Cardiff Economics Working Papers

Working Paper No. E2026/10

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July 2026

ISSN 1749-6010

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Green bonds and the energy transition: From instrumental use to intrinsic value[1]

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1 **Acknowledgement:** Every author has equal contribution to this paper. We thank the participants at the 2024 Conference on International Sustainable and Climate Finance for their constructive comments and discussions. Wenjie Ding would like to thank the National Natural Science Foundation of China (Grant No. 72203244) for funding this research. All errors and omissions are ours.

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Green bonds and the energy transition: From instrumental use to intrinsic value

Abstract: Using bibliometric techniques, we classify green bonds literature into three main clusters: (i) asset-pricing research examining green bonds' connectedness with other assets; (ii) corporate-finance studies on the determinants of green bond issuance; and (iii) corporate-finance research on their environmental effects, such as carbon-emission reductions and renewable-energy deployment. Early studies primarily focused on pricing dynamics and market connectedness, whereas recent research emphasizes the intrinsic environmental value of green bonds, particularly their role in financing renewable-energy projects and supporting climate-policy objectives. This review integrates these strands into a unified energy-finance framework. On the theoretical side, we map green bond studies along a spectrum from instrumental to intrinsic value. On the methodological side, we synthesize the principal identification strategies used to address endogeneity, a challenge central to establishing credible links between green-bond financing and energy-transition outcomes. Building on these foundations, we set out a future research agenda that highlights underexplored issues concerning cross-market dynamics during energy crises, the effectiveness of green bonds in accelerating decarbonization, and the policy implications for energy-market regulators. Taken together, our findings provide a structured foundation for advancing research on green bonds within energy economics and climate finance.

Keywords: Energy Transition; Green Bonds; Carbon Markets; Clean Energy Finance; Systematic Literature Review

JEL classification: G00, G10

1. Introduction

Meeting the Paris Agreement's climate targets requires redirecting trillions of dollars from fossil fuels toward renewable energy, energy efficiency, and low-carbon infrastructure.[2] Green bonds have emerged as a pivotal financing mechanism in this energy transition, with energy and renewable-energy projects consistently ranking among the largest use-of-proceeds categories. How these instruments interact with energy markets, and whether they deliver tangible environmental benefits, is therefore central to understanding the financial foundations of the low-carbon transition.

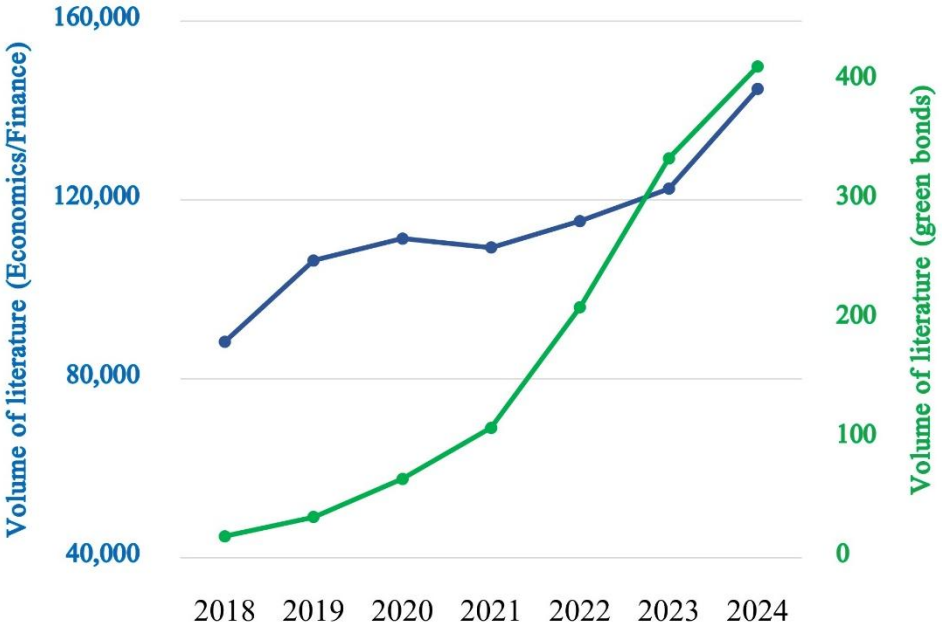
What distinguishes green bonds from conventional bonds is their dedicated use of proceeds for environmentally friendly projects, a requirement formalized through frameworks such as the Green Bond Principles (Zhou, Jin, et al., 2025). The global transition toward sustainable development has driven rapid growth in the green bond market since the European Investment Bank's inaugural issuance in 2007. By 2024, the cumulative value of green bonds reached $818 billion, with participation spanning supranational entities and 112 countries.[3] Parallel to this market expansion, academic research on green bonds has also grown rapidly (**Figure 1**).

[2] For estimates of the climate-finance gap, please see reports from IEA and the Climate Policy Initiative, which place required annual flows at roughly $4-5 trillion and $8.6 trillion by 2030, respectively: www.iea.org/reports/world-energy-investment-2024, and www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2023

[3] For more information about the state of the global sustainable debt market, please see https://www.climatebonds.net/files/reports/cbi_mr_q3_2024_01c.pdf.

Figure 1

The volume of literature on green bonds.



Source: Scopus, articles published in ABS 3/4 journals.

This rapid expansion has been accompanied by heightened scrutiny over the market's environmental integrity, particularly the risk of "greenwashing" (e.g., Berrone et al., 2015; Shi et al., 2023). Such practices undermine the credibility of issuers by creating misalignments between stated sustainability goals and actual environmental impacts, which can distort pricing mechanisms and erode investor trust in green instruments (Henide, 2022). For energy economists, this raises critical questions: do green bonds genuinely accelerate the energy transition, or do they merely relabel existing investments? How do green bonds interact with fossil fuel and clean energy markets during periods of energy price volatility and geopolitical or policy shocks? This review provides a timely contribution amid rising policy emphasis on climate finance and the pressing need to evaluate both the financial dynamics and environmental effectiveness of green bonds.

The existing literature on green bonds remains fragmented across disciplines including economics, finance, and environmental sciences. Prior reviews have focused narrowly on the financial aspects (e.g., Bhutta et al., 2022; Cestau et al., 2019; Tao et al., 2022), while green bonds' connectedness with energy markets and their role in financing the energy transition

have received limited systematic attention. Integration across these dimensions remains insufficient, with inadequate emphasis on theoretical foundations and methodological rigor. Our systematic literature review (SLR) aims to fill this gap with a unified energy-finance framework. Reflecting the dual nature of the term "green bonds", we assess both the "green" or environmental dimension (e.g., carbon-emission reductions, renewable-energy deployment) and the "bond" or financial dimension (e.g., connectedness with energy commodities, risk-return profiles) of the existing literature. To achieve this aim, we answer three related research questions (RQs):

RQ1: What are the predominant themes in green bond research, and how do they relate to energy markets and the energy transition?
RQ2: What theoretical frameworks and empirical approaches are used to examine green bonds' financial dynamics and environmental effects?
RQ3: How has research attention evolved over time, and what are the implications for energy policy and market practice?

Using bibliographic coupling, we classify the existing literature on green bonds into three main thematic clusters (RQ1). Cluster 1 belongs to asset pricing, primarily analyzing the connectedness between green bonds and other assets, with particular emphasis on energy markets, including oil, natural gas, carbon emission allowances, and clean energy indices. Cluster 2 falls under corporate finance, examining the determinants of green bond issuance, yield dynamics, and investor behavior. Cluster 3, also within corporate finance, investigates the environmental effects of green bonds, such as carbon emission reductions and renewable energy deployment. Compared to Clusters 1 and 2, Cluster 3 has received less attention in the literature, though recent studies reflect growing scholarly interest in green bonds' role in financing energy transition.

Recognizing that each thematic cluster rests on distinct theoretical foundations and empirical methods (RQ2) is essential for understanding how the literature on green bonds has evolved (RQ3). Cluster 1 relies on high-frequency financial market data on green bonds' interactions with energy commodities and derivatives. Therefore, little theoretical foundation is involved,

since there is plenty of data to provide evidence-based explanations. As a result, sophisticated empirical approaches such as various connectedness and GARCH models are essential to identify empirical patterns in this strand of literature. In contrast to the "let data speak" philosophy, Clusters 2 and 3 ask research questions related to corporate finance based on low-frequency firm-level data. Thus, theory is critical for developing hypotheses and justifying identification strategies (e.g., Benlemlih et al., 2023; Jia, 2023). Nevertheless, theories can be partial, only capturing a specific aspect of green bonds. For example, taste-based theory emphasizes the intrinsic value of green bonds (Tang & Zhang, 2020), while signaling theory underscores the instrumental value of green bonds (Flammer, 2021). Debates can only be resolved by evidence, which is limited by available data at the firm level. The effect of data availability on literature development is documented in recent systematic reviews as "directed research attention", referring to the systematic shift in scholarly focus toward particular research questions in response to evolving market conditions, policy developments, and data availability (e.g., Zhang et al., 2024; Zhou, Gai, et al., 2025).

Our systematic review aims to make three novel contributions. Theoretically, the existing green bond literature is fragmented across asset pricing, corporate finance, and environmental impact research, with limited dialogue between these strands. We address this by outlining a conceptual framework that distinguishes between instrumental and intrinsic values of green bonds within the broader context of energy-transition financing. This framework reveals the underlying logic connecting the three strands of literature: research has evolved from treating green bonds primarily as financial instruments to examining their actual environmental contributions. We show how existing theories, such as taste-based, signaling, and liquidity theories, map onto this value spectrum, providing researchers and policymakers with a unified lens for understanding both the financial maturity and the still-limited environmental evidence base of the green bond market. Methodologically, we provide a comprehensive empirical toolbox to address endogeneity, a challenge largely overlooked in prior green finance reviews (e.g., Bhutta et al., 2022; Singhania et al., 2023; Tao et al., 2022). This is particularly important for establishing credible links between green-bond financing and energy-transition outcomes.

Practically, we identify emerging research opportunities and propose a structured research agenda that integrates theoretical foundations and empirical rigor. This roadmap is designed to support future research in energy economics and to inform evidence-based climate and energy finance policy.

The remainder of this paper proceeds as follows. Section 2 presents the screening process of the SLR. Section 3 reports identified research clusters on green bonds. Section 4 summarizes prevailing theoretical frameworks and empirical strategies, discusses the evolution of the literature, and proposes a future research agenda. Section 5 concludes.

