Green Finance for Sustainable Infrastructure:

Preliminary Results and Discussion

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Abstract

Financing sustainable infrastructure is essential for reaching UN Sustainable Development Goals, with the involvement of environmental, social, and economic benefits. However, very few of current studies have systematically analysed the various financing sources for sustainable infrastructure. This research first explores the pros and cons of different financing sources and highlights the function of green financial systems in supporting sustainable infrastructure. The review of 45 publications between 2009 to 2021 reveals an understanding of positive contributions of green finance to sustainability in the infrastructure sector compared with public financing, private financing, and public-private partnerships (PPPs). By drawing on theoretical foundations of green financial systems, I propose an integrated conceptual framework for green finance supporting sustainable infrastructure, consisting of three core pillars covering principles, context factors, and operation mode, which provide guidance for stakeholder participation. Second, by researching on the data of corporate green bonds, preliminary results are presented.

Section 1. Systematic Literature Review

1. Introduction

Infrastructure, such as transport, telecommunications, and energy grids, is mostly regarded as high-energy consumption, largely fossil-based, and inefficient. It is estimated that, globally, infrastructure construction, operation, and maintenance account for approximately 70% of greenhouse gas (GHG) emissions (Déséglise and Freijido, 2019; Bhattacharya et al., 2019).Furthermore, existing infrastructure is deteriorating globally imposing huge costs on our society (Lu et al., 2015; Jeong et al., 2017). With the call for a low-carbon economy, the transformation to sustainable infrastructure in the market is imperative, and in line with the Paris Agreement, the UN Sustainable Development Goals (SDGs), and other climate goals of individual countries embodied in the Nationally Determined Contributions (NDCs) (Voola et al., 2022).

The concept of sustainable infrastructure has received increasing attention since the introduction of SDGs and the broader 2030 Development Agenda. At present, however, among researchers, the categories of sustainable infrastructure are still not clear. While the widely accepted aspects of sustainability are social, economic and environmental, in 2018, the Inter-American Development Bank (IDB), officially included four aspects of sustainability in the definition of sustainable infrastructure: economic and financial, social, environmental, and institutional. A similar concept termed green infrastructure, which can be understood as 'a hybrid network of natural, semi-natural, and engineered features to provide multiple ecosystem services and benefits' (Choi et al., 2021), also shares the aims of encompassing environmental, social and economic values (Zimmerman et al., 2019).

Creating sustainable infrastructure supports the access of excluded populations to energy, clean water, mobility, education and health, and helps the transition to a cleaner and decarbonized natural environment. This also laying the foundations for inclusive prosperity, mitigating the adverse impact of global warming, and moving the economy onto a low-carbon growth path (Studart and Gallagher, 2018). Given these potential benefits, numerous studies have suggested cumulative investments in sustainable infrastructure, by both reconciled traditional financing sources (Zimmerman, 2017) and novel financial markets (Holmes and Mabey, 2009). Many international institutions have led the way in delivering sustainability of infrastructure. For example, to become EU's climate bank, in 2019, the European Investment Bank (EIB) adopted a strategy to end funding for fossil fuel projects from the end of 2021. The Asian Infrastructure Investment Bank (AIIB), a sustainability focused organisation, aims to finance green infrastructure with sustainability, innovation, and connectivity[1], and has supported several sustainable infrastructure projects[2] in South Asia since its establishment in 2016.In addition, the Organisation for Economic Cooperation and Development (OECD), the World Bank, and the Inter-American Development Bank (IDB) have all committed to high-quality infrastructure development (Runde et al., 2020) and to the UN's 17 SDG goals.

