criterion by developing keyword combinations based on the existing literature. Third, we developed a screening criterion utilizing bibliometric techniques to narrow down significant studies that are relevant to the scope of our research.

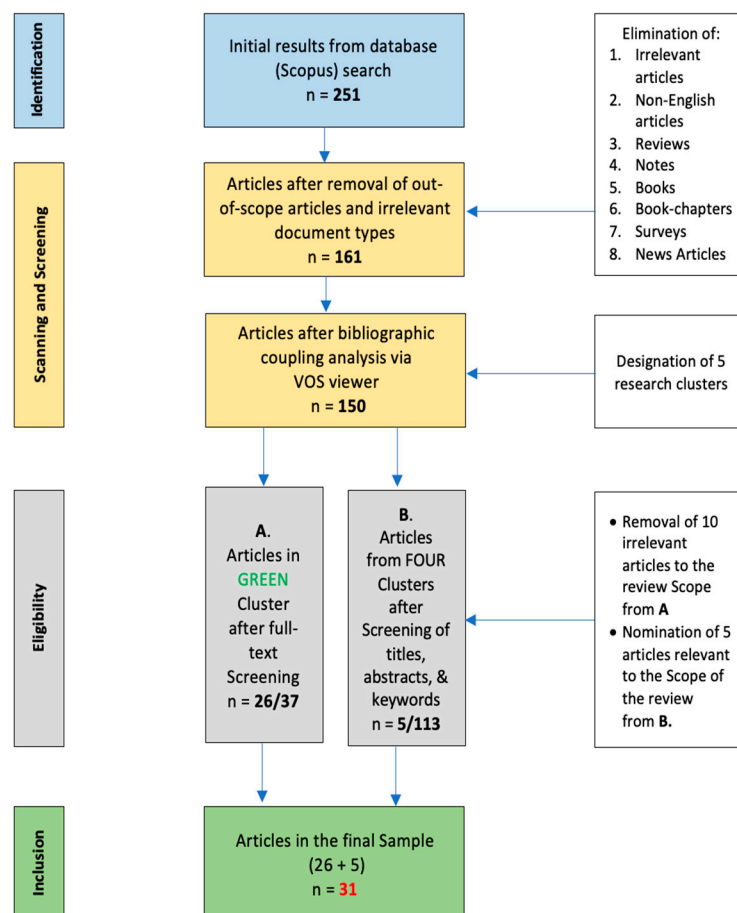


Figure 1. PRISMA Protocol in sample selection (see Supplementary Materials).

2.1. Sample Selection

Our sample selection process started with developing keywords combinations based on a preliminary review of the available literature to incorporate all studies conducted on green bonds. We proposed viable variations of terms used in the extant literature of green bonds, such as “green bonds”, “sustainable bonds”, “climate bonds”, “ecological bonds”, “solar bonds”, “green sukuk”, “greenium”, and “green premium”, separated by the Boolean OR operator as the search query in the Scopus database. The reason behind a general search for all green bond publications in the first step is due to a variation of terminologies used to express market relations, volatilities, and spillovers. We observed that not all papers explicitly use the terms “spillovers” or “connectedness”, and “nexus”, among others on studies that analyze the relationship between green bonds and other markets. Hence, the technique adopted by our study asserts the inclusion of all relevant publications for the review. The result of the initial search is 251 publications.

2.2. Inclusion Criteria

This review did not apply any filters to the publication time frame. All existing studies within the Scopus database relevant to the scope of the review published before March 2022 were considered for our study. In this review, we prioritized peer-reviewed journal articles with a robust methodology and conference proceedings written in English. News articles, short surveys, and other sources were discarded from the study sample. Similarly, we eliminated duplicate copies and studies conducted in any language other than English. As a result, 90 irrelevant publications were discarded from the study sample. To mitigate bias in selection, we utilized the VOSviewer software (1.6.16) to perform a bibliographic coupling analysis, which is based on the commonness of references between publications [15], in order to enumerate interlinked research streams with a minimum of 10 articles per cluster. The bibliographic analysis identified 5 interlinked research clusters, where each cluster focused on a specific research domain of green bonds. The green cluster shown in Figure 2 comprises 37 publications undertaking analyses of green bonds’ association with other markets. Articles from the green cluster were the ideal candidates for this review.

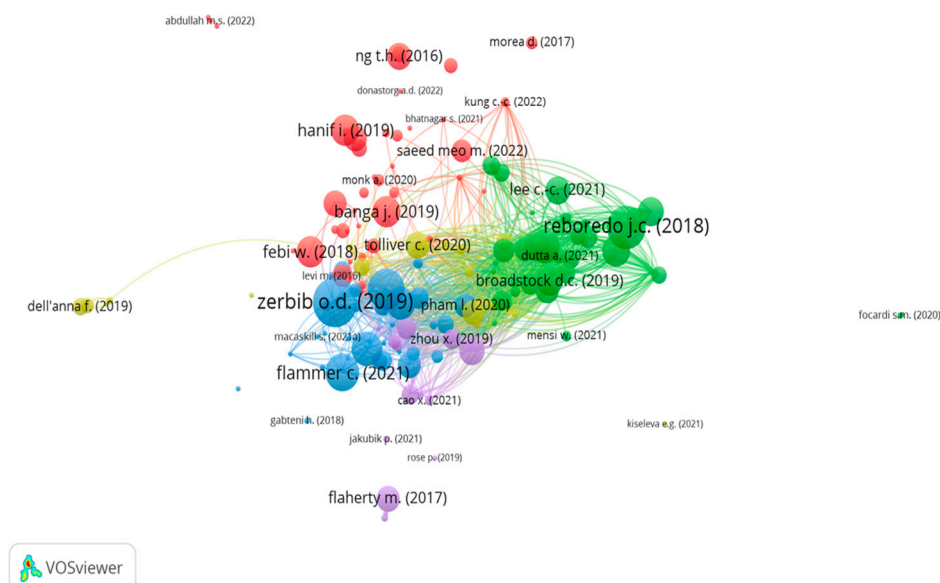


Figure 2. Bibliographic coupling and clusters analysis. The five colors reflect the prevailing research trends in the literature of green bonds. Our research focuses on the green cluster. In a nutshell, papers in the Red cluster elaborated on green financing and the capacity of green bonds to advancing climate financing. Papers in the Blue cluster focuses on green premium in the green bond market. Studies of the Yellow cluster explored the state of the green bond market, challenges and ways to develop the market of green bonds. Finally, the Violet cluster assessed ways to de-risk green bonds, drivers of green bonds, green bonds certification and incentivizing investors among others.

In the next stage, we performed a full-text screening of the research articles from the green cluster to assert the relevance of the selected papers to the scope of our review. Ten publications were removed from the shortlist, since examining green bonds' nexus with other markets was not the focus of these studies. Furthermore, we discarded a study conducted by Gao et al. [16] due to failure of obtaining access to the research paper. To double check our sample selection, we scanned titles, keywords, and abstracts of all publications from the other four clusters (red, blue, yellow, and violet). An additional five publications meeting the inclusion criteria were added to the sample, which brought the final sample to 31 publications. The final sample comprised research papers published between January 2016 and February 2022. The selected papers underwent further analysis by reviewing the full text to identify the objective of each study, applied methodology, study period and frequency, investigated variables, and the findings of the study, as presented in Table 1.

Table 1. A summary review of collected research papers.

No	Author and Year	Title	Freq	Scope	Method	Variables	Findings
1	Tiwari et al. (2022) [5]	Dynamic spillover effects among GB, renewable energy stocks and carbon markets during COVID-19 pandemic: Implications for hedging and investments strategies	Daily	4 January 2015–22 September 2020	TVP-VAR	GB, CO ₂ emissions, and renewable energy stocks	GB significantly reduced investment risks when combined with any assets (bilaterally) but do not hedge other assets
2	Yousaf et al. (2022) [17]	Green investments: A luxury good or a financial necessity?	Daily	31 August 2012–20 November 2020	(DCC)-GARCH Baur and McDermott (2010) [18]	GB, clean energy stocks, gold, indexes (World sustainability, North American sustainability, Eurozone sustainability, the emerging market sustainability, S&P global sukuk, and Dow Jones Islamic)	Clean energy investments and GB have the potential to serve as a safe haven against stock market downturns amid COVID-19
3	Huynh (2022) [19]	When 'green' challenges 'prime': empirical evidence from government bond markets	Monthly	December 2008–November 2019	Copulas tail dependence and transfer entropy	GB and triple-A government bonds of 10 countries	GB are not ideal portfolio diversifier during financial turmoil
4	Guo and Zhou (2021) [20]	GBs as hedging assets before and after COVID: A comparative study between the US and China	Daily	August 2014–August 2021	Copula approach based on the TGARCH	GB, equity, conventional bond, forex, and energy (oil) markets in US and China	Hedging effect of GB is weaker in extreme times but effective in normal times
5	Naeem, Bouri, et al. (2021) [21]	Energy markets and GBs: A tail dependence analysis with time-varying optimal copulas and portfolio implications	Daily	December 2008–June 2020	Time-varying optimal copula (TVOC) model	GB, oil, natural gas, coal, gasoline, and heating oil	GB are efficient in hedging against most energy assets (coal)
6	Dutta et al. (2021) [22]	Climate bond analyses, stock, gold, and oil markets: Dynamic correlations and hedging during the COVID-19 outbreak	Daily	1 March 2017–30 June 2020	VAR-ADCC-GARCH	Climate bonds, S&P 500 index, crude oil, and gold	Climate bonds cannot be an effective hedging asset the COVID-19 pandemic in contrast to normal times
7	Pham and Nguyen (2021) [23]	Asymmetric tail dependence between GBs and other asset classes	Daily	12 October 2014–12 February 2021	Cross-quantilogram	GB, Treasury bond market, energy market, stock market, and corporate bond market	GB are strategic diversifiers for energy markets across all market conditions and for conventional bonds in normal times.
8	Naeem, Nguyen, et al. (2021) [24]	Asymmetric relationship between GBs and commodities: Evidence from extreme quantile approach	Daily	1 December 2008–31 December 2020	Cross-quantilogram	Energy assets, metals, and agricultural assets	GB are effective diversifiers against natural gas, agricultural commodities, and some industrial metals but not precious metals.
9	Naeem, Adekoya, et al. (2021) [25]	Asymmetric spillovers between GBs and commodities	Daily	1 December 2008–31 December 2020	Diebold and Yilmaz (2014) [26] and Barunik and Krehlik (2018) [27]	GB, gold, silver, crude oil, natural gas, wheat, and corn	GB can hedge against risks from precious and agricultural assets and against crude oil in the short term

Table 1. Cont.