2. Methods

To ensure transparency and replicability as well as to address the fragmented state of green bond research, we adopt the three-stage SLR framework proposed by Tranfield et al. (2003), comprising planning, conducting, and reporting. This protocol-driven approach, widely applied in recent SLRs in management (Zhang et al., 2024) and economics (e.g., Zhang et al., 2024; Zhou, Gai, et al., 2025), offers a structured process that minimizes bias and facilitates reproducibility. **Table 1** summarizes the three-stage SLR framework adapted to the context of green bond research. To mitigate the biases identified by (Castañer & Oliveira, 2020), including retrieval bias in the search phase, selection bias during screening, and expectancy bias in analysis, we have carefully calibrated every parameter of the SLR.

In the planning stage, we define the scope of our SLR as articles and reviews on green bonds published since 2007, the same year as the first green bonds issuance. Given the interdisciplinary nature of green bond research, we do not restrict the subject area at the search stage. Decisions regarding inclusion and exclusion are made jointly by the authors through iterative discussion to mitigate potential biases.

Table 1

Procedures of the three-stage SLR.

Stage 1: Planning

• From the review panel and establish the review protocol.
• Conduct an exploratory pilot review.
• Define research scope: green bonds.
  o Inclusion Criteria:
  ▪ Include studies on green bonds.
  ▪ Include studies on green bonds using alternative names like climate bonds.
  o Exclusion Criteria:
  ▪ Exclude studies focusing on other green finance instruments like green loans.
  ▪ Exclude studies focusing on other assets.

Stage 2: Conducting

Stage 2.1: Identification
• Search database: Web of Science; Scopus.
• Search fields: TITLE-ABS-KEY.
• Search term: "green bond*" OR "green sukuk*" OR "green municipal bond*" OR "sustainable bond*" OR "climate bond*".
• Search restrictions:
  o Published year: 2007-2024.
  o Document type: article and review.
  o Subject area: Accounting, Finance, and Economics.
  o Language: English.

Stage 2.2: Screening
• Automated screening: publication quality (ABS 3 or 4).
• 1st round manual screening: based on TITLE-ABS-KEY.
• 2nd round manual screening: based on full text.
  o The results are checked by three raters independently.
  o Disputes are resolved by discussions and votes.

Stage 2.3: Analysis • Quantitative analysis: e.g., bibliometric analysis • Qualitative analysis: e.g., thematic analysis
Stage 3: Reporting
• PRISMA: e.g., Page et al. (2021) • Synthesis: e.g., narrative, tabular, graphical, etc. (Grant & Booth, 2009)

During the conducting stage, we carry out a comprehensive search using both Scopus and Web of Science to minimize retrieval bias. We include articles written in English and published between 2007 and 2024. To capture relevant literature, we search three fields (title, abstract, and keywords) for the following strings: "green bond*", "green sukuk*", "green municipal

bond*", "sustainable bond*", "climate bond*". It returns a total of 1,292 articles after removing duplicates and non-academic records (**Figure 2**). **Figure 3** shows that most of these articles appear in both databases, suggesting a high degree of overlap between Scopus and Web of Science. Articles initially retrieved only from one database are typically indexed in the other within about one month, reflecting a slight delay in coverage.

Figure 2

Article collection process based on the framework from PRISMA.

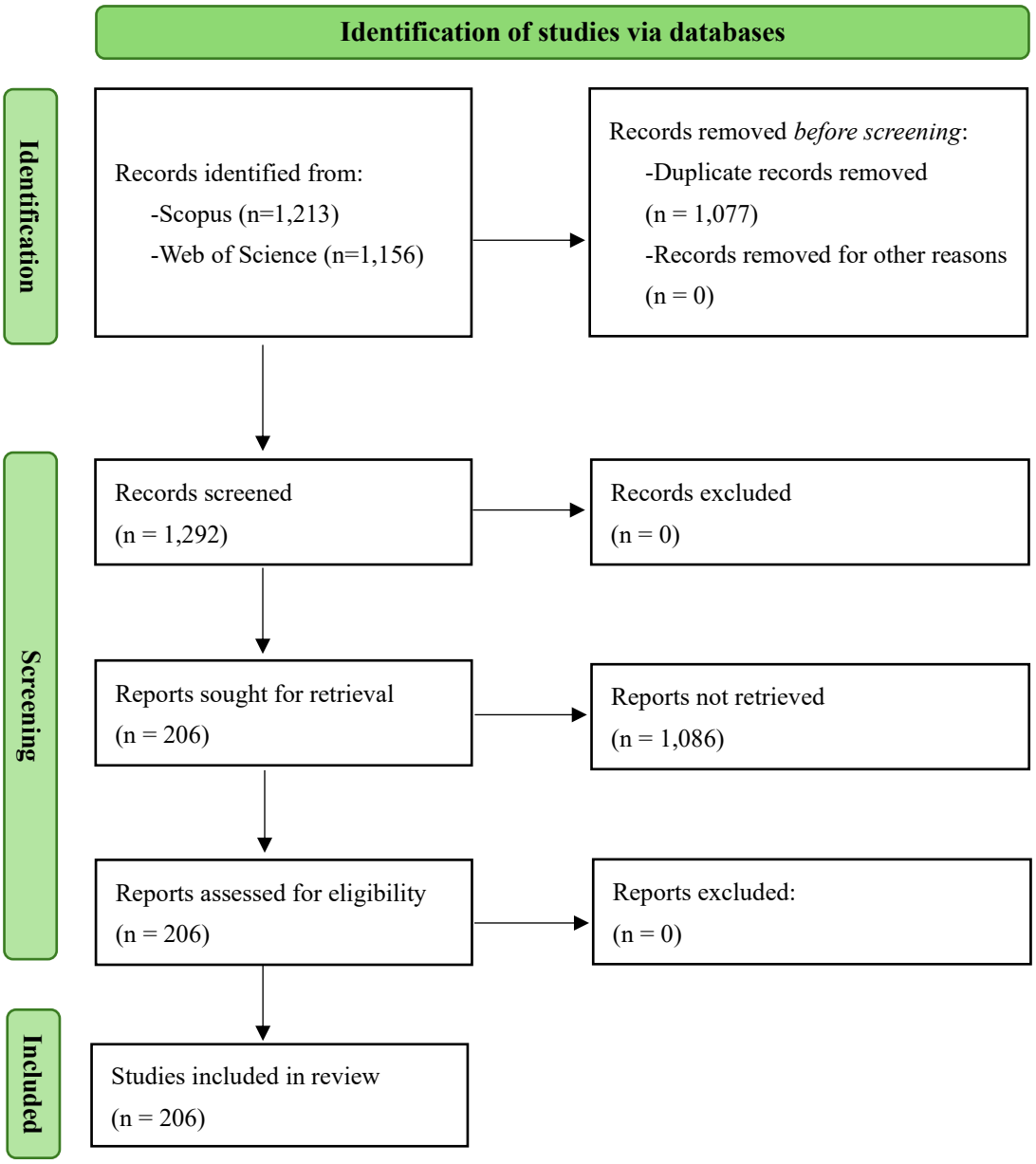
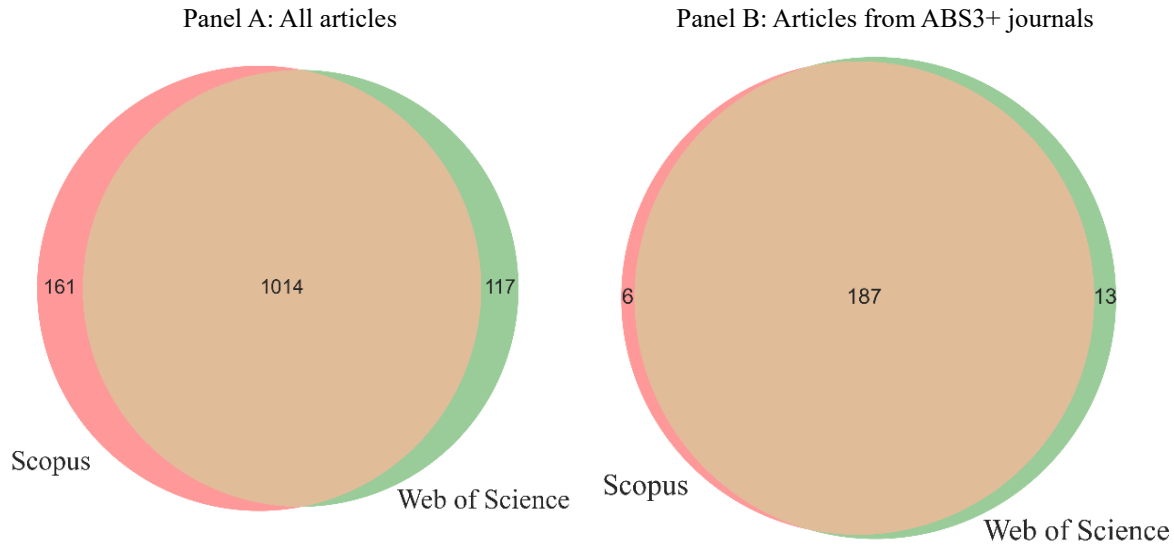


Figure 3

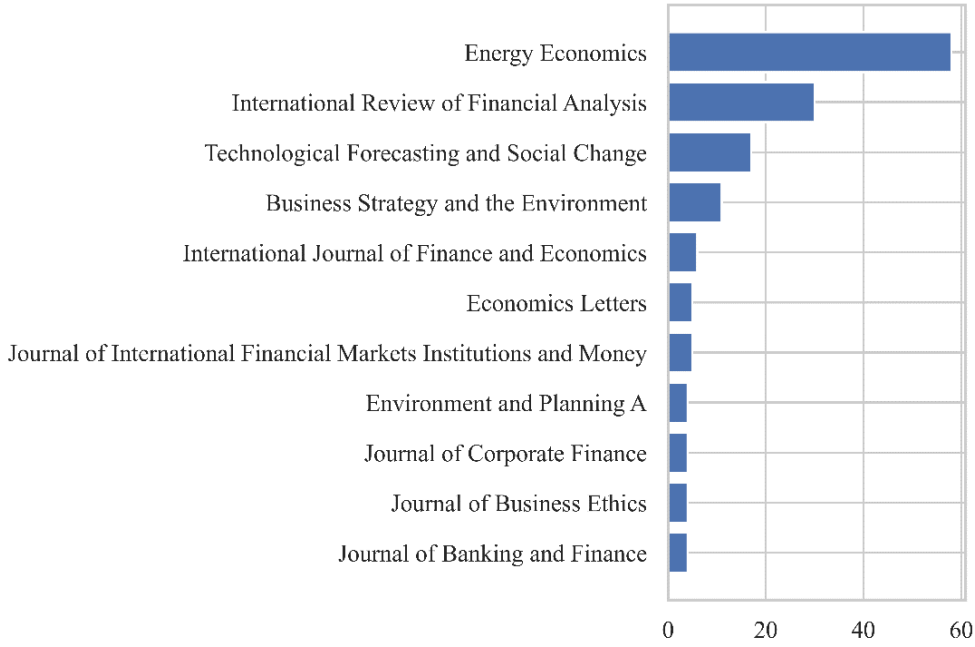
Article database comparison.