However, the long investment horizon, regulatory and policy uncertainty, information asymmetries, lack of coordination and other related issues have restricted investments in infrastructure projects (Bak et al., 2017), and the 'green' investment component remains even more limited. Estimates suggest an additional requirement around USD 6.9 trillion per year in investment from 2016 to 2030 for sustainable infrastructure transformation (OECD, 2017). The G-20 backed Global Infrastructure Hub forecasts that an increase from 3.0% to 3.7% in annual global GDP is needed for infrastructure investment to meet the SDGs[3]. It is clear that a massive funding gap exists and public finances themselves are not adequate to meet it (Studart and Gallagher, 2018). Therefore, new financial mechanisms that encourage wider participation and coordination in the development of sustainable infrastructure are key solutions for filling the funding gap (Holmes and Mabey, 2009; Clark et al., 2018; Toxopeus and Polzin, 2021).

[1] See: https://www.aiib.org/en/about-aiib/
[2] These projects include hydropower, transmission lines and water supply, rural transport, and urban infrastructure renewal. See: https://www.aiib.org/en/about-aiib/who-we-are/infrastructure-for-tomorrow/green-infrastructure/index.html
[3] See: https://outlook.gihub.org/

As early as 2012, the World Bank once proposed a concept of 'green infrastructure finance', which refers to 'a combination of financial and non-financial interventions and instruments that can be utilized for making green investments in infrastructure more affordable and less risky to private sponsors, financial markets and governments' (Baietti et al., 2012).Since then, research, policy and practice have all made efforts to scale up and unlock investments that enhance sustainable infrastructure, exploring some innovative financing systems, from the perspectives of both the public and private sector (Mostafavi et al., 2014). Recently, the green finance framework, associated with the concepts of socially responsible investing (SRI), impact investing, and ESG (environment, social responsibility and governance) strategies, found a novel way to help unlock finance for investment in sustainable infrastructure (Partridge and Medda, 2020).

Green financial systems, aiming at promoting sustainable development of the environment, improving the utilization of resources, and supporting the mitigation and adaptation of climate change through financial instruments (Taghizadeh-Hesary and Yoshino, 2019; Cui et al., 2020b; Hong et al., 2020), are increasingly appealing as potential tools for scaling up and unlocking investments in infrastructure sectors. To be specific, green finance supports the investment needs in the categories of sustainable energy, energy and water efficiency, environmental remediation, and industrial pollution control etc. using different financial vehicles (Ruiz et al., 2016; Holmes and Mabey, 2009; Toxopeus and Polzin, 2021).

To bridge the connection between green finance and sustainable infrastructure, this systematic literature review aims to synthesize the existing evidence on the viable investment vehicles for sustainable infrastructure, and to highlight the function of the green financial system in the development of sustainable infrastructure. This knowledge can be essential for informing the integration of sustainable transition into infrastructure sectors and for the coordination of related policies and investments toward climate-resilient pathways for sustainable development. The following research questions are outlined:

Q1. What types of financial vehicles have been developed for sustainable infrastructure?

Q2. What are the strengths of green financial systems in supporting sustainable infrastructure?

The remainder of this paper is organized as follows: Section 2 presents the methods used for data collection and analysis, which is based on the systematic literature review. Section 3 shows the results of data syntheses on the overview of the studies. Section 4 illustrates the related discussions on linkages between different financing sources and highlights the strategies to maximize green finance for investing in sustainable infrastructure. Finally, based on the structured findings and relevant discussions, in section 5, this study concludes with key implications and potential directions for future research.

2. Research Process and Methods

2.1 Search and selection of relevant studies

In order to limit the bias in search and selection, this paper applies a systematic literature review method according to Tranfield et al. (2003), Petticrew and Roberts (2008), and Pickering and Byrne (2014). This approach is increasingly utilised in the field of environmental and social sciences (Toxopeus and Polzin, 2021; Choi et al., 2021; Morioka and de Carvalho, 2016; Voola et al., 2022) and helps us to differentiate the broad topic of financing issues into sustainable infrastructure domains.

The first stage of the review is to scope the research themes, focusing on the conceptual definition and distinction. To ensure the inclusion of all relevant publications on financing sustainable infrastructure, the following search terms were applied: ("sustainable infrastructure" OR "green infrastructure" OR "infrastructure sustainability") AND (financ* OR invest* OR fund*). The Boolean terms* in the words finance, investment and funding are aimed to include different suffixes. These terms are slightly different due to various search strategies for each database. See Table 1 for the complete search strategy used in this paper.