No	Author and Year	Title	Freq	Scope	Method	Variables	Findings
10	Ul Haq et al. (2021) [28]	Do GBs act as a hedge or a safe haven against economic policy uncertainty? Evidence from the USA and China	Daily	11 March 2014–29 September 2020	DCC-MGARCH	Economic policy uncertainty, GB, clean energy stocks, and global rare earth elements	GB were a strong hedge against China and UK EPU but did not hedge against US EPU and lost safe-haven ability during COVID-19
11	Hung (2021) [29]	Nexus between GBs, financial, and environmental indicators	Daily	January 2013–March 2019	(MPN) Network nonlinear Granger causality and transfer entropy	GB and clean energy, price of CO ₂ emission allowances, Bitcoin, and the S&P 500 stock market	GB provide shelter to price oscillations in stock, Bitcoin, clean energy, and price of CO ₂ emission allowances
12	Kocaarslan (2021) [30]	How does the reserve currency (US dollar) affect the diversification capacity of GB investments?	Daily	1 August 2014–19 October 2019	DCC-GARCH and ARDL	S&P GB, S&P US Aggregate Bond, S&P 500, and S&P GSCI Energy	GB have diversification capacity for investors in energy and stock markets in bad times
13	Gao et al. (2021a) [31]	Risk spillover and network connectedness analysis of China's GB and financial markets: Evidence from financial events of 2015–2020	Daily	8 April 2015–8 April 2020	DCC-GJRGARCH model	GB, stock market, conventional bond market, forex market, commodities market, and monetary markets	GB are not ideal for hedging risks in the forex and monetary markets
14	Kuang (2021) [32]	Are clean energy assets a safe haven for international equity markets?	Daily	9 July 2012–18 December 2020	Standard deviation, maximum drawdown, (VaR), and (CVaR).	GB, clean energy assets, equities, and dirty assets.	GB are efficient risk diversifiers for dirty energy stocks.
15	Pham (2021) [3]	Frequency connectedness and cross-quantile dependence between GB and green equity markets	Daily	August 2014–August 2020	Cross-quantilegram	GB, green equities, and energy and financial markets (corporate bonds and stocks)	GB are a diversifier against clean equity in normal conditions and diminish in extreme conditions
16	Naeem, Farid, et al. (2021) [33]	Comparative efficiency of green and conventional bonds pre- and during COVID-19: An asymmetric multifractal detrended fluctuation analysis	Daily	3 November 2014–3 September 2020	Asymmetric multifractal detrended fluctuation analysis (A-MF-DFA)	S&P, Solactive, and Bloomberg Barclays MSCI GB indexes The S&P Global Developed Aggregate Ex-Collateralized Bond, Solactive Global Developed Government Bond TR EU, and Bloomberg Barclays Global Aggregate Total Return Indexes	GB are an effective diversifier for traditional assets in extreme market turmoil periods
17	Nguyen et al. (2021) [34]	Time-frequency comovement among GBs, stocks, commodities, clean energy, and conventional bonds	Daily	December 2008–December 2019	Wavelet correlation	S&P GB Index, S&P 500 Composite Index, S&P GSCI Commodity Index, S&P Clean Energy Index, Barclays Bloomberg Global Treasury Index.	GB are a strategic diversifier against volatilities from stocks and commodities in the short term and at a lower degree in the long run.
18	Ferrer et al. (2021) [4]	Are GBs a different asset class? Evidence from time-frequency connectedness analysis	Daily	14 October 2014–19 December 2019	Barunik and Krehlik (2018) [27]	GB, renewable market, corporate bond, treasury, stock, currency markets, and oil	GB are not a different class and do not offer diversification benefits in the short term
19	Saeed et al. (2021) [35]	Extreme return connectedness and its determinants between clean/green and dirty energy investments	Daily	3 January 2012–29 November 2019	Quantile VAR model	GB, oil, energy ETFs, and clean energy stock	GB offer diversification benefits against dirty assets
20	Liu et al. (2021) [36]	Dependence and risk spillovers between GBs and clean energy markets	Daily	5 July 2011–24 February 2020	Marginal and copula models (CoVaR) and delta CoVaR.	GB, solar, wind, renewable energy, and clean technology index, and 3 clean energy indexes	Long positions in GB cannot hedge long positions in clean energy assets and vice versa
21	Naeem, Raza, et al. (2021) [37]	Religion vs ethics: hedge and safe haven properties of sukuk and GBs for stock markets pre- and during COVID-19	NA	2020–2021	DCC-GARCH Ratner and Chiu (2013) model [38]	GB, sukuk, and stock markets	GB exhibit safe-haven and diversification benefits for low-risk investors in economic distress spells
22	Thai (2021) [39]	Quantile dependence between GBs, stocks, bitcoin, commodities and clean energy	Daily	April 2013–December 2019	Quantile regression and quantile Granger causality	GB, stocks, Bitcoin, commodities, and clean energy	GB offer shelter to price oscillations in the stock, bitcoin, and commodity markets

Table 1. Cont.

No	Author and Year	Title	Freq	Scope	Method	Variables	Findings
23	Lee et al. (2021) [40]	Oil price shocks, geopolitical risks, and GB market dynamics	Monthly	December 2013–January 2019	Quantile-based methods Granger causality in quantile tests	Brent crude oil prices, MSCI GB index, and geopolitical risk index	GB hedge against oil price shocks in bearish market conditions and are a diversifier in bullish markets
24	Hammoudeh et al. (2020) [41]	Relationship between GBs and financial and environmental variables: A novel time-varying causality	Daily	30 July 2014–10 February 2020	Time-varying Granger causality test	GB, US conventional bonds, WilderHill clean energy index, and CO ₂ emission allowances	GB are a diversifier in a commercial and sovereign bonds portfolio
25	Saeed et al. (2020) [42]	Hedging strategies of green assets against dirty energy assets	Daily	3 January 2012–29 November 2019	DCC-GARCH and dynamic optimal hedge ratios	GB, clean energy stocks, energy ETFs, and crude oil	Hedge effectiveness of clean energy stocks against dirty energy assets is superior to GB
26	Reboredo and Ugolini 2020 [43]	Price connectedness between GB and financial markets	Daily	14 October 2014–25 June 2019	Structural vector autoregressive (VAR) model	GB Index, high-yield corporate debt market, USD currency market, global stock market, and energy commodity market	GB hedge against portfolio risks and minimize downside risks from stocks, energy assets, and high-yield corporate debt but are impacted by changes in the USD and Treasury bonds
27	Park et al. (2020) [44]	Volatility spillovers between equity and GB markets	NA	January 2010–January 2020	ADCC-GARCH, BEKK, and DCC-GARCH models	GB and equity market (S&P 500)	Evidence of insignificant volatility spillovers between GB and equity
28	Reboredo et al. (2020) [45]	Network connectedness of GBs and asset classes	Daily	12 October 2014–20 December 2018	Wavelet VAR models Granger causality	GB Index, Treasury, corporate, and high-yield corporate debt market, USD currency market, global stock market, and energy commodity market	GB are effective for portfolio hedging and risk diversification over different investment horizons for stocks, high-yield corporate bonds, and energy stocks
29	Broadstock and Cheng (2019) [46]	Time-varying relation between black and GB price benchmarks: Macroeconomic determinants for the first decade	Daily	28 October 2008–31 July 2018	(DCC) with dynamic model averaging methods.	GB, black bonds, daily economic activity, US financial market index returns, VIX, EPU, NEWS, and oil	Connectedness between green and black bonds is sensitive to changes in selected variables
30	Reboredo (2018) [47]	GB and financial markets: Co-movement, diversification and price spillover effects	Daily	14 October 2014–31 August 2017	Time-varying copulas models, conditional diversification benefit measure, and (VaR)	GB, fixed income, and stock and energy markets	GB have sizeable diversification benefits for stock and energy markets but not for corporate and treasury bond markets
31	Pham (2016) [48]	Is it risky to go green? A volatility analysis of the GB market	Daily	30 April 2010–29 April 2015	Multivariate GARCH framework	S&P GB, S&P Green Project Bond, and S&P US Aggregate Bond	A strong correlation between the two markets' limiting diversifications opportunities

Note: GB denotes Green Bonds.