Furthermore, to ensure publication quality, we keep articles published in journals rated 3-star or above in the Academic Journal Guide 2024 (ABS journal ranking), a standard quality criterion used in SLRs (Zhang et al., 2024). This screening process resulted in 206 articles, most of which are indexed by both databases (**Figure 3**, Panel B). Based on this result, we identify major journal outlets for green bond research in (**Figure 4**). *Energy Economics* is the most popular source, publishing a large volume of studies nearly equal to the combined total of the next two sources, *International Review of Financial Analysis* and *Technological Forecasting and Social Change*. To date, only six studies on green bonds have been published in ABS 4-star journals (e.g., Dutordoir et al., 2023; Flammer, 2021; Krüger, 2015; Larcker & Watts, 2020; Pástor et al., 2022; Tang & Zhang, 2020).

Figure 4

Key source journals (article number >=5).



Finally, in the reporting stage, we use the bibliographic coupling method in *VOSviewer* to identify thematic clusters within the green bond literature. To capture changes in the field, we divide the articles into two subperiods because the outbreak of Covid-19 sets a structural break in both investment practices and finance research (Ferriani, 2023). As visualized in **Figures 5** and **6**, three main clusters emerge: the red cluster (Cluster 1) explores the connectedness between green bonds and other assets; the blue cluster (Cluster 2) investigates the determinants of green bonds; and the green cluster (Cluster 3) examines the impacts of green bonds.[4] To track changes in research impact across clusters over time, we also compute normalized citations following *VOSviewer*'s definition: a paper's normalized citations are defined as its raw citations divided by the average citations of all papers published in the same year that are included in the dataset, thereby accounting for the additional time older publications have had to accrue citations.

Section 3 presents key findings in each cluster, and Section 4 synthesizes the theoretical foundations, empirical strategies, literature evolution, and the research agenda.

[4] Yellow spots in Figures 4 and 5 refer to the other articles, which contain reviews on municipal bond markets (Cestau et al., 2019), green bond studies (Bhutta et al., 2022), and environmental finance (Tao et al., 2022).

Figure 5

Bibliographic coupling for green bonds studies published from 2018 to 2020.

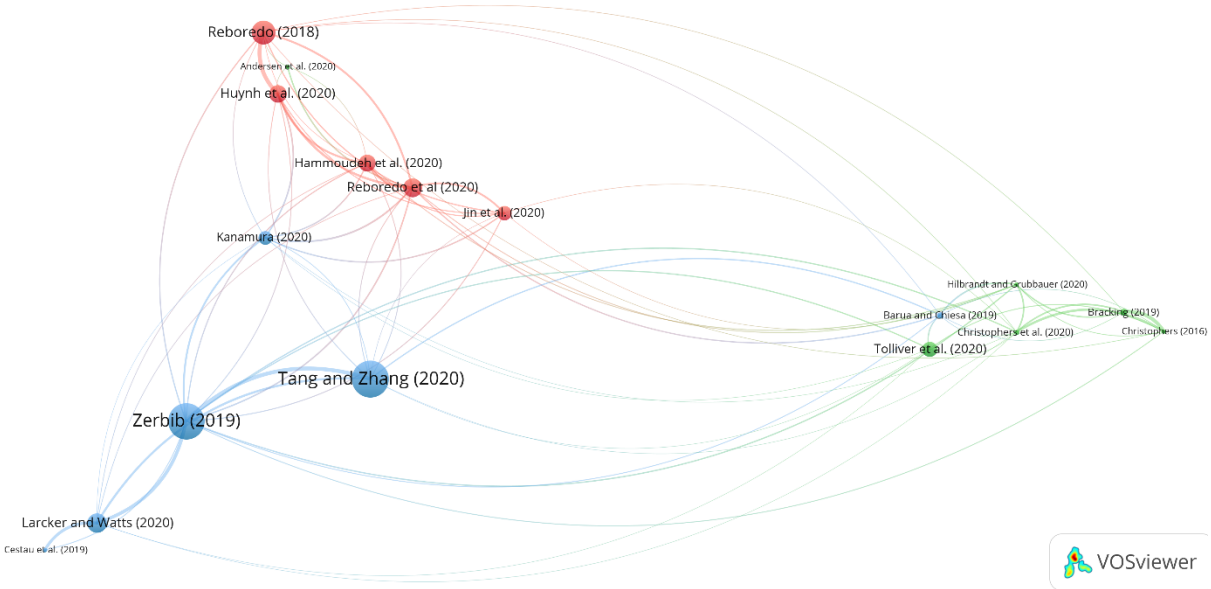
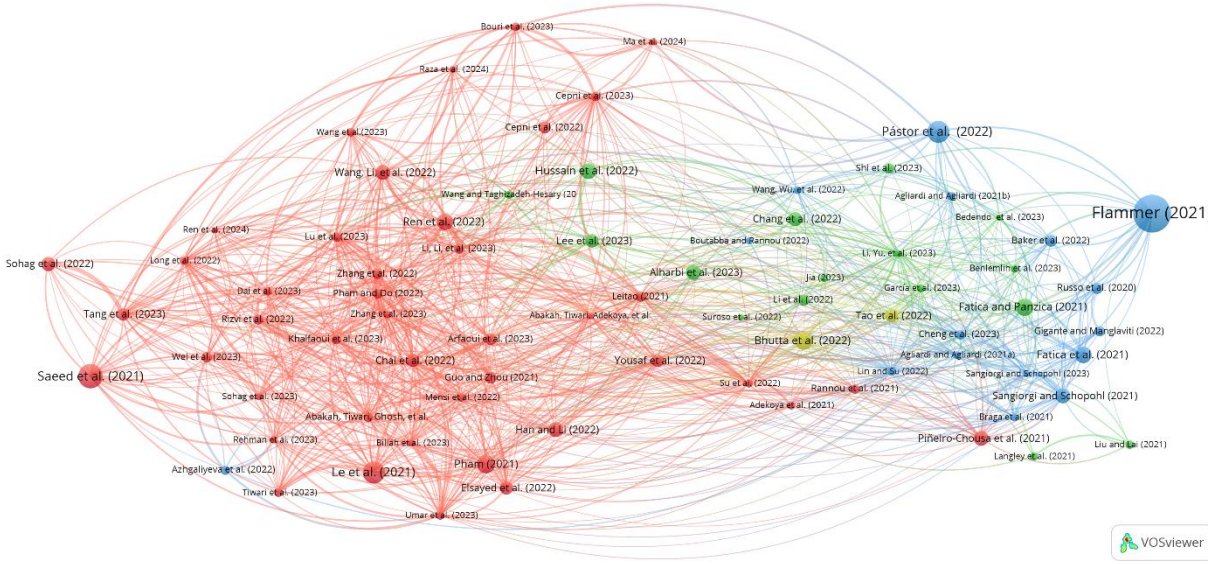


Figure 6

Bibliographic coupling for green bonds studies published from 2021 to 2024.



3. Thematic Clusters

Based on the three main clusters identified in **Figures 5** and **6,** this section focuses on topics with debatable results in each cluster. This section answers RQ1.

3.1. Cluster 1: asset pricing of green bonds

Cluster 1 focuses on the connectedness between green bonds and other assets, with particular emphasis on energy markets including oil, natural gas, carbon emission allowances, and clean

energy indices. This literature also examines connectedness with equities, traditional bonds, and alternative investments (e.g., cryptocurrencies, AI, and FinTech). This strand of literature requires little theoretical foundation and emphasizes timely empirical analyses of green bonds' performance across various market shocks. In terms of the pairing asset, we organize studies in Cluster 1 into three sub-tables of **Table 2**. **Table 2 (a)** presents studies on the connectedness between green bonds and non-energy assets. Findings generally suggest that green bonds offer diversification benefits to equity investors, but their safe-haven feature is weaker than gold. Early studies in equity markets show that green bonds act as a net receiver of the spillover effect from the stock market (e.g., Pham, 2021; Reboredo, 2018; Zhang et al., 2022). The directional relationship evolves over time, but green bonds' role as the net receiver becomes stronger in extreme events (e.g., Guo & Zhou, 2021; Reboredo et al., 2020). Similarly, studies on bond markets also reveal that green bonds receive more but transmit less volatility to treasury bonds (Hammoudeh et al., 2020). Furthermore, as green bonds bring sizeable benefits to both stock and bond investors, further comparisons have been made between green bonds and traditional safe-haven assets. Han and Li (2022) show that portfolios with green bonds bring higher risk-adjusted returns than portfolios with conventional bonds in both the US and EU markets, while Rizvi et al. (2022) document that gold overperforms green bonds under bearish or extremely volatile periods. Accordingly, green bonds bring diversification benefits to equity and bond investors, but their safe-haven feature is still weaker than gold (Yousaf et al., 2022). Only a few studies consider the connectedness within green bonds or with other green equities (e.g., Long et al., 2022; Mensi et al., 2022).

Several factors help explain the variation in findings across this sub-literature. First, market institutional context matters: green bond markets in the US and EU are relatively mature with deeper liquidity, while China's market is more policy-driven, which may account for the differing spillover directions documented by Guo and Zhou (2021) and Long et al. (2022). Second, sample period plays a role, as studies covering crisis episodes such as COVID-19 or the Russia-Ukraine energy shock tend to find stronger connectedness and a shift in green bonds' role from net receiver to net transmitter (Reboredo et al., 2020). Third, methodological choices

also contribute: static connectedness measures capture average relationships, whereas time-varying models (e.g., TVP-VAR) reveal that the direction and magnitude of spillovers can reverse during turbulent periods, reconciling seemingly contradictory findings within the same asset pair.