Table 1 Themes, longlist and shortlist for systematic literature review

Theme	Longlist	Shortlist
Sustainable infrastructure	Sustainable infrastructure, sustainability, ecological infrastructure, environmental infrastructure, soft infrastructure, natural infrastructure, green infrastructure, resilient infrastructure	"sustainable infrastructure" OR "green infrastructure" OR "infrastructure sustainability"
Financing	Financial structure, financing, public-private finance, investment, funding	financ* OR invest* OR fund*

The literature search was conducted in June 2021, with no start date specified in the search allowing a broad search of all literature. The search was based on two databases: Web of Science and Science Direct. These search engines combined covers extensive literature on social science and multidisciplinary topics and they allow complex keyword strings for literature search and refinement.

For the data extraction stage, we utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology (Moher et al., 2009). The search identified 1901 papers obtained from the databases. As outlined in Table 2, the analysis of the studies started with the abstract screening after the removal of duplicates. Studies remaining after assessing the abstracts were subject to full-text screening and a final decision was made on their relevance for inclusion in the review. Studies were required to focus on the theme of investment in infrastructure for sustainability. In addition, they must also report an identifiable type of financing sources towards sustainable infrastructure, such as private financing and public financing, etc. Ultimately, a total of 45 papers were selected for data extraction and synthesis in this review paper. The PRISMA flowchart below shows the process and results of our paper selection (See Figure 1).

Table 2 Literature selection process

Source	**Number of Papers**
Papers search in Web of Science	1038
Papers search in ScienceDirect	863
Removing duplicates	-43 (1858)
Title, keywords, abstract	-1568 (290)
Full-text screening	-245 (45)
Analysis studies	45

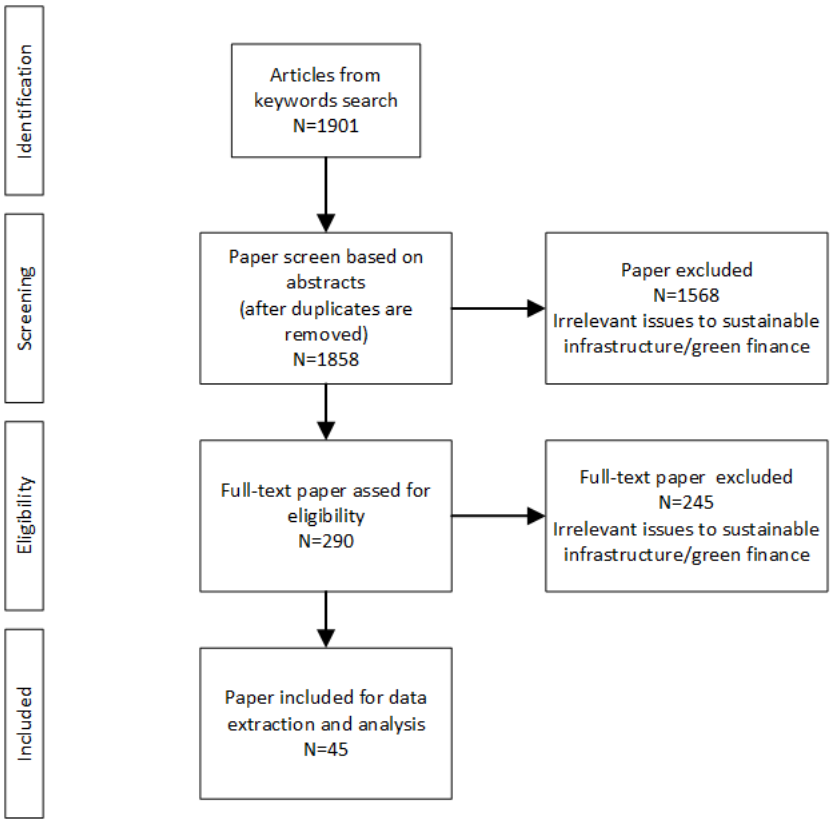

Figure 1 Overview of reviewed papers identified in the steps of the systematic literature review inspired by the flow diagram from PRISMA