3. Results and Discussion

3.1. Background

3.1.1. Green Bonds and the Green Bonds Market

Green bonds are best known as fixed-income financial instruments employed to tap funds from investors through the debt capital market to deliver ecological benefits in a quest of promoting a transition to a low-carbon economy [49]. What distinguishes green bonds from their conventional peers is issuers' commitment to utilize green bonds' proceeds in financing or refinancing eco-friendly projects with a mandate of delivering environmental benefits. According to green bonds' studies, the proceeds of green bonds are predominantly concentrated in renewable energy and energy efficiency projects [50]. The cost of green bonds is another distinctive feature of green bonds. Issuers would normally incur additional costs associated with transparency and disclosure of the mechanism of project selection and evaluation, management of proceeds, allocation of proceeds, and reporting framework [51]. Investors, on the other hand, are likely to pay a negative price premium in green bonds investments, in comparison with conventional bonds, reflecting

their willingness to accept a low return from their green investments. The green premium caters to investors' accrued additional costs associated with green bonds issuance [52,53]. Overall, the additional costs of green bonds issuance oscillate between 0.3 and 0.6 basis points for a USD 500 million issuance [52,54].

The first ever green bond was issued in 2007 by the European Investment Bank (EIB) in Luxembourg. Ever since, the green bond market has experienced exponential expansion in issuance volumes, target sectors (e.g., renewable energy, energy efficiency, climate change adaptation, waste management, clean transportation, etc.), issuance format (e.g., corporate bond, municipal bond, project bond, and asset-backed security (ABS), supranational, sub-sovereign, and agency bond (SSA)), and geographical base (e.g., European nations, Asian countries, and African countries). The Thompson Reuters database reported that green bonds hit the milestone of the USD 2.24 trillion mark in September 2022, attributed to the substantial expansion of the issuers' base. Green bonds are issued by corporations (e.g., Tesla and Apple), supranational institutions (e.g., the European Investment Bank and World Bank), development banks (e.g., Asian Development Bank and African Development Bank), financial institutions (e.g., commercial banks), and sovereigns (e.g., Poland, France, India, Hong Kong, and Nigeria). Furthermore, green bonds penetrated new markets in over 23 jurisdictions (e.g., USA, UK, Columbia, Seychelles, Hong Kong, and India) in 23 different currencies (e.g., Euro, USD, Malaysian ringgit, and South African Rand) [55].

Notwithstanding a continuous upward trend of green bond issuances reflecting a rapid evolution of the green instrument, the green bond market is facing a number of challenges, such as an absence of a long-term pipeline of infrastructure projects to support a transition to a low-carbon economy, limited investors' awareness towards the environmental impact of green investments, and the lack of unified green bonds standards for the identification, selection, evaluation, and reporting of green bonds projects [49].

3.1.2. Safe Haven, Hedge and Diversifier

Deeply engrained modern portfolio theory views portfolio optimization as a strategic process of integrating assets of different classes to offset portfolio risks. Since the cross-market relationships are heterogeneous and highly dynamic across multiple horizons, the incorporation of uncorrelated asset classes is vital for portfolio optimization. The efficacy of assets' capacities to offset risks and reduce volatility and spillover effects for a specific outcome, event, or time ranges from a safe-haven asset, a hedge, or a diversifier [18,56]. The following analysis is based on the definitions proposed by Baur and Lucey [56]:

Safe haven refers to a negative correlation or an absence of correlation between two assets or portfolios in extreme market conditions (such as economic turmoil, financial crisis and COVID-19 pandemic). The concept of a strong (weak) safe haven asset coincides with the proposed definition of haven by Webster's dictionary as a refuge, port, place of safety offering favorable opportunities and conditions. Safe-haven assets offer investors refuge in extreme or adverse market conditions. In bullish market conditions (normal conditions), a safe haven asset can demonstrate a positive or negative co-movement or even lose its value. Not to mention, it may fail to compensate for losses incurred. The attribute of a safe haven asset resides in its capacity to hold or increase in value during economic uncertainty and compensate investors for losses incurred in other assets [57].

A hedge is defined as an absence of correlation (weak hedge) or negative correlation (strong hedge) between an asset and other assets or portfolio on average (normal market conditions). An investor can enhance the overall portfolio risk reduction and potential losses by taking an offsetting position in a hedging asset. The divergence of returns' movements of uncorrelated or negatively correlated assets aids hedging assets efficiency to limit the severity of assets' volatilities and spillover effects. A hedging asset can be positively correlated with assets or portfolios during economic distress periods and ultimately fail to offset risks [58].

Diversifier denotes an average positive (not perfect) correlation between an asset and other assets or portfolio. A strategic diversifier depicts a weak positive co-movement and

shields investors from unsystematic risk. Overall, safe havens, hedges and diversifiers induce a flight-to-quality phenomenon and smooth out investment portfolio risk on different degrees and across multiple market conditions [59].

3.1.3. Financial Contagion and Spillover

Empirical and analytical studies on cross-market transmission of financial crises have experienced explosive growth in recent years. These studies focus on the analysis of financial contagion, interdependence, and spillover effects across markets. Contagion is commonly defined as “a significant increase in co-movements of prices and quantities across markets, conditional on a crisis occurring in one market or group of markets” [60]. This definition implies that volatility in asset prices induces market uncertainty and financial instability [61]. Furthermore, the definition stresses crises and their impact on financial markets as the driving factor of the high degree of co-movements to distinguish a financial contagion from excessive co-movements in spells of bullish market conditions. The latter is known as interdependence [60].

Spillover refers to a phenomenon where fluctuations (volatility) in the price of an asset in one market (country) trigger changes in prices of a similar asset class or other class in the same or another market (country) [62,63]. The changes in prices can stem from both desirable effects (good news) and undesirable effects (bad news). Spillover effects between two assets, markets, or countries depend on a number of factors, such as the source of volatility in assets prices, channels of shock transmission, and existence of risk mitigation mechanisms in the two markets, among others [63].

Spillover and contagion are two common concepts widely used to express cross-market linkages between assets’ returns [64]. In the context of green bonds, cross-market co-movement prompted by an occurrence of a crisis (contagion) or in normal market conditions (spillover) significantly reduces the benefits of portfolio diversification. A nonexistence or low degree of spillover (contagion) is crucial for portfolio optimization to mitigate poor performance of one market and limiting contagion of risks across markets. This scenario explains the growing interest in the literature of green bonds’ connectedness with other markets. Awareness of market dynamics and their interdependence is insightful for investment decisions and reduction of portfolio risk.

3.2. Evolution of Research in Green Bonds’ Connectedness with Other Markets

In 2016: The first research paper on the nexus between green bonds and other markets was conducted by Pham [48]. In this paper, the author analyzed the volatility behavior of the green bond market with the conventional bonds market using the univariate GARCH and multivariate Dynamic Conditional Correlation (DCC) GARCH methodologies. This study marks the first attempt of assessing the risk and return behavior of the green bonds market using time series data of daily closing prices of the S&P Green Bond Index and S&P Green Project Bond Index as indicators of the performance of green bonds and S&P US Aggregate Bond Index as a proxy for conventional bonds markets’ performances between April 2010 and April 2015. The evolution of studies in green bonds markets’ connectedness is shown in Figure 3.

In 2018: A couple of years later, Reboredo [47] studied the structure of dependence between the green bonds market and financial markets between October 2014 and August 2017. The study attempted to assess the influence of price oscillations in the financial markets on the green bonds market and search for diversification benefits of incorporating green bonds in a stock, bonds, or energy commodities investment portfolio. In addition to the conventional bond markets, the study also incorporated in the sample, under study treasury, the stock market and energy commodity markets presented by Bloomberg Barclays Global Treasury Total Return Index Value, MSCI World Index, and S&P GSCI Energy Spot CME Index, respectively.

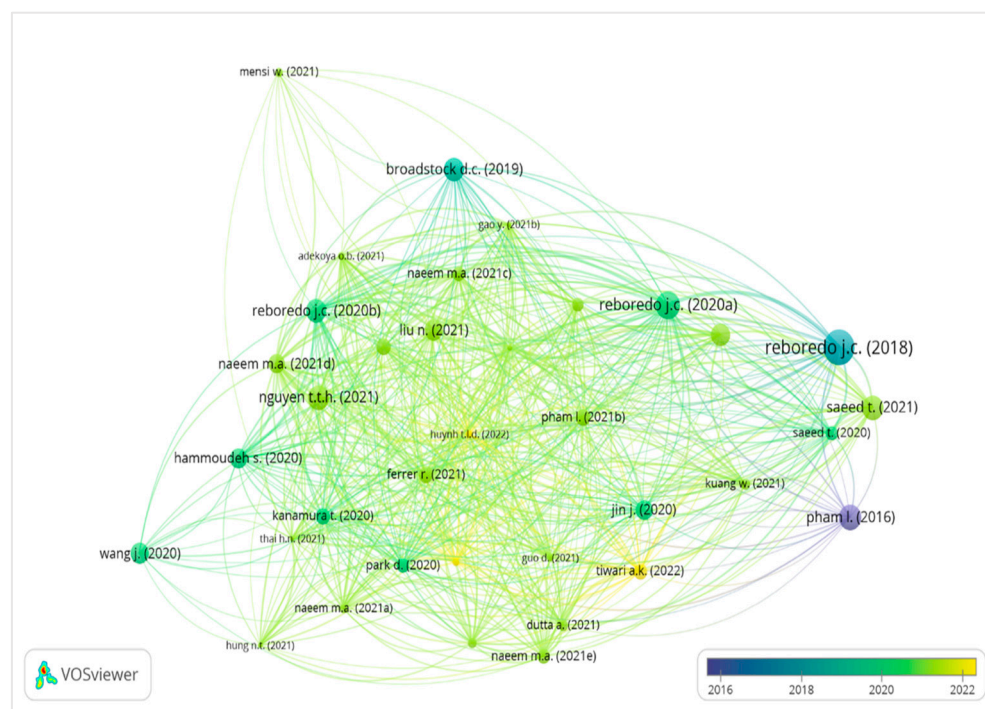


Figure 3. Evolution of green bonds cross-market studies.