Table 2 (a)

Key literature on the connectedness between green bonds and non-energy assets.

Theme	Market	Article	Data
equity	US	Yousaf et al. (2022)	S&P 500 Index
	US; EU	Reboredo et al. (2020)	MSCI USA Price Return USD Index; MSCI Europe Index
	US; China	Guo and Zhou (2021)	Dow Jones Index; Shanghai Security Exchange Composite Index
	US; EU; China	Long et al. (2022)	CBOE Volatility Index
	China	Su et al. (2022)	MSCI China index; Shanghai Composite Index
	Global	Reboredo (2018)	MSCI World Index
		Chai et al. (2022)	MSCI ACWI Index
		Elsayed et al. (2022)	MSCI World Index
		Pham and Do (2022)	US VIX Index; EU VSTOXX Index; China VXFXI Index; Emerging Markets VXXEM Index
		Zhang et al. (2022)	MSCI World ESG Leaders Index; NEX WilderHill New Energy Global Innovation Index; SPGB S&P Green Bond Index Total Return; DJS Dow Jones Sustainability World Composite
		Sohag et al. (2023)	Green Equity Index; Oil Equity Index
green equity	Global	Pham (2021)	NASDAQ OMX Clean Energy Focused Index; NASDAQ OMX Green Building Index; NASDAQ OMX Green Transportation Index; NASDAQ OMX Global Water Index
		Lu et al. (2023)	S&P Global 1200 ESG Index; S&P Global 1200 Carbon Efficient Index; S&P Global 1200 Fossil Fuel Free Index
bond	US	Hammoudeh et al. (2020)	US 10-year Treasury Bond Index
		Abakah, Tiwari, Ghosh, et al. (2023)	S&P US Treasury Bond Index
	US; EU	Reboredo et al. (2020)	Bloomberg Barclays US Treasury Total Return Index; Bloomberg Barclays US Corporate Total Return Value Index; Bloomberg Barclays US Corporate High Yield Total Return Index; Bloomberg Barclays Euro Aggregate Treasury Total Return Index; Bloomberg Barclays Euro Aggregate Corporate Total Return Index; Bloomberg Barclays Pan-European High Yield Total Return Index
		Han and Li (2022)	Bloomberg Barclays US Aggregate Total Return Index; Barclays Euro Aggregate Total Return Index
	US; China	Guo and Zhou (2021)	10-year US Government Bond Index; 10-year Chinese Government Bond Index
	China	Su et al. (2022)	China Bond Treasury Bond Index; China Bond Corporate Bond Index
	Global	Elsayed et al. (2022)	Bloomberg Barclays Global Treasury Index; Bloomberg Barclays Global Corporate Index
		Reboredo (2018)	Barclays Global Aggregate Corporate Index; Bloomberg Barclays Global Treasury Total Return Index
		Rizvi et al. (2022)	USD 5-Year Treasury Yield
		Abakah, Tiwari, Ghosh, et al. (2023)	S&P 500 Composite Price Index; Dow Jones Islamic Market World Index
		Billah et al. (2023)	15 Sukuk markets
green bond	Global	Long et al. (2022)	Bloomberg US Green Bond Index; Bloomberg European Green Bond Index; China Bond Green Bond Index
		Mensi et al. (2022)	Green Building; Green Industrial; Green Financial; Green Utility
gold	Global	Rizvi et al. (2022)	Philadelphia SE Gold Silver Index
		Yousaf et al. (2022)	S&P GSCI Gold Spot Price Index

Table 2 (b) shows the literature on the connectedness between green bonds and energy-related assets. It reports more mixed findings, with results varying across countries and over time. For example, Leitao et al. (2021) find that green bonds have positive effects on the EU carbon market, at odds with Li, Li, et al. (2023), who identify a significant negative impact on China's carbon emission trading price. Moreover, mixed results across countries are also found in the connectedness with oil markets. Saeed et al. (2021) document that spillovers among clean energy stocks, green bonds, crude oil, and energy ETFs in lower and upper quantiles are stronger than those in the middle quantile. This finding is further complicated by Long et al. (2022), where US green bonds act as net transmitters while China's green bonds primarily function as net receivers. Similarly, studies on traditional energy and clean energy markets confirm green bonds' long-term diversification benefits for investors (e.g., Arfaoui et al., 2023; Elsayed et al., 2022; Reboredo, 2018), and also highlight the time-varying nature of such benefits (e.g., Pham & Do, 2022; Reboredo et al., 2020; Saeed et al., 2021). However, as summarized in **Table 2 (b)**, green bond studies on clean energy and gas markets mainly concentrate on the US and China, while less are based on the EU market.

The heterogeneity in findings across energy assets can be attributed to similar factors. Market-specific energy policies and carbon pricing regimes shape the 'green bond – energy' nexus differently: for instance, the opposing carbon market results of Leitao et al. (2021) in the EU and Li, Li, et al. (2023) in China likely reflect the structural differences between the EU ETS and China's nascent regional carbon markets. Sample period is again important, as studies spanning the 2022 energy crisis document markedly stronger spillovers than those using pre-crisis data. Methodologically, the choice between quantile-based approaches and mean-based connectedness models matters considerably, since 'green bond – energy' linkages appear substantially stronger in tail quantiles than at the median Saeed et al. (2021), a pattern that mean-based models would understate.

Table 2 (b)

Key literature on the connectedness between green bonds and energy assets.

Theme	Market	Article	Data
carbon emission trade	US	Hammoudeh et al. (2020)	CO2 emission allowances
	EU	Rannou et al. (2021)	EUA Futures Contract
		Ren et al. (2022)	ECX EUA carbon futures
	China	Dai et al. (2023)	high-carbon-emission stocks
	Global	Jin et al. (2020)	EUA Futures Contract
		Leitao et al. (2021)	EUA Futures Contract
		Ren et al. (2022)	EUA Futures Contract
		Wang, Li, et al. (2022)	S&P GSCI Carbon Emission Allowances
		Wang et al. (2023)	ICE EUA future price
		Zhang et al. (2022)	Carbon Emissions Futures
oil	US; EU; China	Long et al. (2022)	CBOE Crude Oil ETF Volatility Index
	US; China	Guo and Zhou (2021)	West Texas Intermediate Crude Oil Index Brent Crude Oil
		Dai et al. (2023)	West Texas Intermediate Crude Oil Index
	China	Ren et al. (2024)	South China Sea crude oil spot steam coal futures
	Global	Saeed et al. (2021)	Crude oil prices
		Pham and Do (2022)	Brent Crude Oil
		Wang, Li, et al. (2022)	CBOE Crude Oil ETF Volatility Index
		Wang et al. (2023)	Newcastle coal future price Average of WTI, Brent and Dubai crude oil future prices
		Rehman et al. (2023)	World Integrated Oil and Gas Producer Index
		Umar et al. (2023)	World Integrated Oil and Gas Producer Index
		Wei et al. (2023)	NYMEX Oil Futures Contract
energy	US; EU	Reboredo et al. (2020)	Thomson Reuters United States Energy Index Thomson Reuters Europe Energy Index
	Global	Reboredo (2018)	S&P GSCI Energy Spot CME Index
		Saeed et al. (2021)	iShares U.S. Oil & Gas Exploration & Production ETF
		Elsayed et al. (2022)	MSCI World Energy Price Index
		Pham and Do (2022)	Energy VXXLE Index
clean energy	US	Hammoudeh et al. (2020)	WilderHill's Clean Energy Price Index
	China	Ren et al. (2024)	New energy index Green investment index Green power index
	Global	Saeed et al. (2021)	WilderHill's Clean Energy Price Index
		Chai et al. (2022)	S&P Global Clean Energy Index
		Wang, Li, et al. (2022)	S&P Global Clean Energy Index
		Abakah, Tiwari, Ghosh, et al. (2023)	S&P Global Clean Energy Index
		Arfaoui et al. (2023)	S&P Global Clean Energy Index
		Lu et al. (2023)	S&P Global Clean Energy Index
gas	China	Ren et al. (2024)	Natural Gas Index
	Global	Abakah, Tiwari, Adekoya, et al. (2023)	Shale Gas Price Index Henry Hub Natural Gas Price Index
		Wang et al. (2023)	Average of the European Union and the US Henry Hub natural gas future prices

Table 2 (c) documents studies on the connectedness between green bonds and alternative investments. Evidence shows that green bonds exhibit heavy-tail dependence on both cryptocurrencies and artificial intelligence stocks (e.g., Huynh et al., 2020; Khalfaoui et al., 2023; Le et al., 2021). It has been found that green bonds are an effective hedging tool against shocks arising from climate uncertainty, Fintech, and Bitcoin markets (Cepni et al., 2022; Le et al., 2021). For commodity markets, Pham and Do (2022) show that green bonds act as a net receiver of the spillover effect, but this relationship is again state-dependent. Similarly, Naeem

et al. (2022) reveal that risk spillovers between green bonds and agricultural indices are weak when volatility is very low. Finally, findings on the impacts of geopolitical risks on green bonds are complex. Sohag et al. (2022) illustrate that all measures of geopolitical risk (except geopolitical acts) transmit positive shocks to green investments (both stocks and bonds). Tang et al. (2023) further add that the return on green bonds is negatively affected by US economic policy uncertainties and geopolitical threats. Moreover, Zhang et al. (2022) find that geopolitical risks have a more prolonged impact on the volatility of green bonds than on their returns.

Table 2 (c)

Key literature on the connectedness between green bonds and emerging indices.