2.2 Data extraction and analysis

Relevant information was extracted from each study including general information (title, author, and publication details), study features and specific information (Tranfield et al., 2003). We structured the extraction of data, content analysis, and synthesis of findings in terms of types of sustainable infrastructure and their financing sources, alongside with the research characteristics focused on publication year, geographic location, and research methods. The review was framed around the comparison of various financing sources for sustainable infrastructure and types of sustainable infrastructure were investigated and interpreted.

During the preliminary review, we found that the concept of sustainable infrastructure and its classification can be variable due to different scenarios of countries, research contexts, and the main purpose of a study. Similar findings have been addressed by Choi et al. (2021). This rather implicit and vague understanding of 'sustainability' in the infrastructure sector, to a great extent, impedes the study in the field of financing sustainable infrastructure. Considering that the broad range of infrastructure projects may increase the difficulties in defining 'sustainable infrastructure', we recorded every specific type of sustainable infrastructure project mentioned in the reviewed papers to promote a better understanding towards sustainable infrastructure. By differentiating, classifying and summarizing the characteristics of infrastructure types in the reviewed literature, we achieved a relative comprehensive definition of 'sustainability' for infrastructure.

In terms of financing sources, based on the emphasis on the narrative content of each study selected, we broadly classified the financing sources for sustainable infrastructure into public financing; private financing; public-private partnerships (PPPs, a novel method combining public and private financing); and green financing. As it is reasonable that more than one financing approaches were mentioned in a single study, and that overlaps exist between different financing sources, only the major sources, with a full description, mentioned in the study were recorded.

3. Results

3.1 Research trends

The analysis of the selected literature (45 studies) on financing sustainable infrastructure by year of publication, geographic region, and research methods used is given in Figure 2.

As regards year of publication, the reviewed studies were published between 2009 and 2021, with the bulk of literature published from 2015 around the timing of the Paris Agreement and adoption of the Sustainable Development Goals (SDGs). The peak publication year was 2018, when nine articles were published addressing the issues of investing in sustainable infrastructure.