In 2019: By 2019, the number of publications in the context of green bonds' relationship with other markets reached three publications in total. Unlike Pham [48] and Reboredo [47], Broadstock and Cheng [46] analyzed the determinants of correlation trends between green bonds and black bonds markets. This study forms the second strand in the literature of green bonds connectedness with other markets, where the focus of the study is on the factors impacting the connectedness between markets rather than market volatilities and spillovers. The three studies can be considered as pioneers of green bonds studies in their respective scope.

In 2020: Despite a dearth of green bonds studies in this dimension, the year 2020 witnessed a significant increase in green bonds market dynamics and interdependence publications. Studies exploring green bonds association with financial markets [43], carbon market risk [65], and clean and dirty assets [42], among others, flourished in this period. One reason prompting significant interest in green bonds publications was the outbreak of the COVID-19 pandemic in China, which stimulated research and sparked academia's appetite to analyze the influence of the prevailing market conditions on the ferocity of market connectedness. This step facilitated the emergence of a strand of studies in the literature focused on documenting the devastating effects of the COVID-19 pandemic on financial markets and the promotion of green bonds as a potential diversifier and hedging asset against volatilities and risk spillover from other markets. For instance, Park et al. [44] investigated asymmetric volatility and spillovers between the equity markets (S&P 500) and green bonds using GARCH models. Extending the sample to include clean energy equity and CO₂ emission allowances (in addition to green bonds and conventional bonds), Hammoudeh et al. [41] followed Shi et al.'s [66] time-varying Granger causality model to investigate causal relationships between green bonds assets under study.

In 2021: Research on the dynamics of the green bonds market gained momentum in 2021, where 17 research papers were published in total. The economic impact of green bonds' integration was demonstrated in several studies. Factoring economic turmoil and extreme market conditions, Naeem et al. [37] examined the capacities of sukuk and green bonds to hedge and serve as safe-haven assets to the stock market during the COVID-19 pandemic. Using the asymmetric multifractal detrended fluctuation analysis (A-MF-DFA) approach, Naeem, Farid et al. [33] assessed the comparative efficiency of green bonds and

conventional bonds between 2014 and 2020. Along the same lines, studies tested green bonds' diversification capacity in extreme market conditions against energy commodities and stocks [30], energy assets [21,23,24], precious metal and agricultural commodities [25], dirty energy assets [32], and oil prices [40]. In the same vein, researchers conducted studies on green bonds' hedging effectiveness against spillovers from clean energy markets [3,36], S&P 500 Index, crude oil and gold [22], stock markets, conventional bond markets, forex markets, commodities markets, and monetary markets [20,31].

In 2022: Since this review was initially conducted in March 2022, only three studies from 2022 relevant to the scope of the review are included. In a nutshell, studies in this period assessed the three properties of green bonds (diversifier, hedge, and safe haven). The study by Huynh [19] analyzed the interaction of green bonds and triple A government bonds of 10 countries. In another study, Tiwari et al. [5] evaluated return spillover effects between green bonds, carbon prices, and renewable energy stocks between January 2015 and September 2020. Finally, Yousaf et al. [17] tested the potential of green bonds to serve as a safe-haven asset against stock market volatilities during the COVID-19 pandemic.

3.3. Data Frequencies

Table 1 evinces the preference of most studies to utilize daily frequency data for assessment of market volatilities and spillovers. In our sample, 28 out of 31 research papers use daily data for market connectedness analysis. As some studies suggest, green bonds are a substitute for conventional bonds from a same asset class [4,48]; it is fair to anticipate speculative motives in green bond transactions, similar to stocks and conventional bonds. Thus, green bonds can be considered as high-frequency variables where intraday data and daily data have the potency to reflect tick-by-tick fluctuations and effectively demonstrate market reactions to shocks from natural disasters, good or bad news, financial crises, health pandemics, and business cycles, among others. One advantage of examining volatility via high-frequency data is the ease of volatility estimation for reasonable lengthy data and without delay [67]. Furthermore, high-frequency data have proven to be efficient and accurate in forecasting and time series modeling [68]. A case in point is the studies by Guo and Zhou [20] and Naeem, Adekoya et al. [25], where the cross-market relationship between green bonds and selected assets was assessed using daily data. The high-frequency data facilitated the evaluation of the markets' interactions across multiple horizons and the estimation of green bond hedging ratios.

Another group of studies used monthly frequency data in their analysis [19,40]. One reason behind favoring monthly data over daily could be the possibility of delay in some markets' reaction to a shock, resulting in a failure to synchronously record some markets reactions to the shock in their respective prices [69]. Furthermore, high-frequency data are known to be extremely noisy, leading, in some instances, to a strong negative first-order autocorrelation in daily returns [67]. One way to overcome this challenge is by shifting to low-frequency data. Additionally, markets' volatilities tend to show different trends across multiple horizons. For instance, monthly data are better fitted than high-frequency data to visualize seasonality and mean reversion scenarios in markets [70,71]. The findings of the studies utilizing low-frequency data are a better match for medium- and long-term analyses.

3.4. Methodologies

This section discusses the prominent methodologies employed for cross-market analysis. The objective of reviewing research methodologies is to demonstrate the efficiency of each methodology in cross-market analysis without favoring any of the models used in the sample. Table 1 presents a summary of the methodologies used in the selected articles for review.

3.4.1. The GARCH Family Models

GARCH family models emerged as the predominant methodology utilized in the sample. A total of 13 research papers from the sample, constituting about 42% of all

publications, used the GARCH family models. GARCH models are derived from the Auto-regressive conditional Heteroskedasticity (ARCH) model, which is based on time-varying variance. This model was originally introduced by Engle [72] and further developed by Bollerslev [73] to a Generalized Auto-regressive conditional Heteroskedasticity (GARCH) model by integrating the Auto-regressive moving average (ARMA) structure. Historically, the GARCH models were employed to forecast stock market prices [74]. The GARCH model has experienced multiple extensions and modifications over the years. The significance of these models in analyzing time-varying volatilities between markets resides in its embeddedness of stylized facts of financial markets [75], giving it a slight edge over other models. The multivariate GARCH (mGARCH) models such as DCC-GARCH, ADCC-GARCH, BEKK-GARCH, and so on have proven to be useful in modeling the volatility dynamics between markets to visualize the existence of potential diversification or hedging benefits for investors.

Several studies capitalized on the unique features of the Dynamic Conditional Correlation (DCC) GARCH model to explore time-varying interdependence between green bonds and conventional bonds, stocks, crude oil, energy assets, clean energy stocks, global rare earth metals, sukuk, gold, and uncertainties variables (CBOE Volatility Index (VIX), Economic Policy Uncertainty (EPU), and NEWS) [17,28,30,37,42,46,48]. A wide employment of this model in these studies underpins the superiority of this model in capturing multivariate relationships between green bonds and other markets. Since the relationship between markets is heterogeneous, DCC-GARCH uses standardized residuals to account for heterogeneity, which facilitates the assessment of multiple variable return directions, while keeping a minimal number of parameters [76]. This approach enhanced studies' abilities to understand and showcase green bonds' co-movements with other assets in normal market conditions and, most importantly, in crises and extreme market conditions [77]. On that note, Yousaf et al. [17] and Kocaarslan [30], for instance, studied the relationship between green bonds and conventional bonds and energy assets. The study documented the effectiveness of green bonds to serve as a safe-haven asset against stock market volatilities. Furthermore, green bonds emerged as a hedging asset against UK EPU and a diversifier in an energy assets portfolio in times of economic distress.

Gao et al. [31] used the extended model DCC-GJR-GARCH to accommodate large dimensions and improve the DCC-based dynamic conditional correlation. This model enhances asymmetry observations in financial markets and facilitates tracing the reaction of conditional volatility to a positive or negative past incident [78]. This methodology remarkably highlighted spillover effects in China's financial market and nullified any hedging benefits of green bonds against the risks from the forex and monetary markets. Similarly, Dutta et al. [22] employed the asymmetric version of the DCC (ADCC-GARCH) model to reflect the asymmetrical effects of the COVID-19 pandemic in shaping the relationship between climate bonds and stocks, crude oil, and gold [79]. In another study by Park et al. [44], the ADCC-GARCH model was used to assess spillovers between the markets of green bonds and stocks from a negative shock from the other market. Other modifications of GARCH models used in the sample under review include BEKK GARCH [44], DCC-APGARCH, and DCC-TGARCH [65]. Both models were utilized to calculate market spillovers and volatilities between green bonds and equity markets [44] and estimate hedge ratios of green bonds, commodity, and energy indexes for carbon futures [65].