Theme	Market	Article	Data
crypto-currency	Global; US; EU	Khalfaoui et al. (2023)	Bitcoin; Ethereum; Litecoin; Ripple
	Global	Huynh et al. (2020)	Bitcoin
		Le et al. (2021)	Bitcoin
		Rizvi et al. (2022)	Bitwise 10 Large Cap Crypto Index
		Abakah, Tiwari, Ghosh, et al. (2023)	Bitcoin
		Arfaoui et al. (2023)	Bitcoin; Cardano; Ethereum; Ripple
AI robotics	Global	Huynh et al. (2020)	NASDAQ Artificial Intelligence Index
		Abakah, Tiwari, Ghosh, et al. (2023)	NASDAQ CTA Artificial Intelligence and Robotics Index
FinTech	Global	Le et al. (2021)	KBW NASDAQ Technology Index
		Abakah, Tiwari, Ghosh, et al. (2023)	KBW NASDAQ Technology Index
		Tiwari et al. (2023)	KBW NASDAQ Technology Index
Forex	US; China	Guo and Zhou (2021)	US Dollar Index returns of USD/CNY exchange rate
commodity	Global	Pham and Do (2022)	Gold GVZ Index Silver VXSLV Index
		Cepni et al. (2022) Cepni et al. (2023)	Physical Risk Index Transition Risk Index
climate risk	US	Bouri et al. (2023)	Physical Risk Index Transition Risk Index
	EU	Ma et al. (2024)	Climate change news indexes
	Global	Tang et al. (2023)	US Economic Policy Uncertainty Index Geopolitical Threats Index Geopolitical Acts Index
political uncertainty	US	Li, Li, et al. (2023)	China Economic Policy Uncertainty Index
	China	Sohag et al. (2022)	Geopolitical Risk Index Geopolitical Threats Index Geopolitical Acts Index Geopolitical Risks Broad Index
	Global	Wang, Li, et al. (2022)	US Economic Policy Uncertainty Index
		Wang et al. (2023)	Climate Policy Uncertainty Index
		Zhang et al. (2023)	Geopolitical Risk Index
		Raza et al. (2024)	Climate Policy Uncertainty Index
		Adekoya et al. (2021)	S&P 500 Bond Price Index
investor sentiment	US	Piñeiro-Chousa et al. (2022)	Twitter sentiment

Across these alternative asset classes, the divergence in findings is driven less by geographic market differences and more by the nature of the paired asset and the type of risk considered. The heavy-tail dependence with cryptocurrencies and AI stocks (e.g., Huynh et al., 2020;

Khalfaoui et al., 2023) reflects speculative and sentiment-driven co-movement during periods of market stress, whereas the state-dependent relationship with commodities (Pham & Do, 2022; Naeem et al., 2022) suggests a more fundamentals-based channel tied to real economic activity. For geopolitical risk, the distinction between threat and act matters: Sohag et al. (2022) show that geopolitical acts transmit positive shocks to green bonds, while Tang et al. (2023) find negative effects from broader policy uncertainty, suggesting that the type and proximity of the geopolitical shock determine whether green bonds serve as a hedge or become a casualty. These nuances are frequently obscured when studies employ different risk measures or sample frequencies.

3.2. Cluster 2: corporate finance of green bonds

Cluster 2 covers corporate finance topics such as issuance, yield, liquidity, and investor behavior of green bonds. Studies in this cluster typically require a solid theoretical foundation to support the proposed relationship. At the same time, empirical identification lies at the center of causal inference.

According to studies in **Table 3**, green bonds issuance is determined by both internal and external factors. Internal factors include not only bond attributes (e.g., coupon rate, credit rating, issuance size) but also issuer-specific factors such as Environmental, Social, and Governance (ESG) disclosure score, brand reputation, and board structure (e.g., Barua & Chiesa, 2019; Cheng et al., 2023; García et al., 2023). As for external factors, existing studies show that oil supply and demand shocks, financing conditions, and sovereign green bond issuance all have significant impacts on issuers' decisions to issue green bonds (e.g., Azhgaliyeva et al., 2022; Lin & Su, 2022).

Table 3

Key literature on corporate finance topics on green bonds.

Theme	Market	Article	Data
issuance	China	Lin and Su (2022);	Green Bonds Issuance (0 or 1)
		Wang, Wu, et al. (2022);	Climate Risk Concerns in Ratios; Ratios of Climate Risks
		García et al. (2023)	The Likelihood of Green Bonds Issuance
	Global	Barua and Chiesa (2019);	Amount Issued
		Azhgaliyeva et al. (2022);	Green Bonds Issuance (0 or 1); Market Share of Green Bond
		Cheng et al. (2023)	Green Bonds Issuance (0 or 1); Conventional bonds Issuance (0 or 1)
		Sangiorgi and Schopohl (2023)	survey of green bonds issuers
yield	US	Baker et al. (2022)	Offering Yield
	EU	Agliardi and Agliardi (2021a);	Green Bonds Premium (based on daily yield)
		Agliardi and Agliardi (2021b);	
		Gigante and Manglaviti (2022)	Offering Yield
	German	Pástor et al. (2022)	Daily Yield
	Global	Zerbib (2019);	Green Bonds Premium (based on daily yield)
		Kanamura (2020);	Green Bonds Premium (based on daily yield)
		Larcker and Watts (2020);	Green Bonds Premium (based on offering yield)
		Russo et al. (2020);	Green Bonds Performance
		Tang and Zhang (2020);	Green Bonds Premium (based on offering yield)
		Braga et al. (2021);	Daily Yield; Beta Price
		Fatica et al. (2021);	Offering Yield
		Flammer (2021);	Offering Yield
liquidity	EU	Boutabba and Rannou (2022)	Liquidity Premium
investor behavior	US	Baker et al. (2022)	Herfindahl-Hirschman Index of ownership concentration
	Global	Larcker and Watts (2020);	Herfindahl-Hirschman Index of ownership concentration; Institutional Ownership
		Tang and Zhang (2020);	Cumulative Abnormal Return; Institutional Ownership; Stock Liquidity
		Flammer (2021);	Cumulative Abnormal Return; Institutional Ownership; State-level Green Preference
		Sangiorgi and Schopohl (2021)	Green Bonds Investment Activities

Around half of the key studies in **Table 3** focus on the determinants of bond yields because there has been a long debate on whether green bonds enjoy a lower required yield (the "greenium"). The existence of greenium aligns with the taste-based asset pricing framework (Fama & French, 2007), and is supported by empirical research (e.g., Baker et al., 2022; Lau et al., 2022; Zerbib, 2019). However, other studies find that green bonds do not significantly differ from conventional bonds in yields once all factors are controlled (e.g., Flammer, 2021; Gigante & Manglaviti, 2022; Larcker & Watts, 2020). For example, Tang and Zhang (2020) show that the significant greenium in their baseline model disappears when comparing yield spreads within the same issuing firm in the same year. Further studies reveal that the existence of greenium depends on issuer type (e.g., Braga et al., 2021; Fatica et al., 2021; Russo et al., 2020) and label type (e.g., Ghitti et al., 2023; Zhou, Jin, et al., 2025). Notably, these studies

suggest that certification standard and the presence of external review are meaningful moderating variables: greenium estimates differ between certified and self-labeled bonds, indicating that definitional heterogeneity is not merely a classification issue but a substantive source of variation in pricing outcomes. However, such differentiation remains rare in the literature, with the vast majority of greenium studies treating all green bonds as a single category.

In contrast with the large volume on return premium, fewer studies investigate the liquidity premium of green bonds. Boutabba and Rannou (2022) reveal that the magnitudes of short-term and long-term premia in the German government bond market are affected by economic factors and by spillover effects between them, which contribute to the U-shape liquidity premium. Besides, green bond issuance also attracts greater market attention, which can result in increased stock turnover, market attention, and ownership diversity (e.g., Flammer, 2021; Larcker & Watts, 2020; Tang & Zhang, 2020). Flammer (2021) finds that green bond issuance is attractive to long-term and green retail investors, but the effect on institutional investors is not statistically significant. In contrast, Tang and Zhang (2020) document a significant rise in institutional holdings, which are particularly driven by domestic institutions. Furthermore, survey-based evidence from Sangiorgi and Schopohl (2021) explains that institutional investors value strong environmental credentials and competitive pricing, while inadequate reporting on the use of proceeds can significantly deter investor participation. These findings consistently suggest that issuing green bonds enhances corporate visibility and attracts an investor base that values transparency, sustainability, and long-term orientation.

From a theoretical perspective, studies in Cluster 2 primarily draw on the signaling theory, stakeholder theory, and strategic corporate social responsibility (CSR) frameworks to explain the motivations of green bond issuance. According to the signaling theory, firms are believed to use green bonds as a credible signal of environmental commitment, which is particularly supported by governance structures such as sustainability committees or enhanced ESG disclosure (e.g., Flammer, 2021; García et al., 2023). On the demand side, investor behavior is

often interpreted through the taste-based asset pricing framework (Fama & French, 2007), suggesting that non-pecuniary motives may drive the willingness to accept lower returns in exchange for environmental benefits (e.g., Baker et al., 2022; Zerbib, 2019). These theoretical perspectives underpin a wide range of empirical strategies aimed at identifying the causal effects of green bond issuance.

From a methodological perspective, difference-in-differences (DiD) models are widely employed, often in combination with propensity score matching (PSM), to compare firm behavior or market reactions before and after green bond issuance (e.g., Tang & Zhang, 2020; Wang, Wu, et al., 2022). Meanwhile, as a special case of DiD, event study is also a popular choice to capture short-term market responses to issuance announcements (Flammer, 2021), while regression discontinuity designs (RDD) are used to test whether ESG performance thresholds influence borrowing costs (Gigante & Manglaviti, 2022). Matching techniques and fixed-effects panel regressions are also frequently employed to isolate the "greenium" by comparing green and conventional bonds with similar characteristics (e.g., Flammer, 2021; Larcker & Watts, 2020; Zerbib, 2019). Together, these theoretical and empirical advances enhance the credibility of research findings in this thematic cluster.

3.3. Cluster 3: environmental effects of green bonds

The third cluster focuses on studies examining green bonds' environmental effects, particularly their role in supporting renewable energy deployment and carbon emission reductions in the energy sector (as studies reported in **Table 4**). Compared to Clusters 1 and 2, which focus on financial attributes such as pricing, connectedness, and issuance determinants, studies in Cluster 3 address whether green bonds contribute to real environmental outcomes (e.g., Andersen et al., 2020; Bracking, 2019; Hussain et al., 2022). Fewer studies fall into this cluster, partly because environmental outcomes take longer to materialize and the data needed to measure them have only recently become available. This question lies at the core of the paper's overarching theme: whether green bonds contribute meaningfully to the energy transition, or whether their value remains primarily instrumental (Langley et al., 2021).

Table 4

Key literature on environmental effects of green bonds.