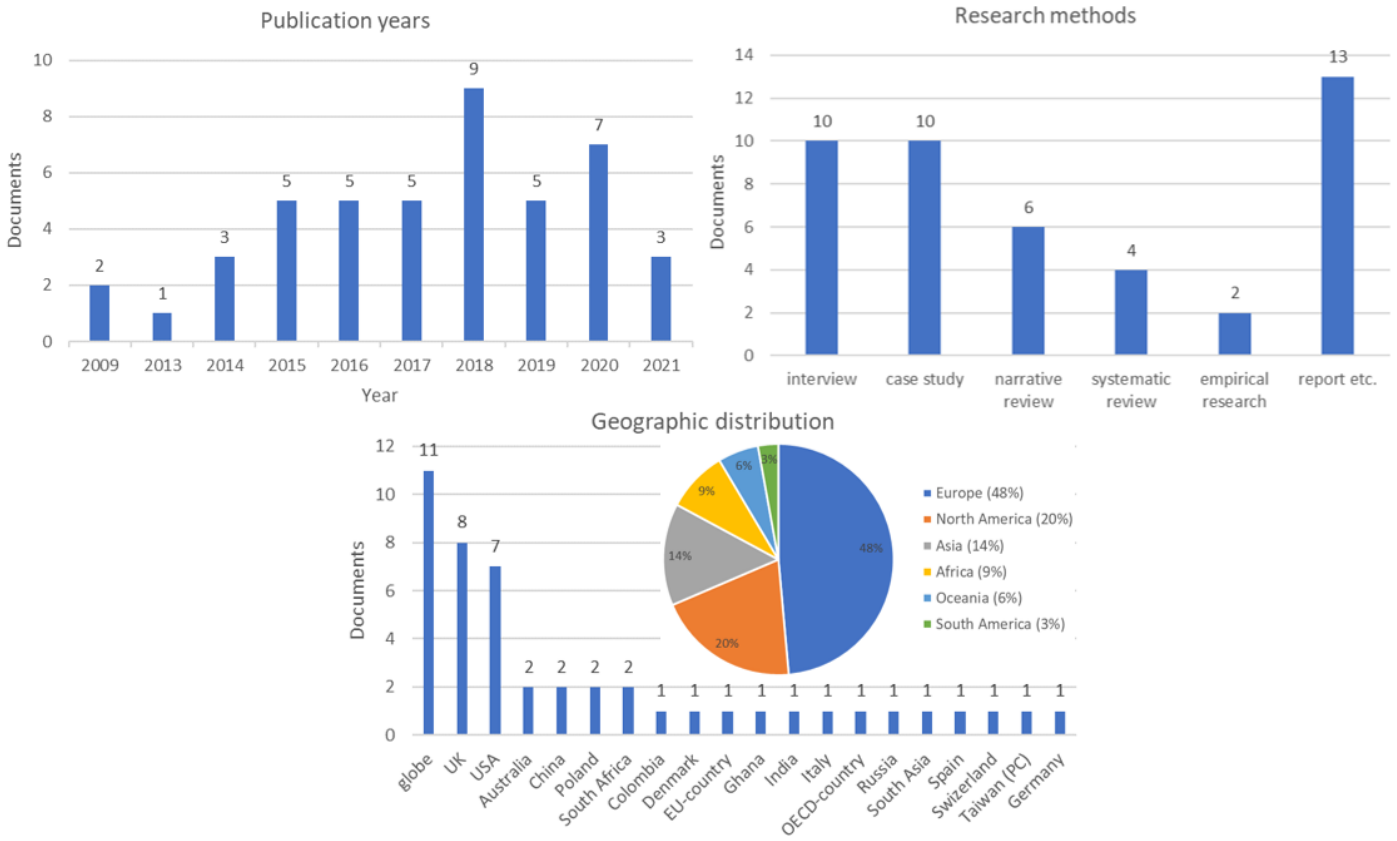

Figure 2 Research trends of reviewed papers (Note: Pie-chart excludes 'Global')

In terms of geographic locations, most studies did not focus on a specific country, regarding investments in sustainable infrastructure as global issue. The rest of the reviewed studies had a clear geographic focus on Europe (48%), North America (20%), and Asia (14%). Far fewer studies focused on Africa (9%), Oceania (6%), and South America (3%). To be more specific, the UK ranked first with right papers collecting both primary (Davies et al., 2018) and secondary data (Bolton and Foxon, 2015) concerning the funding of sustainable infrastructure. The USA was the second highest ranking country with seven studies, and the numbers of studies for the remaining countries were two or one and below. This result shows the increasing interests in financing sustainable infrastructure among developed and industrialized countries, while inadequate attention in most developing countries, including China, which stands out for its massive scale of infrastructure expansion in the past two decades (Dinlersoz and Fu, 2022). Such imbalance in geographic distribution, on the one hand, reflects that very little attention has been attracted to the concept of 'sustainable infrastructure' in developing countries till now. On the other

hand, it can also be seen that the functions served by green capital markets are still not complete.

As regards research methods, most of the studies utilized qualitative research, describing the idea of financing sustainable infrastructure in different contexts. Only a small number of the reviewed papers - 6 out of 45 - collected quantitative data; four were systematic literature review, and two were empirical studies. In terms of qualitative methodology, one-third -13 out of 39 - of the reviewed studies illustrated viable ways for funding sustainable infrastructure without supporting evidence. The remaining two thirds - 26 studies covered interviews (10), case studies (10) o, and narrative literature review (6). Hence, more quantitative studies, developing more empirical understandings of financing sustainable infrastructure, are needed in the future.