3.4.2. Cross-Quantilogram

A cross-quantilogram is an insightful methodology to examine markets' quantile dependence and estimate directional predictability between markets. This methodology is effective when dealing with data suffering from heavy tails [74,80,81] and allows the integration of long lags [74]. Naeem, Nguyen et al. 2021 [24] studied asymmetric dependence between green bonds and energy assets, precious metals, and agricultural commodities using a cross-quantilogram. Likewise, Pham and Nguyen [23] explored tail dependence (tail risk) between the green bond market and markets of treasury bonds, corporate bonds,

stocks, and energy. Pham [3] decomposed the time series data of green bonds and green equity into different horizons to examine the cross-quantile dependence and frequency connectedness between the two assets using a cross-quantilogram approach.

3.4.3. The Spillover Indexes

The spillover indexes of Diebold and Yilmaz (2014) [26] and Barunik and Krehlik (2018) [27] were used by Naeem, Adekoya et al. [25] to evaluate time-varying connectedness between green bonds and precious metals, energy assets, and agricultural commodities. The spillover indexes of Diebold and Yilmaz [26] and Baruník and Křehlík [27] are significant in decomposing time series to three investment horizons (short–medium and long term) to estimate total spillover, directional spillover, net spillover, and net pairwise spillover. The decomposition process is efficient in identifying the presence of diversification and hedging benefits of incorporating green bonds in a portfolio across different time horizons. Ferrer et al. [4] adopted Baruník and Křehlík [27] to examine the dynamic interaction between green bonds and the markets for renewable energy, corporate bonds, treasury, stocks, currency, and oil. Similarly, Saeed et al. [35] employed the Quantile VAR model complemented by Diebold and Yilmaz 2012 [82] to evaluate the connectedness between clean assets (green bonds and clean energy assets) and dirty assets (oil and energy ETFs).

3.4.4. The Wavelet

Another method used by a few research papers in our sample is the wavelet one. The wavelet approach facilitates the analysis of time–frequency dynamics of time series to determine the variation of time series correlations over time and across multiple horizons [83]. Wavelet (coherence) is complemented by figures to visualize the co-movements and the lead and lag relationship between time series. The combination of wavelet estimations and figures is what makes this methodology unique. Applying cross-wavelet transform and wavelet coherence framework, Reboredo et al. [45] examined dynamic correlations between prices of green bonds and markets of fixed-income assets, stocks, energy, commodities, and currencies. Similarly, Nguyen et al. [34] explored time-varying co-movements between green bonds and stocks, commodities, clean energy, and conventional bonds.

3.4.5. The Copula Approaches

An alternative method to capture nonlinear dependence, dynamic dependence, and tail dependence between markets is via the copula approach. Under economic distress and extreme market conditions, copulas can demonstrate dependence structures across markets and estimate extreme co-movements between assets [84]. Reboredo [47] examined quantile and tail dependence between green bonds and the energy and financial markets using the time-varying optimal copula (TVOC) model. Similarly, Naeem, Bouri et al. [21] calculated asymmetric and extreme tail dependence between green bonds and a set of energy markets using the TVOC model. The aforementioned studies capitalized on the unique characteristics of the copula models to detect dynamic dependence and asymmetric dependence across markets to propose potential diversification and hedging benefits of green bonds. Copula models were further called upon to examine tail dependence between green bonds and triple A government bonds of 10 countries [19], test efficacy of green bonds in hedging against equity, fixed-income, forex, and energy markets in the US and China [20], and explore the dependence and spillover effects between green bonds and clean energy markets [36].

3.4.6. Granger Causality

Time-varying Granger causality model is an effective way to capture the dynamic causality relationships between two variables and overcome the challenges inherent in linear time-invariance estimation models. The significance of the time-varying Granger causality model resides in the efficiency of the model to delineate an overview of the dynamic causal relationship between two time series and identify time periods in which an

intensity of the causality increases or decreases to identify the determinants of volatilities in the time series' connectedness [85]. Hammoudeh [41] examined the dynamic causal relationship between green bonds and conventional bonds, clean energy indexes, and CO₂ emission allowance using three causality tests, namely forward recursive causality, rolling causality, and recursive causality. Similarly, Lee et al. [40] employed Granger causality in quantile tests to explore the causal relationship among green bonds, geopolitical risks, and oil prices in the US. In another study by Hung [29], a modified version of Granger causality, namely Multilayer Perceptron Neural Network Nonlinear Granger causality, complemented with Transfer Entropy, was employed to investigate the causal relationship between green bonds and CO₂ emission allowance, Bitcoin, clean energy markets, and stock markets. Finally, the Granger causality model was coupled with quantile regression analysis to assess the asymmetric dependence between green bonds and stocks, Bitcoin, clean energy markets, and commodity markets [39].

3.4.7. VAR Models and Other Models

A few studies in the sample employed VAR models to examine green bonds co-movement with other markets. To overcome the issues of contemporaneous and lagged feedback effects exhibited in financial markets, Reboredo and Ugolini [43] studied the co-movements and price dynamics of the green bond market and the markets for conventional bonds, currency, global stocks, and energy using the Structural VAR model. In another study, Tiwari et al. [5] capitalized on the distinctive feature of TVP-VAR of capturing forms of nonlinearity exhibited by most macroeconomic time series to assess return spillovers between green bonds, carbon prices, and renewable energy stocks. The model facilitated a robust and flexible investigation of time-varying connectedness between green bonds and other asset classes, while factoring the underlying structure in the economy (COVID-19 pandemic). Furthermore, the study tested portfolio performance using various metrics, such as minimum connectedness portfolio, minimum correlation portfolio, and minimum variance portfolio.

Despite the usefulness of Value at Risk (VaR) and asymmetric multifractal detrended fluctuation analysis (A-MF-DFA) models in cross-markets analyses, most studies in our sample prioritized other methodologies for markets relations. In the context of portfolio risk assessment, Kuang [32] assessed the safe-haven properties of green bonds and clean energy assets for international investors in the stock markets using four risks metrics, namely Value at Risk (VaR) and Conditional Value at Risk (CVaR), for the evaluation of tail risk, Maximum Drawdown (MDD) for assessing tail risk, and Standard Deviation to measure upside and downside deviation from the average.

In turn, Naeem, Farid et al. [33] examined the efficiency of green bonds and conventional bonds comparatively pre and during the COVID-19 pandemic using the asymmetric multifractal detrended fluctuation analysis (A-MF-DFA) approach. The significance of this model lies in its ability to detect the presence of asymmetric multifractality in the markets of green and conventional bonds under bullish and bearish market conditions [86]. The information from the analysis of multifractal scaling behavior of the two markets separately under normal and extreme market spells is insightful for risk management and portfolio optimization. Moreover, the A-MF-DFA approach is effective in testing long memory persistence and market efficiencies [87].

3.5. Green Bonds as a Diversifier, Hedge, and Safe-Haven Asset

The literature on green bonds' cross-market linkages focuses on a wide range of assets across different market conditions to highlight the added value of green bonds' incorporation into a portfolio for risk management motives. This section explores green bonds' relationship with other assets grouped into six clusters. Furthermore, it identifies factors influencing the intensity of cross-market correlations.

3.5.1. The Financial Markets

The dependence between green bonds and other financial markets is well documented in the growing literature. Studies have examined green bonds' relationship with conventional bonds, treasury bonds, high-yield corporate bonds, triple A government bonds, and stocks in bullish and bearish market conditions.

Conventional Bonds

The literature on green bonds' and conventional bonds' connectedness is filled with mixed results. The first branch of studies in the literature failed to report any benefits of integrating green bonds in conventional bond portfolios. Given the resemblance of green bonds' characteristics with those of conventional bonds, such as credit ratings, maturity, and coupon rates, researchers were intrigued to analyze the green bonds' asset class [4] and explore its co-movements with conventional bonds. Evidence of co-movement and high dynamic correlations between the two markets was reported by [4,20,30,31,34,45–48]. Furthermore, Pham and Nguyen [23] evinced tail dependence between green bonds and conventional bonds, indicating a transmission of risks between the two markets and an absence of diversification or hedging benefits for investors, particularly in bearish markets conditions. Similar results were reported between green bonds and treasury bonds by Reboredo and Ugolini [43], Reboredo et al. [45], Ferrer et al. [4], Nguyen et al. [34], and Huynh [19]. When two assets are highly correlated, the volatility in one asset will ultimately induce changes in the other in such a way that the probability of using one of the two assets to hedge or diversify a portfolio of the respective assets is unrealistic and not financially viable.

Another strand of studies in the literature advocates for green bonds' diversification capacity against conventional bonds. These studies report the ability of green bonds to mitigate investment risks associated with conventional bonds in extreme negative events [33]. Likewise, the findings of Hammoudeh et al. [41] failed to register causality effects from the green bonds market to sovereign bonds, indicating potential diversification benefits of integrating green bonds in a sovereign bond portfolio. In the same vein, the findings of Pham and Nguyen [23] endorsed the combination of green bonds and conventional bonds or treasury bonds in the same portfolio for diversification purposes under bullish market conditions. In the context of high-yield corporate bonds, Reboredo et al. [45] found evidence for the potential of green bonds to offer shelter to high-yield corporate bond volatilities over different investments horizons. Likewise, Reboredo and Ugolini [43] revealed that green bonds have the potential to minimize downside risks from high-yield corporate debt. The results of the two studies support green bonds' efficacy as diversifiers in a corporate bonds portfolio or as hedging assets against risks from high-yield corporate debt markets.