Theme	Market	Article	Data
sustainability	US; Russian Federation; China	Jia (2023)	political steps and initiatives taken in the field of green finance, and initiatives of international actors in the field of decarbonization
	OECD countries	Wang and Taghizadeh-Hesary (2023)	Wind Energy; Solar Energy; Hydro Energy
	G10 countries	Li et al. (2022)	CO_2 Emissions;
	China	Li, Yu, et al. (2023)	total factor productivity
		Shi et al. (2023)	number of green patents
	Indonesia	Suroso et al. (2022)	nationally determined contribution target
	Malaysia	Liu and Lai (2021)	policy documents, non-governmental organization publications, corporate reports, and interviews
	Global	Fatica and Panzica (2021);	Total Greenhouse Gas Emissions; Direct (Scope 1) Emissions
		Flammer (2021);	CO_2 Emissions; Environment Rating
		Benlemlih et al. (2023);	Resource Use Grade; Environmental Innovation Grade; CO_2 Emission Grade; CO_2 Intensity
		Chang et al. (2022);	Environmental quality; Ecological Footprint
		Alharbi et al. (2023);	net generation of renewable energy from bio-mass and non-biomass sources
		Bedendo et al. (2023)	bank environmental footprint
		García et al. (2023)	Environmental Pillar Score; Emission Score; Resource Use Score; Environmental Innovation Score; CO2 emissions relative to total sales
policy	Mexico	Hilbrandt and Grubbauer (2020)	Regulatory Shifts
	Global	Tolliver et al. (2020)	Nationally Determined Contributions Index
	China	Lee et al. (2023)	Green Bonds Policy

The existing evidence spans four outcome types. First, studies on carbon emission reductions generally find a positive relationship at the macro level. Li et al. (2022) document that climate technology and green finance contribute to lower CO2 emissions across G10 countries, and Chang et al. (2022) report a positive association between green bonds and environmental quality measured by ecological footprint. At the global firm level, Fatica and Panzica (2021) find that green bond issuers reduce their direct (Scope 1) emissions after issuance, and Flammer (2021) reports improvements in both CO2 emissions and environmental ratings. García et al. (2023) further confirm this using multiple environmental performance measures. However, not all firm-level evidence is supportive. For instance, Benlemlih et al. (2023) find no conclusive effect on CO2 intensity, and Jia (2023) reaches a similar conclusion across the US, China, and Russia. These studies attribute the null results to limited post-issuance disclosure and short observation windows. In a similar vein, Bedendo et al. (2023) document mixed evidence on the impact of green bond issuance on the environmental footprint of financial institutions. The

divergence between positive macro-level findings and inconclusive firm-level evidence suggests that the environmental benefits of green bonds may be real but difficult to isolate at the individual issuer level with currently available data.

Second, studies on renewable energy deployment directly address whether green bonds contribute to the energy transition. Wang and Taghizadeh-Hesary (2023) find that green bond issuance is associated with increased wind and hydro energy consumption across OECD countries, though the effect on solar energy is not significant, suggesting that green bond financing may not uniformly benefit all renewable energy sources. Tolliver et al. (2020) approach the question from a policy perspective, showing that countries with more stringent nationally determined contributions allocate a larger share of green bond proceeds to renewable energy projects. Alharbi et al. (2023) further document a positive relationship between green finance and renewable energy generation from both biomass and non-biomass sources. Together, these studies provide encouraging macro-level evidence, but project-level data linking specific bond proceeds to specific energy assets remain scarce.

Third, a smaller group of studies examines green innovation. Li, Yu, et al. (2023) find that green bond issuance in China improves total factor productivity, while Shi et al. (2023) show that it promotes green patents. Both studies suggest that green bonds ease financial constraints and channel resources toward environmentally oriented R&D. However, this evidence is concentrated in the Chinese market, and it remains unclear whether these findings generalize to other institutional settings.

Fourth, policy and institutional studies explore how regulatory frameworks shape the green bond-environment relationship at the country or regional level. Lee et al. (2023) examine how green bond policy in China promotes green innovation and green space in the context of net-zero targets. Suroso et al. (2022) assess Indonesia's progress toward its nationally determined contribution, highlighting the role of green bond financing in climate adaptation. Liu and Lai (2021) provide a qualitative perspective on the development of green sukuk in Malaysia,

illustrating how Islamic finance frameworks intersect with sustainability objectives. Hilbrandt and Grubbauer (2020) examine municipal green bonds in Mexico City, revealing how standardization processes shape the deepening of local green finance markets.

Taken together, evidence across these four outcome types reveals two cross-cutting patterns. The first is the systematic divergence between firm-level and macro-level findings: studies tend to report positive environmental effects (e.g., Chang et al., 2022; Li et al., 2022), while firm-level studies are more mixed (e.g., Benlemlih et al., 2023; Jia, 2023). This reflect the shorter observation windows available at the firm level, the time lag between bond issuance and observable environmental outcomes (Jia, 2023), and the possibility that aggregation masks heterogeneous responses across individual firms. The second is that most studies treat "green bond" as a single category, without distinguishing between certified and self-labeled bonds. Although Shi et al. (2023) show that post-issuance disclosure helps mitigate greenwashing concerns, no study directly compares environmental outcomes across different certification standards. This is a notable gap, as pooling bonds with varying levels of certification may obscure the true environmental effects of green bond financing. It is also worth noting that a small number of studies in this cluster examine non-corporate contexts, such as country-level climate commitments (Tolliver et al., 2020) and municipal green bonds (Hilbrandt & Grubbauer, 2020), where the mechanisms driving environmental outcomes may differ substantially from those at the corporate level.

Addressing these challenges requires both solid theoretical foundations and rigorous empirical identification (Christophers, 2018). On the theoretical side, studies in this cluster draw primarily on signaling theory, particularly in studies examining green bond issuance as a credible indicator of environmental commitment (e.g., Bedendo et al., 2023; Fatica & Panzica, 2021). The strength of the signal often depends on the presence of external certification and post-issuance disclosure, which help mitigate concerns about greenwashing (Shi et al., 2023). In addition, resource-based theory underpins arguments that green bonds enhance firms' capabilities to pursue green innovation by easing financial constraints (Wang et al., 2023).

On the empirical side, fixed-effects regressions and first-difference models are commonly used to control for unobservable confounding effects across firms and over time (e.g., García et al., 2023; Li et al., 2022). Similar to Cluster 2, quasi-experimental approaches such as DiD, PSM, and coarsened exact matching are also widely employed by studies in Cluster 3 (e.g., Fatica & Panzica, 2021; Shi et al., 2023; Tolliver et al., 2020). Furthermore, some cross-country studies apply fully modified ordinary least squares (FMOLS) to examine long-run relationships between green finance and renewable energy adoption (Wang & Taghizadeh-Hesary, 2023), while others use panel data cointegration techniques or common correlated effects estimators to address cross-sectional dependence (Alharbi et al., 2023). Additionally, policy-based identification strategies using nationally determined contributions (NDCs) as quasi-treatment variables are used to capture institutional drivers of green bond allocation (Tolliver et al., 2020). Despite methodological advances, the literature in Cluster 3 still calls for improved environmental disclosure standards and more granular, project-level data to accurately trace the environmental outcomes of green bonds financing (e.g., Christophers, 2018; Jia, 2023).

4. Discussion

Based on the three clusters of literature, we synthesize insights regarding the theoretical foundation and empirical identification approaches in existing research on green bonds (RQ2). We additionally examine how research attention has evolved over time, offering evidence-based perspectives on future research directions (RQ3).

4.1. Theoretical Foundations

Researchers make decisions like other economic agents. The three thematic clusters of literature on green bonds answer different research questions ("objectives") using different types of data ("constraints"). For cases where high-frequency data (usually daily) are available and appropriate for questions at hand (e.g., Cluster 1), less theoretical foundation is needed apart from a general assumption of the Efficient Market Hypothesis (EMH). In contrast, when only low-frequency data (e.g., yearly or quarterly) is available, a more theoretical foundation

is needed to understand corporate behavior and identify causal relationships in green bonds markets (e.g., clusters 2 and 3). We summarize the following three popular theoretical foundations adopted in the green bond literature.

Taste-based Theory. This theoretical framework has been widely used to describe investor behavior in green bonds markets (e.g., Bellucci et al., 2023; Flammer, 2021; Halim et al., 2019). This theory suggests that investors are willing to accept a lower financial return, known as the "greenium", in exchange for environmental benefits associated with green investments (Tang & Zhang, 2020). However, empirical evidence suggests that while taste-based preferences can explain some aspects of greenium, additional factors such as second-party opinion and the type of green labels must be at play (e.g., Ghitti et al., 2023; Yu et al., 2024; Zhou, Jin, et al., 2025). While this theory has been predominantly applied to explain why investors accept lower yields on green bonds (Cluster 2), the same preference channel also helps explain why capital flows toward projects with environmental benefits, even when financial returns are not superior (Cluster 3).

Signaling Theory. The signaling theory emphasizes the role of asymmetric information and posits that firms issue green bonds as a way to signal their commitment to environmental sustainability and responsible practices to the market (Flammer, 2021). Green bonds, especially those certified by third-party regulators, are generally regarded as strong signals about firms' ESG objectives. This can bring about reputational benefits and investor trust. Empirical studies have shown that signaling effects can increase short-term investor attention (e.g., Bellucci et al., 2023; Flammer, 2021; Halim et al., 2019). This theory explains why firms issue green bonds and how markets respond to issuance announcements (Cluster 2), while in Cluster 3 it underpins the credibility of environmental commitments, where the strength of the signal depends on whether the bond is backed by external certification and transparent post-issuance disclosure. Nonetheless, more research is needed to explore how these signaling effects vary across regulatory environments and certification standards (e.g., Climate Bond Standard, EU Green Bond Standard, Green Bond Principles).

Liquidity Theory. Developing markets tend to suffer from lower liquidity in green finance. For example, Boutabba and Rannou (2022) highlight liquidity challenges in the EU green bonds markets. They show that the liquidity premium follows a U-shaped pattern where both short and long maturities carry higher liquidity premiums due to spillover effects and clientele segmentation. A recent theoretical model by Bongaerts and Schoenmaker (2024) links fragmentation, clientele preferences, and liquidity premiums in green bonds design. They highlight that liquidity-induced rationing can limit both economic and environmental welfare when project types are mismatched with investor preferences. In the context of the African market, Owusu-Manu et al. (2022) also emphasize the importance of green bond liquidity in market deepening and renewable energy financing, though liquidity constraints remain a key concern. A related but underexplored factor is the dominance of institutional investors in the green bond market. Institutional investors tend to adopt buy-and-hold strategies, which contributes to thin secondary markets and elevated liquidity premia. The type of investor may also affect demand-side dynamics and greenium estimates (e.g., whether dedicated green funds, pension funds, or retail participants), but this dimension remains largely unexamined in the literature. These studies underscore that theoretical exploration of liquidity in green bond markets, especially in emerging economies, requires deeper empirical investigation.