3.2 Research Characteristics

3.2.1 Categories of sustainable infrastructure

The literature summarised key aspects of sustainable infrastructure into topics identified in the figure below (Figure 3). Similar to the classification by the Inter-American Development Bank (IDB), we classified the categories of sustainable infrastructure mentioned in the reviewed papers into four dimensions of sustainability: economic sustainability, environmental sustainability, social sustainability, and institutional sustainability. For each dimension, we listed the corresponding sub-categories to better identify the benefits which sustainable infrastructure bring. It can be common, and even necessary, to label an infrastructure project as having multiple dimensions of sustainability because the benefits of sustainable infrastructure can have direct or indirect implications for economic, environmental, social, and institutional values simultaneously (Choi et al., 2021). For example, a renewable-energy project shares the value of resources efficiency, social responsibility, circular economy, and development strategies, covering all four dimensions identified above.

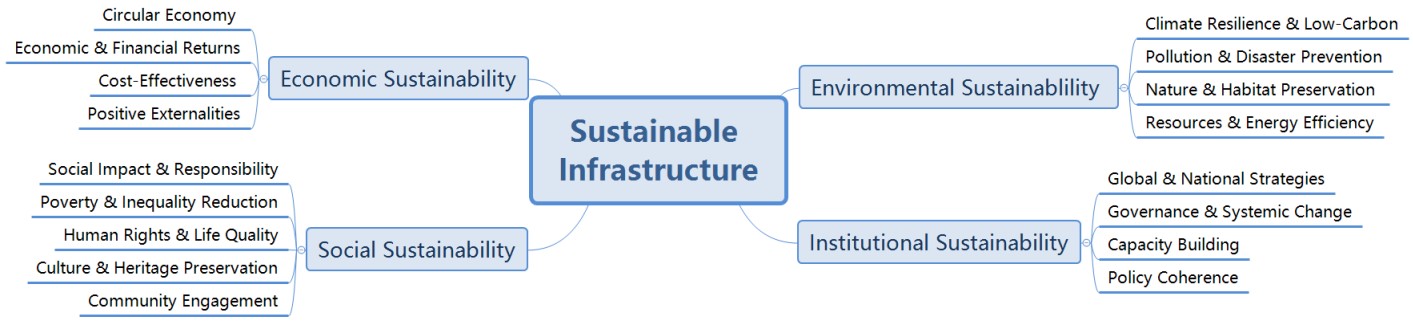

Figure 3 Four dimensions of sustainable infrastructure

Analysis reveals that despite sharing values, different types of sustainable infrastructure projects have diverse focuses on the dimensions of sustainability. Based on the primary aims of the projects described by the reviewed studies, a distribution of sustainable infrastructure is provided in Figure 4. The result shows that urban facilities (9, 20%), water management (9, 21%), and energy utilization (8, 18%) were the most popular infrastructure divisions in the context of sustainable development. Articles examining financial tools for climate-smart project (5, 11%), green space (5, 11%), and ecosystem (4, 9%) were less numerous. In addition, far fewer studies investigated funding towards resilient transport (2, 5%), emergency service (1, 2%), sustainable tourism (1, 2%) and waste disposal (1, 2%). It indicates that in comparison to focusing on a particular type of infrastructure project, nearly one-third (14 out of 45) of the reviewed studies jointly studied urban and climate-based solutions for sustainable infrastructure, illustrating various benefits of sustainability in an integrated way. The rest of the studies identified specific types of sustainable infrastructure individually, with predominant attention on the water and energy sectors.