Stocks

The literature on green bonds' market relationship with stocks and the stock market is growing tremendously. A total of 58% of the research articles in our sample evaluated the capacity of green bonds to offset risks from the stock market as a diversifier or hedging asset. In fact, the findings of these studies collectively position green bonds as a strategic asset sheltering price spillovers from the stock market over different market conditions. A weak co-movement was depicted between green bonds and stock markets, attesting to green bonds' diversification potential for stock market investors [4,22,31,43–45,47]. Furthermore, the findings of Thai [39], Nguyen et al. [34], and Hung [29] can be considered as a testimony for green bonds' hedging ability against price oscillation from the stock market. The capacity of green bonds to serve as a safe-haven asset amid dramatic risk reduction capabilities was validated by the studies of Kuang [32], Kocaarslan [30], and Yousaf et al. [17].

A few studies reported that the diversification effectiveness of green bonds was limited to bullish market conditions. The correlation between green bonds and stocks weakens in

normal market conditions but strengthened significantly post COVID-19 pandemic [23], leading to a significant dissipation of green bonds hedging efficiency in extreme downturns [20]. One reason behind the effectiveness of green bonds to serve as a diversifier, hedge asset or even a safe-haven asset in a stock portfolio is the difference in characteristics between green bonds and stocks, particularly in terms of their risk behavior [45], since the two assets belong to different classes.

3.5.2. The Energy Markets

Given the importance of green bonds as a catalyst for the transition to a low-carbon economy, understanding the relationship between the markets of clean energy assets and dirty energy assets is of paramount importance. This relationship has the potency to offer investors an insightful understanding of dynamic cross-market relations and determine favorable investment opportunities across different investment dimensions. Green investments have proven to offset the downside risks of dirty energy assets [32], which sparked investors' attention towards green bonds and attracted more investments towards green projects. Many studies in our sample have attempted to analyze the relationship between green bonds and dirty energy assets, proxied as the energy market, crude oil, gasoline, natural gas, energy ETFs, and CO₂ emissions, among others.

Energy Market

We found mixed results in cross-market studies between the green bond market and the energy market. While assessing the co-movements between green bonds' returns and the returns of the energy market, represented by crude oil, heating oil, gasoline, and natural gas, Naeem, Nguyen et al. [24] reported that a sharp decline in the returns of crude oil, heating oil, and gasoline has a negative impact on green bond returns in both bearish and bullish market conditions. The study found a significant positive correlation between the returns of green bonds and those of crude oil, heating oil, and gasoline. Moreover, the results of the study indicate the presence of both negative and positive return spillovers from crude oil to green bonds in periods of increasing crude oil returns. A significant negative correlation, however, was spotted between the returns of natural gas and green bonds, indicating that green bonds can deliver effective diversification benefits to fluctuations in the returns of natural gas. Similarly, Pham and Nguyen [23] reported a statistically insignificant or positive correlation between green bonds and the energy market in the median or upper quantiles post COVID-19 pandemic, implying that green bonds offer insignificant or fewer diversification benefits to investors in the energy market during extreme market conditions.

The opposite results are found in the study of Naeem, Bouri et al. [21]. The results of their study reveal the correlation between green bonds and oil, heating oil, gasoline, and coal remained low during the COVID-19 pandemic. Thereby, green bonds can effectively provide shelter against volatilities from oil, gasoline, heating oil, and coal during extreme markets downturn. Reboredo and Ugolini [43] found that green bonds are immune to price oscillations of the energy market, enhancing the hedging potential of green bonds and their capacity in minimizing downside risks. Furthermore, the transmission of shocks between the two markets was found to be negligible in all investment horizons [45,47]. Along the same lines, supporting evidence for the safe-haven features of green bonds was provided by Kuang [32] and Kocaarslan [30]. Kuang [32] found that green bonds can be a safe haven for international energy asset investors amid effective mitigation of downside risks of dirty energy stocks in times of market stress, such as the COVID-19 pandemic period. The green assets proved to enhance global investors' ability to close out their risky positions in dirty energy investments in extreme market conditions [30] and reduce downside risks [32]. These findings unveil the importance of green bonds in serving as a safe haven against risks in bearish markets.

On the connection of the green bonds market with the energy market, Jin et al. [65] analyzed the connectedness between the returns of carbon futures and green bonds. Jin

et al. [65] demonstrated that green bonds are an effective hedging instrument against carbon risks. Similar results were reported by Tiwari et al. [5]. In another study, Hammoudeh et al. [41] evaluated the time-varying causal relationship between CO₂ emission allowance prices and the price of green bonds between July 2014 to February 2020. The findings failed to detect a significant time-varying causality between the two assets post 2015, indicating that the predictive power of either of the two assets for the returns of the other asset is insignificant. Consequently, green bonds can offer shelter to price oscillations in CO₂ emissions [29] and energy ETFs in extreme market turmoil [42].

Crude Oil

Evidence for green bonds' efficiency to serve as a diversifier against oil price shocks is discussed by Saeed et al. [42] and Lee et al. [40]. In their studies, green bonds were found to be a diversifier in bullish market conditions and a hedging asset in extreme downturns (bearish). Similar to the findings of the previous studies, there is validation for green bonds' diversification potential [4,35] to oil markets in normal market conditions [23]. Other prominent studies in our sample are in favor of the hedging properties of green bonds against risks from the oil market. While testing the hedging effectiveness of green bonds post COVID-19, Guo and Zhou [20] found evidence that green bonds can provide shelter to price oscillations in CO₂ emissions in bullish market conditions. The results are consistent with the findings of Dutta et al. [22]. Contrary to previous studies, Naeem, Adekoya et al. [25] questioned the hedging and diversification capacity of green bonds against the crude oil market. While green bonds serve as succor against risks from the crude oil market in bullish market conditions, the hedging ability of green bonds against shocks from the crude oil market is sensitive to investment horizons. The presence of strong spillover effects between the two markets in the long run limits green bonds' diversification trait against shocks from the oil market [25].

3.5.3. Precious Metals

Precious metals are the next assets of interest in our review. Several studies focused on examining precious metals' association with green bonds over different investment horizons. While analyzing the dynamic interaction between the climate bonds market and gold, Dutta et al. [22] found evidence of climate bonds' (green bonds) ability to significantly induce hedging benefits for gold investors. Risks associated with a long position on gold can be mitigated by a short position on climate bonds. On the contrary, Naeem, Adekoya et al. [25] found strong correlations between green bonds, gold, and silver in both the short and long terms. A higher return of green bonds is likely to be associated with a higher return of precious metals. The findings posit a lack of diversification properties against shocks from precious metals. The results of Naeem, Adekoya et al. [25] are in line with the findings of Naeem, Nguyen et al. [24]. In their study, they found a positive correlation between the market of green bonds and precious metals, inferring green bonds' vulnerability to shocks from precious metals [24].

In addition to precious metal, we found suggestive evidence that green bonds can be a strategic avenue for diversification and risk mitigation for industrial metals. Naeem, Nguyen et al. [24] unveiled the efficiency of green bonds in diversifying a portfolio of industrial metals (aluminum, copper, nickel, and zinc) in normal and extreme market conditions. Likewise, Ul Haq et al. [28] revealed that green bonds and global rare earth elements can be combined collectively for diversification and hedging purposes.

3.5.4. Renewable and Clean Energy Assets

The debate on the significance of green bonds' connectedness with clean energy assets is filled with mixed and inconclusive results. On one hand, we found studies in favor of the interdependence of the two markets, suggesting that the correlation between green bonds and clean energy assets is negligible and insignificant. On the other hand, suggestive

evidence of time-varying dependence between the two markets is presented, invalidating any potential hedging or diversification benefits from the green bonds.

While exploring the causal interactions between green bonds and clean energy indexes, Hammoudeh et al. [41] observed the absence of causal effects from green bonds on the clean energy indexes and a limited causality from the clean energy indexes to green bonds in 2019. Since neither green bonds nor the clean energy indexes have predictive power or influence on the returns of the other assets, the study suggests a potential diversification benefit in constructing a portfolio comprising the two assets. Consistent with the findings of Hammoudeh et al. [41], Nguyen et al. [34] found a low correlation between green bonds and clean energy stocks across all frequencies, indicating interdependence between the two markets and the presence of diversification benefits of incorporating green bonds in a clean energy stock portfolio.

In the same vein, Pham [3] reported a negligible connectedness between green bonds and clean energy stocks and a short-lived dependence between the two assets during extreme market conditions. This finding is confirmed by Tiwari et al. [5] and Ul Haq et al. [28], where diversification benefits of integrating green bonds in a renewable energy equities portfolio are pronounced in all market conditions. Finally, Hung [29] found evidence for green bonds' competence to provide shelter to the price oscillations in clean energy markets. The findings suggest that green bonds can serve the role of a hedging asset against risks from clean energy stocks. Ferrer et al. [4] found weak linkages between green bonds and clean energy stocks, indicating that green bonds are a viable diversifier of portfolio risk for investors in renewable energy equities.

In contrast, Liu et al. [36] reported a positive interaction between green bonds and clean energy markets, suggesting that both markets co-move in the same direction across different market conditions. The findings posit the inefficiency of long positions in green bonds to hedge or diversify a long position in clean energy stocks. The study also detected extreme risk spillover effects between green bonds and clean energy assets, particularly the downside risks of clean energy assets on green bonds. Furthermore, the tail risk of green bonds is likely to be triggered by fluctuations in the returns of clean energy assets. Hence, a shock in clean energy assets is anticipated to spill over to the green bonds market. The findings of this study are supported by Thai [39].