Energy Market Context. The three theoretical frameworks above take on particular significance in energy markets. For instance, taste-based preferences may be shaped by energy security concerns and decarbonization commitments, while signaling effects are heightened during energy crises when energy companies face heightened scrutiny. Liquidity constraints in green energy bonds can directly impede renewable energy deployment if investors face rationing. For example, the 2022 Russia-Ukraine energy crisis created a natural experiment in which energy security concerns, fossil fuel price spikes, and accelerated renewable energy commitments simultaneously affected green bond demand, pricing, and perceived environmental value. Future theoretical work should explicitly model how these mechanisms function in energy-transition financing, where time horizons, regulatory frameworks, and stakeholder incentives differ from traditional financial markets.

These theories are useful for corporate-level research on green bonds, but they downplay the role of stakeholders other than issuers and investors of green bonds. Given that environmental problems have significant market externalities, other theories involving broader stakeholders can be used to explain activities involving green bonds. For instance, future research could employ the institutional theory (DiMaggio & Powell, 1983) to analyze how regulatory pressures and evolving market norms influence the behaviors of issuers and investors of green bonds. Similarly, stakeholder theory (Parmar et al., 2010) provides insights into how firms issue green bonds to meet the demands of various stakeholders beyond shareholders, such as regulators, environmental groups, and consumers. Agency theory (Baiman, 1990) may also be relevant, offering explanations for how green bonds align managerial actions with shareholder preferences for sustainability. Issuing green bonds may reduce agency costs by directing capital toward projects that serve both corporate and societal interests.

4.2. Endogeneity Toolbox

Cluster 1 studies primarily employ time-series econometric methods such as connectedness and GARCH models, where identification concerns are less prominent. Empirical studies in Clusters 2 and 3, by contrast, predominantly rely on regression-based methods. A central methodological challenge in these studies is establishing causal inference, particularly addressing endogeneity concerns. Following the framework proposed by Roberts and Whited (2013), this subsection outlines key identification strategies used in the green bond literature.

Among matching-based approaches, the construction of the counterfactual, what a green bond's yield would have been absent the green label, is the central identification challenge in greenium studies. Different strategies make different assumptions and can yield divergent estimates. Zerbib (2019) popularized the Synthetic Pairs Method, which constructs a counterfactual by weighting multiple conventional bonds to match a green bond on maturity, rating, currency, and other observable characteristics. This approach assumes that the matching variables fully capture all relevant pricing factors, which may not hold if unobserved differences remain. Larcker and Watts (2020) adopt a same-issuer matched pair design,

comparing green and conventional bonds from the same firm, which controls for issuer-level confounders but restricts the sample to firms that issue both types simultaneously, introducing potential selection effects. Zerbib (2019) finds a small but significant greenium, (Larcker & Watts, 2020) find no meaningful yield difference, illustrating how the definition of the counterfactual can shape conclusions. Other studies combine matching with DiD designs (e.g., Flammer, 2021; Tang & Zhang, 2020) or use coarsened exact matching (Fatica et al., 2021), each relying on the assumption that observable covariates are sufficient to eliminate selection bias. The diversity of these approaches, and the sensitivity of greenium estimates to the choice among them, suggests that future research should pay closer attention to the robustness of matching assumptions and consider reporting results across multiple counterfactual definitions.

As summarized in **Table 5**, the main endogeneity problems, commonly addressed in this literature are reverse causality and omitted variable bias. Prior studies often use lagged explanatory variables to estimate the determinants of green bond issuance and yield dynamics (e.g., Cheng et al., 2023; Pástor et al., 2022) as a strategy to mitigate concerns about reverse causality. This approach can help mitigate potential biases and provide more robust estimates, but it falls short in addressing unobserved, time-invariant firm characteristics or omitted confounders that jointly influence issuance and market outcomes. To address these omitted variable concerns, researchers commonly employ matching techniques, such as propensity score matching (PSM), to construct counterfactuals for firms that issue green bonds (e.g., Fatica et al., 2021; Flammer, 2021; Wang, Wu, et al., 2022). These methods are also applied to correct the self-selection bias in green bond issuance (e.g., Boutabba & Rannou, 2022; Tang & Zhang, 2020). Nonetheless, the success of matching hinges on selecting appropriate covariates and ensuring comparability between treatment and control groups**.** Imprecise matching may lead to biased estimates and undermine the internal validity of the results.

Table 5

Endogeneity concerns and identification strategies in existing studies.

Dependent Variable	Independent Variable	Endogeneity Issue	Identification Strategy
green bonds issuance	brand effects	reverse causation	Probit regress lagged green bonds issuance through brand effects (Cheng et al., 2023); Regress lagged green bonds issuance through ESG score (Cheng et al., 2023). Lag brand effects by 1 year (Cheng et al., 2023).
daily yield	demands to ESG	reverse causation	Instrumenting for same-quarter ESG flow through its previous quarter value in the 2SLS estimation (Pástor et al., 2022).
offering yield	finance by green bond	omitted variable	Matching green issuers to similar non-green issuers based on a set of criteria (Fatica et al., 2021).
environmental outcome; ownership structure	green bonds issuance	omitted variable	Matching green issuers to similar non-green issuers based on a set of criteria and then regressing in DiD (Flammer, 2021).
climate risk concerns	green bonds issuance	omitted variable	Propensity score matching and DiD test (Wang, Wu, et al., 2022).
stock liquidity	green bonds issuance	reverse causation	Matching green issuers to similar non-green issuers based on a set of criteria and then regressing in DiD (Tang & Zhang, 2020).
liquidity premium	credit risk	reverse causation	The concern can be ignored if credit-related variables have insignificant coefficients when estimating the liquidity premium (Boutabba & Rannou, 2022).
traditional cointegration models	green bonds policy; green bonds performance	reverse causality; omitted variable; serial correlation and heteroskedasticity	Apply the quantile-based cointegration test (e.g., Chang et al., 2022; Sinha et al., 2021); Using the regression discontinuity design model (Lee et al., 2023). Apply the fully modified ordinary least squares model (Wang & Taghizadeh-Hesary, 2023).

Furthermore, to mitigate endogeneity issues resulting from traditional cointegration models, researchers also employ methods such as quantile-based cointegration tests, regression discontinuity designs, and fully modified ordinary least squares estimators (e.g., Lee et al., 2023; Sinha et al., 2021; Wang & Taghizadeh-Hesary, 2023). However, future studies should carefully assess the appropriateness of these methods based on their research context and data characteristics.

In addition to the above conventional approaches, recent advances in causal machine learning offer promising alternatives to address endogeneity in complex data environments. Techniques such as causal forests, double machine learning (DML), and targeted maximum likelihood estimation (TMLE) have been increasingly applied in economics and finance to uncover heterogeneous treatment effects and control for high-dimensional confounders. While these methods have seen limited use so far in green bond research (e.g., Kocaarslan & Soytas, 2023;

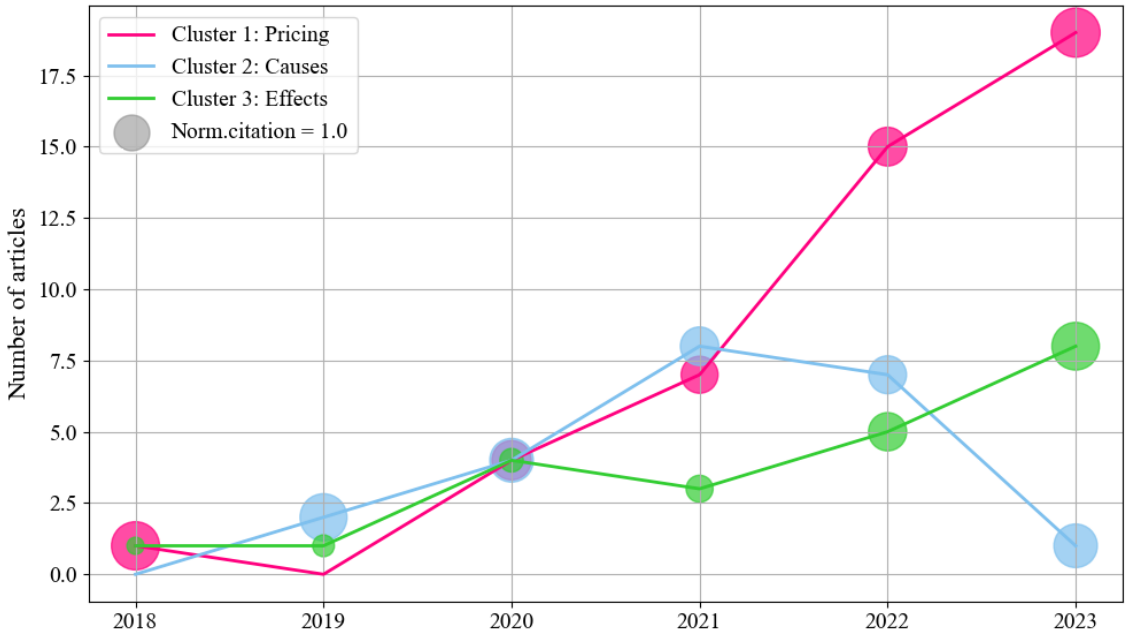
Mahmood et al., 2024), future studies could explore their potential to improve identification strategies, particularly in settings with rich covariates and large-scale datasets.

4.3. Literature Evolution

A comparison of **Figures 5** and **6** shows that all three clusters have grown in scale, but the distribution of research attention has shifted over time. Specifically, Cluster 2 has seen a relative decline in prominence (as reflected in the reduced number of larger nodes), while Clusters 1 and 3 have experienced a notable increase in academic interest. In general, research in green bonds pays more attention to the intrinsic value of green bonds (environmental effects).

To better visualize the evolution of literature, we use normalized citations as a proxy to plot changes in literature focus over time in **Figure 7**. The figure highlights a clear shift in research priorities: whereas early influential work was generally balanced, the period from 2021 to 2023 has seen a growing emphasis on the environmental and economic impacts of green bonds, reflected in Cluster 3's expansion.

Figure 7
Volumes and citations of published articles of the three clusters.



Note: The circle size indicates the average normalized citations of each cluster.

Shifting from the authors' perspective to the citers' perspective, the changes in circle size (normalized citations, as defined in Section 2) demonstrate the growing prominence of Cluster 3 (green) through time, adjusting for the additional time older publications have had to accrue citations.

This academic trend of green bond research aligns with the economics principle for rational decision-making, to maximize the "objective function" subject to "constraints". In our context, the "objective function" of scholars is research impact, which evolves with historical conditions of markets and policy priorities. The revised ICMA Green Bond Principles (June 2021) codified disclosure and external-review practices[5], while the EU proposed (2021) and finalized (2023) a voluntary European Green Bond Standard that reduces informational barriers for green bond issuers. As norms converged, take-up continued to rise, with particular growth in energy-related green bonds. Consequently, the academic return to research on antecedents (Cluster 2) fell, while research on consequences (Cluster 3) rose. This shift reflects growing emphasis on energy-transition outcomes and the credibility of green bonds during energy market volatility. Regulatory debates about "greenwash", energy security concerns (particularly following the Russia-Ukraine crisis in 2022), and the urgency of renewable energy deployment require rigorous empirical answers.

Data availability imposes a fundamental constraint on research. When data are scarce, researchers must rely more heavily on theories; yet theory cannot falsify theory—only evidence can. Therefore, the high-frequency secondary-market data of green bond transactions gives asset pricing research (Cluster 1) a privilege and a head start. By contrast, assessing environmental impacts (Cluster 3) requires lengthy time-series that have only become accessible as bonds issued in the mid-2010s mature, and their projects reach completion. The resulting ex-post information now permits researchers to track emissions, energy efficiency,

[5] International Capital Market Association (ICMA) is a not-for-profit global trade association, for participants in the cross-border debt capital markets.

and clean-investment metrics (e.g., Benlemlih et al., 2023; Fatica & Panzica, 2021; Wang & Taghizadeh-Hesary, 2023). In addition, exogenous shocks such as the COVID-19 market collapse (2020) and the Russia-Ukraine war (2022) generated sizable shifts in liquidity, risk premia, and energy prices. Daily indices (e.g., the S&P Green Bond Index) and newly released trade-and-quote datasets enable analysts to study the hedging properties and real-economy consequences of green bonds during these episodes, and empirical evidence already documents differential price behavior and resilience (e.g., Batra et al., 2025; Guo & Zhou, 2021; Zeng et al., 2025).

4.4. Research Agenda

Based on the findings above, we propose several promising directions for future research. The growth of green bond studies has led to thematic saturation in pricing and issuance domains, while the environmental effects of green bonds remain relatively under-theorized and under-examined. A growing body of recent work has begun to address some of these gaps, and we build on this emerging evidence to identify directions where significant questions remain:

First, Wang, Wu, et al. (2022) provide early causal evidence that green bond issuance increases firm-level attention to climate risk, and Lee et al. (2023) find that green bond policy can promote green innovation in the context of net-zero targets. However, these findings remain limited to indirect proxies of environmental impact. A critical gap exists in understanding whether green energy bonds meaningfully accelerate renewable energy deployment or merely finance projects that would have proceeded anyway under existing renewable energy targets and subsidies. Addressing this requires project-level data linking green bond proceeds to specific renewable energy assets (solar, wind, hydro), capacity additions, and avoided emissions. Future research should leverage emerging environmental disclosure standards, satellite-based emissions tracking, and corporate sustainability reports to develop outcome-based measures. Methodologically, this calls for innovative matching strategies and quasi-experimental designs anchored in impact measurement, not just market responses. In addition, future studies can also integrate climate policy modeling and organizational theories of

legitimacy and sensemaking to capture the long-run and system-level effects of green bonds, including how they align (or misalign) with global climate goals and energy-transition pathways.

Second, current studies have mainly drawn from countries with relatively mature financial and ESG infrastructure (e.g., the US, EU, and China). Mertzanis (2023) shows that energy policy diversity is associated with higher green bond issuance across countries, but the mechanisms through which different regulatory frameworks shape issuance decisions and environmental credibility remain largely unexplored. Future research can use comparative institutional approaches to explore how legal systems, policy coherence, and cultural expectations shape market functioning and the perception of green credibility. This calls for broader geographic coverage and inclusion of hidden dimensions of green finance under heterogeneous governance regimes. In addition, the environmental effects of sovereign and municipal green bonds remain largely unexamined. Given that non-corporate issuers operate under different incentive structures and accountability mechanisms, extending the analysis beyond corporate green bonds is an important priority.

Third, Wang et al. (2023) and Liu et al. (2024) have begun to map how climate policy uncertainty and geopolitical risk transmit across green bond, energy, and carbon markets. However, these studies primarily document connectedness patterns rather than explaining why green bonds respond differently from conventional bonds to the same shocks. Given that green bonds co-exist with many other sustainability-linked bonds, transition bonds, and social bonds, future research should explore whether these instruments compete for capital or create synergistic complementarity. For instance, do investors diversify across instruments to hedge regulatory or reputational risks? Do firms substitute one label for another to meet shifting disclosure requirements? Network-based methods and portfolio-level studies can offer fresh insights into cross-asset dynamics in sustainable finance. Relatedly, the role of investor type in shaping green bond market outcomes remains underexplored. Institutional investors dominate the green bond market and tend to adopt buy-and-hold strategies, contributing to thin secondary

markets and elevated liquidity premia. Future research should examine how the composition of the investor base affects liquidity, pricing, and environmental effectiveness across different green finance instruments.

Fourth, a cross-cutting limitation of the existing literature is that "green bond" is treated as a homogeneous category across virtually all empirical studies, without distinguishing between bonds issued under different certification standards. Green bond frameworks, such as the ICMA Green Bond Principles, the Climate Bonds Standard, and the EU Green Bond Standard, emerged at different times and are adopted unevenly across markets, meaning that certified and self-labeled bonds coexist within any given sample (Zhou, Jin, et al., 2025). This definitional heterogeneity may be a substantive source of variation in both greenium estimates (Cluster 2) and environmental effect assessments (Cluster 3). As mandatory certification frameworks mature, future research should incorporate certification type as a key design variable, enabling researchers to compare pricing, issuance behavior, and environmental outcomes across different standards and to assess whether certification genuinely reduces greenwashing risk.

Finally, Hu et al. (2024) demonstrate that greenium depends on both bond-level and issuer-level greenness, suggesting that credibility and transparency mechanisms are already being priced by investors. Most recently, Bartolini et al. (2025) directly compare the climate-risk exposure of green and non-green corporate bonds in a European setting, finding that green bonds from renewable energy issuers can offer protection against physical risk. These studies represent important steps toward integrating climate policy modeling with green bond market analysis, but remain limited in geographic and issuer-type coverage. More broadly, one enduring limitation of the green bond market is the insufficient monitoring of issuers' post-issuance performance related to funded projects. Future research can explore how institutional designs (e.g., penalty clauses, bond covenants) might improve credibility and align long-term incentives for issuers. Contract theory (Hart & Moore, 1999) and public-private partnership frameworks (Martimort & Pouyet, 2008) may provide theoretical frameworks to assess how rules and incentives shape green outcomes over time.

5. Conclusion

Drawing on 206 high-quality studies, this systematic literature review provides a comprehensive synthesis of green bond research from an energy economics perspective. Using bibliometric and content analyses, we identify three dominant thematic clusters: asset pricing and energy market connectedness, issuance determinants, and environmental effects. The evolution of these clusters reveals a clear transition in the literature, from a primary focus on financial attributes toward a growing emphasis on sustainability-related and energy-transition outcomes.

This review makes three contributions to the energy economics literature. First, it consolidates scattered evidence on how green bonds interact with energy markets, including fossil fuels, carbon markets, and clean energy assets (e.g., Arfaoui et al., 2023; Elsayed et al., 2022; Reboredo, 2018; Saeed et al., 2021), and outlines a conceptual framework that distinguishes between instrumental and intrinsic values of green bonds, providing a unified lens for understanding how the literature has evolved from pricing-focused research toward examining real environmental contributions. Second, by systematically organizing empirical approaches to endogeneity, a challenge largely overlooked in prior green finance reviews (e.g., Bhutta et al., 2022; Tao et al., 2022), this review strengthens the methodological foundation for future causal research in climate and energy finance. Third, it proposes a structured research agenda that moves beyond identifying topical gaps. By grounding future directions in the theoretical frameworks and identification challenges synthesized in this review, the agenda offers researchers actionable guidance on both what questions to pursue and how to pursue them credibly. In particular, it highlights the need to bridge the disconnect between the financial maturity of green bond markets and the still-limited causal evidence on their environmental effectiveness.

From a policy perspective, our findings suggest that green bonds can support energy transition financing not only by mobilizing capital, but also by offering hedging benefits against fossil fuel price volatility (e.g., Guo & Zhou, 2021; Pham & Do, 2022). However, their environmental

effectiveness hinges on rigorous post-issuance monitoring, transparent disclosure standards, and credible certification regimes (Shi et al., 2023). For energy policymakers, this implies that green bond market development should be embedded within broader regulatory architectures, such as the EU Green Bond Standard and national climate policy frameworks, to prevent greenwashing and to ensure alignment with decarbonization targets. For market participants, the documented time-varying connectedness with energy assets underscores both diversification opportunities and contagion risks during energy crises (e.g., Long et al., 2022; Reboredo et al., 2020).

Looking forward, future research should prioritize five directions: (i) evaluating the effectiveness of green bonds in financing large-scale renewable energy infrastructure (Wang & Taghizadeh-Hesary, 2023); (ii) examining cross-market dynamics during major energy price shocks and geopolitical events; (iii) conducting comparative studies across regulatory regimes; (iv) distinguishing between green bonds issued under different certification standards to assess how definitional heterogeneity affects pricing and environmental outcomes; and (v) integrating climate policy modeling with green bond market analysis. By bridging financial market behavior with real-world energy and environmental outcomes, green bond research can play a more meaningful role in supporting evidence-based energy transition and climate finance strategies.

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