3.5.5. The Commodity Market

In response to increasing interest in the time-varying nexus between green bonds and other markets, Naeem, Adekoya et al. [25] empirically examined the connectedness between green bonds and soft commodities (wheat and corn) and spotted a weak correlation between the two assets. The findings of the study posit the hedging proficiency of green bonds against risks in soft commodities. The appropriateness of green bonds for portfolio diversification against fluctuations in agricultural commodities, particularly in the long run, was further validated by Naeem, Nguyen et al. [24]. In their study, they evaluated the asymmetric relationship between green bonds and commodities. The results of their empirical analysis indicate a significant decline in correlation between green bonds and agricultural assets post lag 22.

In another study, Thai [39] investigated the asymmetric relationship between green bonds and the GSCI Commodity Index. The findings of asymmetric dynamic interrelatedness documented green bonds' ability to hedge against price oscillation in the commodity market. On the contrary, Gao et al. [31] found evidence for significant one-way risk spillover from the commodity market to the green bonds market. Furthermore, a moderate correlation was detected between the two markets, inciting investors to take precautions in periods of market distress due to the generation of significant one-way risk contagion in the green bond market. The reason behind the cross-market dependence is that the commodity market's financial risk is likely to transmit private information via the cross-market transactions of investors. As a result, green bonds will be indirectly affected, prompting medium-level market linkages [31].

3.5.6. Bitcoin, Forex, and Money Markets

The literature on the nexus between green bonds and Bitcoin or the crypto-currency market is limited to a few studies. In our review, the interaction between green bonds and Bitcoin was documented by two studies. Hung [29] found a bidirectional relationship between green bonds and Bitcoin. Furthermore, significant connectedness between the two assets was reported via Multilayer Perceptron Neural Network Nonlinear Granger causality model, inferring a potential hedging avenue in green bonds to price oscillations in Bitcoin. The results are in line with the findings of Thai [39].

Similar to Bitcoin, there is a dearth of studies on green bonds' interaction with the forex and money markets. In the context of forex markets, Guo and Zhou [20] examined the hedging effectiveness of green bonds against price volatilities in forex markets in the US and China. A stable correlation between green bonds and the forex market in China was observed throughout the sample period. Furthermore, the weakest tail dependence in the US with green bonds was found in the forex market. The findings of the study asserted the significant hedging role of green bonds against risks from the forex market. In addition, green bonds emerged as a safe haven during the COVID-19 pandemic and boosted the hedging effectiveness in forex markets. In another study by Gao et al. [31], the green bond market demonstrated low correlation with the forex market. Risk spillovers between the two markets were insignificant, implying that the forex market will not generate significant risk spillovers to the green bond market and vice versa. According to the findings of the study, the role of green bonds is limited to providing diversification benefits to investors in the forex markets.

With regards to the money markets, Reboredo and Ugolini [43] found a close connectedness between the money market and green bonds, where the money market transmits significant price spillovers. The study reported the significant influence of the money market on the green bonds market, positing the inappropriateness of green bonds to offer hedging or diversification risks against shocks from money markets. The connectedness in returns and volatilities between the two markets is more apparent at shorter horizons (up to five days), with a rapid short-lived transmission of shocks across market [4]. The significant connectedness between the two markets is a result of green bonds' denomination in about 23 currencies, where large fluctuations in the forex markets tend to have an impact on the values of international green bond portfolios. In fact, international green bond investment is prone to short-term fluctuations in money markets [43]. However, it is worth noting that the returns of each of the monetary and green bond markets is dictated by its own idiosyncratic factors [4].

On the contrary, Gao et al. [31] found evidence for low correlations between the markets of green bonds and money in China and insignificant risk spillovers between the two markets. The finding positions green bonds as a potential diversifier of risks from money markets. The low correlation between the Chinese green bonds and money markets can be explained by Chinese interest rate regulation. The monetary market's financing costs tend to be driven by changes in interest rates. A rise in interest rates is most likely to enhance green bond market risk levels via heightening monetary market financing costs, which induces large capital inflows to the green bond market. On the contrary, large capital outflows from the green bond market to the currency market are subject to a decline in interest rates. As a result, monetary markets further insulate risk transmission and low-risk correlation [31].

3.5.7. Global and Macroeconomic Factors

A strand of studies in the sample analyzed global and macroeconomic factors influencing green bonds' hedging properties and correlation trends between green bonds and assets under study [23,28,30,35,39,42,45,46]. Focusing on green and black bonds' connectedness, Broadstock and Cheng [46] tested the influence of macroeconomic factors on green bonds' interaction with black bonds. The correlation between the two assets was found to be prone to economic policy uncertainty (EPU), fluctuations in financial markets volatility, daily

economic activity, and green bond market sentiment. It is worth noting that the impact of EPU on green bonds' hedging ability varies across countries. While green bonds were effective against the EPU indices of China and the UK, a positive dynamic correlation between US EPU and green bonds indices was observed, inferring the inappropriateness of green bonds to hedge against US EPU.

Along the same lines, Saeed et al. [42] employed eight explanatory variables in examining the hedging ability of green instruments against dirty stocks. Strong evidence for the dissipation of green bonds' hedging properties against crude oil and energy ETFs was linked to an increase in OVX or VIX. Similar effects were influenced by inflation and deflation. Saeed et al. [35] also noted that the total spillover index of green and dirty assets is negatively impacted by the use of high technology for clean energy assets and the geopolitical risk index, while positively impacted by EPU, the performance of USD against six major currencies (DXY), and monetary policy index (FFR) at the middle quantile. The lower and upper tails were positively affected by OVX and VIX, respectively. A positive and negative influence of the volatility in 10-year Treasury note future prices (TYVIX) was detected in the lower and upper tails, respectively. Likewise, the use of high technology for clean energy assets demonstrated a negative effect on the upper quantile and a positive influence in the lower quantile. Similar results can be found in the studies by Thai [39] and Pham and Nguyen [23].

In parallel to previous studies, Kocaarslan [30] investigated the long-run determinants of the dynamic correlations between green bonds, conventional bonds, stocks, and energy assets. The findings indicated that the appreciation of the US dollar value is associated not only with a significant increase in green bonds' and conventional bonds' dynamic correlations but also a decline in dynamic correlation levels between green bonds and the markets of stocks and energy assets. Furthermore, the study reported that the correlation between green bonds and conventional bonds is affected by uncertainty in the money markets and default spread. The level of dynamic correlations between green bonds and conventional bonds deteriorates with an increase in money markets' uncertainty and default spread. In another study, Lee et al. [40] unveiled the explanatory power of geopolitical risks on prices of green bonds in the lower quantiles. In this regard, the findings reported unidirectional causality from geopolitical risks to green bonds prices at lower quantiles. Finally, the aftermath of the COVID-19 pandemic and its apparent impact on the intensification of cross-market correlations and market connectedness were documented by several studies. While the COVID-19 pandemic reduced green bonds' effectiveness in hedging and diversification properties against some assets, such as crude oil [25], the COVID-19 pandemic boosted green bonds' ability to diversify and provide shelter to price oscillations in some markets (e.g., in a stocks' portfolio) [20,23].

4. Future Research Trends

This review offers a broad and comprehensive overview of cross-market relations between the green bonds market and the other markets under study, namely financial markets, energy markets, clean energy markets, precious metals markets, commodity markets, crypto-currency markets, forex markets, and money markets, in addition to global and macroeconomic factors. The summary of the findings of our systematic review of the literature is presented in Table 2. In a nutshell, the prevailing research on the interrelationships between green bonds with other markets validates green bonds as safe-haven asset in a portfolio of stocks, dirty energy stocks, or forex. Green bonds serve as a hedge against risks from CO₂ emission allowances, soft commodities, Bitcoin, crude oil, and the forex market in normal market conditions. Alternatively, green bonds were found to be strategic diversifier in a portfolio of natural gas, crude oil, industrial metals, and global rare earth elements. On the contrary, green bonds had no hedge or diversification benefits when combined with conventional bonds in a same portfolio. The existing literature between green bonds and gold, clean energy assets, the commodity market, and the money market is filled with mixed results and is subject to further investigations. Finally, the existing

literature pinpointed some macroeconomic and global factors influencing the relationship between green bonds and other markets.

Table 2. Summary of our findings on green bonds' interaction with other markets.

Market	Instrument	Findings
Financial markets	Stocks	Safe haven and hedge
	Conventional bonds	Not safe haven or hedge
Energy market	Natural gas	Diversifier
	Dirty energy stocks	Safe haven in market stress
	CO ₂ emission allowance	Hedge
	Crude oil	Diversifier and hedge
Precious metals	Gold	Mixed results (hedge and not hedge)
	Industrial metals	Diversifier
	Global rare earth elements	Diversifier
Clean energy	Clean energy assets	Mixed results (diversifier, hedge, and no benefits)
Commodity market	Soft commodities	Hedge
	Commodity market	Mixed results (hedge and not hedge)
Bitcoin		Hedge
Forex		Hedge and safe haven in COVID-19 and diversifier
Money market		Mixed results (diversifier and no benefits)
Global and macroeconomic factors	Economic policy uncertainty	Influences the intensity of markets relations
	Green bonds market sentiment	Influences the intensity of markets relations
	Daily economic activity	Influences the intensity of markets relations
	OVX	Influences the intensity of markets relations
	VIX	Influences the intensity of markets relations

In this section, we identify potential gaps in the literature requiring further research. Furthermore, based on the outcome of the review, we briefly discuss the vital role green bonds can play in risk management and portfolio optimization given the evolving landscape of green investments and the pressing need to mobilize more capital from the private sector to support green finance and a transition to a low-carbon economy. Based on our research findings, we identified six areas for further research.

- a. The nascent research field of green bonds' connectedness with other asset classes, coupled with the dearth of publications in the respective scope, led to the emergence of mixed and contradictory results of green bonds' interaction with other markets. In fact, we are yet to reach a consensus on the types of correlations between green bonds with most of the investigated markets. Mixed results can be found in green bonds' relationship with conventional bonds [20,43,45–48], renewable equities and clean energy stocks [4,36,39,41], energy stocks [5,21,23,24], and money markets [4,31,43]. The

contradictions in research findings can be attributed to the differences in the applied methodologies, the specified sample, and the employed control variables, as well as the factorization of crises in the overall models (such as the COVID-19 pandemic), among others. Future research can extend the sample period to comprehensively analyze cross-market relationships under different market conditions using robust methodologies which account for various aspects of market relationships to generate robust results.

- b. The vast majority of studies included in the sample under study focused on specific geographical regions, such as the US, Europe, and China. Given the evolving green bonds market coupled with an ease of green bond data access, extending this line of research to incorporate studies on green bonds from various regions (developed countries, emerging economies, etc.) will offer a holistic overview of green bonds' cross-market relationships across multiple regions accounting for various regional determinant factors and can be a step forward towards promoting a consensus in green bonds' hedging and safe-haven properties.
- c. Generally, the focus of the studies on green bonds' market connectedness has been on traditional financial markets, commodity markets, and energy markets. With the evolving landscape of crypto-assets' innovation and regulations, understanding green bonds connectedness to novel markets is vital to reduce the variance of investments portfolios. Furthermore, the use of crypto-currencies for speculative purposes is apparent in the literature [88–90]. Hence, a combination of green bonds with crypto-currencies in the same portfolio can facilitate testing short-medium- and long-term diversifying, hedging, and safe-haven properties between the two markets.
- d. Our study demonstrated the dominance of high-frequency (daily) data in about 90% of the research papers in our sample. While high-frequency data are efficient in short-term cross-market interdependence analyses and forecasting, the long-term nature of green projects suggests the appropriateness of using low-frequency data (such as weekly or monthly) or mixed data for long-term investment decision making. This step will attract a wide range of investors in green investments and is a better fit to forecast long-term relationships between green bonds and other markets.
- e. The severity of the novel COVID-19 pandemic has crippled the foundations of financial systems and markets worldwide. Green investments are no exception, nor are they immune to the negative impact of the COVID-19 pandemic, as demonstrated in this review. The aftermath of the crisis led to high volatilities in green bond prices and spillovers from other markets, which shows the significant predictive power of the COVID-19 pandemic on asset prices and market relationships. This is a perfect example of the influence of global and macroeconomic factors on cross-market interactions. However, only a handful of studies in our sample factored global and macroeconomic factors into their models. Future studies may consider integrating factors such as the COVID-19 pandemic recovery, the development of COVID-19 vaccines, and other macroeconomic determinants, among others. Similarly, future studies can explore the channels of markets interdependence and correlations (idiosyncratic or systematic or external) to generate robust results.
- f. The research papers under study use the data of corporate green bonds. Green bonds issued by sovereign and supranatural organizations are yet to be analyzed in cross-market studies despite their data's availability. The use of such data can pave the way to tap new research dimensions, such as testing how green bonds can be used by corporations, financial institutions, and even central banks for risk management and portfolio optimization and diversification. For instance, future research can evaluate the eligibility of sovereign green bonds to serve as a High-Quality Liquid Asset (HQLA) to meet Basel III regulations using sophisticated econometric methodologies, such as copula models [36], quantile time-frequency models [39], and Markov-switching dependence models [91].

5. Conclusions

The extraordinary growth of the green bonds market since its inception in 2007 is a positive indicator of the efficiency of green instruments to support climate change mitigation and green economy transitions. Apart from the ecological significance of green bonds manifested in promoting a smooth transition to a low-carbon economy, suggestive evidence points towards the efficiency of the green fixed-income assets to offer diversification, hedging, and safe-haven benefits to investors under normal and extreme market conditions. This phenomenon has sparked great interest in the academia community to explore the relationship between green bonds and other asset classes across multiple investment horizons in both bull and bear market conditions. To this end, we conducted a systematic literature review to explore green bonds' market interactions with other markets and shed light on potential financial benefits of incorporating green bonds in investment portfolios.

Following an extensive search in the Scopus database coupled with bibliometric analysis techniques, we identified 31 research articles as candidates for our review. The review focused on four main points, namely the evolution of green bonds' cross-market research, data frequency and the applied methodology in the research sample, the role of green bonds as a hedge, diversifier or safe haven in investment portfolios, and future research trends. Despite the lack of consensus with regards to the nature of green bonds' relationship with other markets, the role of green bonds in portfolios' risk management is irrefutable. For instance, studies have validated green bonds' capacity to serve as a diversifier or safe-haven asset against risks from the oil market. A summary of the findings of our comprehensive review is presented in Table 2.

The relationship between green bonds and other asset classes is heterogenous across markets. As such, the role of green bonds as a hedge, diversifier, and safe haven varies between markets and over different investment horizons. The findings of the prevailing literature reported green bonds as a hedge and safe-haven asset for stock investors in bullish and bearish market conditions, respectively. In addition to stocks, green bonds can play the role of safe-haven asset in a portfolio of dirty energy stocks and foreign exchange markets in extreme market downturns, such as the COVID-19 pandemic. The findings of the systematic review also validated green bonds as a potential hedging avenue for price oscillations in CO₂ emission allowances, soft commodities, Bitcoin, and crude oil in normal market conditions. The efficacy of green bonds as a diversifier was confirmed in a portfolio of natural gas, crude oil, industrial metals, and global rare earth elements. With regards to green bonds' market relationship with gold and commodity markets, the prevailing literature is filled with mixed results. Finally, the findings of the review failed to spot any diversification, hedge, or safe-haven benefits of integrating green bonds into a portfolio of conventional bonds.

This study has some limitations, which can be addressed by future studies. The sample of the study was extracted from a single database (Scopus) limited to research articles and conference papers published in the English language. The probability of excluding publications published in other databases and in languages other than English is high. Furthermore, difficulty in accessing some research papers lessened the study sample.

6. Policy Recommendations

The risk management properties of green bonds can have several implications for investors, academia, and policy makers. From an investor's perspective, the emergence of green bonds as a strategic asset for portfolio risk management can promote investors' confidence in green projects' abilities to generate favorable investment returns. While impactful investors seek to achieve environmental impacts from their investments in green assets, their motivation to make hefty returns remains unquestionable. Thus, a high return on green investments can enhance investors' retention in green bonds investments.

Furthermore, the fact that the resilience of green bonds against rare catastrophes, such as the COVID-19 pandemic, was validated, green bonds are likely to attract international and global investors in spells of market downturns. In return, enormous capital inflow from private investors to green projects is expected. Hence, positioning green bonds as a hedge and

safe-haven asset can broaden green bonds' investor base to also attract capital from investors searching for a shelter to market volatilities. However, in some cases, green bonds fall prey to cross-border speculations and arbitrage, leading to short-term instability in the forex markets.

From the perspective of policy makers, they can capitalize on the increasing demand for green bonds, for diversification and hedging purposes, to scale up the green bond market. The green nature of the projects financed by green bonds contributes to the achievement of climate change mitigation and sustainable development objectives, thus meeting countries' commitments to the Paris Agreement and the Sustainable Development Goals (SDGs) agenda. Furthermore, promoting climate-resilient economic activities can also support financial stability and shock resilience.

Additionally, policy makers should prioritize shaping green incentives to attract more private capital for green investments in order to support the transition to a low-carbon economy. In the absence of incentives for green investments, investors will be inclined to prioritize traditional assets with higher returns over paying a premium for green bonds with lower returns.

We urge policy makers to pay special attention to market movements while studying interdependence and risk transmission between markets due to their paramount importance in the process of designing policies. Understanding the role of green bonds in cross-market interactions as risk transmitters or receivers can enhance policy development to support a smooth recovery process over different market conditions and promote efficiency and stability in the green bond market. Similarly, policy makers can work on formulating policies that deter any violation or misuse of green investments in arbitrage or speculation strategies to maintain the virtue of green bonds and ensure green bonds' promotion of sustainable development.

The absence of a long-term pipeline of infrastructure projects to support the transition to a low-carbon economy, coupled with the lack of unified green bonds standards for the identification, selection, evaluation, and reporting of green bonds projects, are some of the challenges hindering the potential of green bonds. Policy makers should prioritize the promotion of green principles, standardized frameworks, and transparency. This step will prove to be crucial for the advancement of green bond markets and mobilizing additional capital for green projects.

From an academic point of view, the literature on green bonds' relationship with other markets is thin and scattered. With an evolving financial system coupled with the emergence of crisis and pandemics, there is a need, now more than ever, for empirical studies analyzing the influence of prevailing market conditions on the ferocity of market connectedness and predicting future trends and volatilities between green bonds and other markets. A detailed proposition of future trends in green bonds research is presented in Section 4.

Supplementary Materials: The supporting information [92] can be downloaded at: <https://www.mdpi.com/article/10.3390/su15086841/s1>.

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