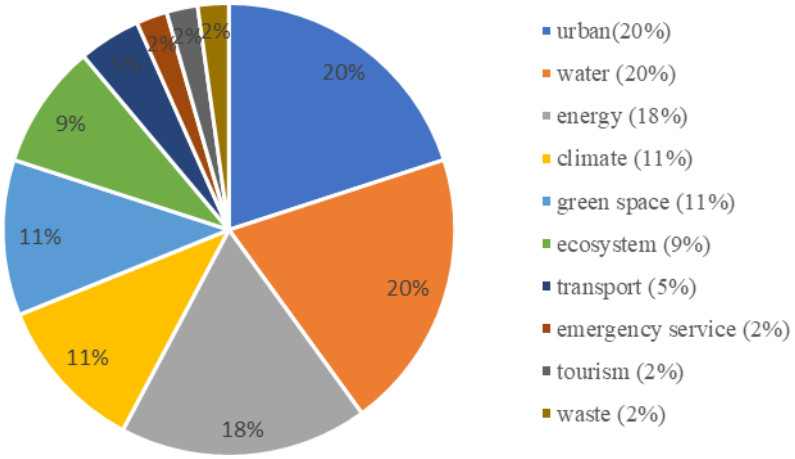

Figure 4 Distribution of reviewed literature across sustainable infrastructure domains

3.2.2 Financing sources for sustainable infrastructure

As regards different ways of funding sustainable infrastructure, Figure 5 shows the distribution of reviewed studies across various investors. Limited research focused on the theme of green finance, with only 10 out of 45 papers (22%). Topics of the remaining 35 reviewed studies were concentrated on traditional financing, i.e. - public-private partnerships (PPPs), public financing, and private financing. Nearly half of these studies - 16 out of 35 - focused on public-private partnerships (PPPs). 13 studies focused on public financing -eight on multilateral and bilateral lenders such as the Asian Infrastructure Investment Bank (AIIB) (Kumar and Arora, 2019) which were noted for their ability to support a vast amount of capital and five on public funds and grants including disaster financing, across federal, state and local governments (Zimmerman et al., 2019; Brodmerkel et al., 2020). In comparison, fewer studies focused on private financing (6 out of 35), including business financing (Davies et al., 2018).

In terms of the ten green financial schemes mentioned in the reviewed studies, green bonds and green funds ranked as the first and second most popular green finance sources for sustainable infrastructure with five and three studies, respectively. Among the remaining categories of green finance, green equity (Voica et al., 2015) and green investment bank (Geddes et al., 2018) were both studied once as sources for investments in sustainable infrastructure.

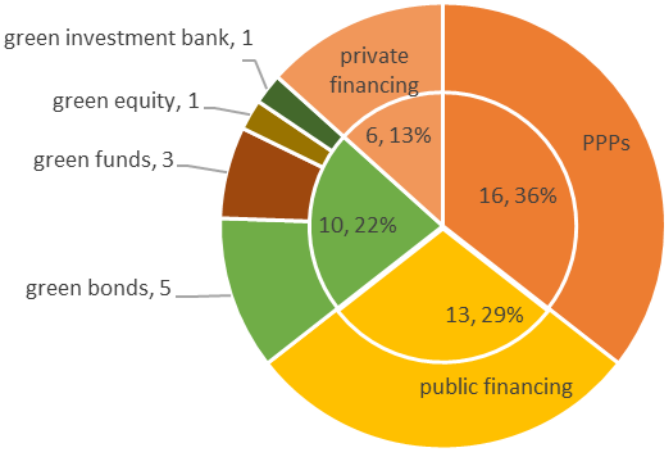

Figure 5 Financing sources for sustainable infrastructure

3.3 Research highlights

To advance the understanding of different financing sources for sustainable infrastructure, we compared the pros and cons of the four categories of financing channels identified within the reviewed literature - public financing, private financing, public-private partnership, and green financing) and concluded the general advantages of green financial systems in supporting sustainable infrastructure projects by following standards: administrative, behavioural, financial, legal/legislative, managerial, political, regulatory and market mechanisms (see Table 3).

Table 3 Pros and cons of different financing sources for sustainable infrastructure

Financing sources	**Categories**	**Description**	**Pros**	**Cons**	**Reference**
Public financing	Multilateral and bilateral lenders	International lenders helping developing countries with the accessibility of physical infrastructures such as transport, communication, and energy (for example AIIB)	Cover the limitations of governments in the subregion with overstretched budgets; long-term and large-scale; clearer aim in sustainability	Only a small portion of the region's infrastructure investment; lack of clear standard on investment	(Alamgir et al., 2017; Kumar and Arora, 2019; Bradlow, 2015; Vazquez and Chin, 2019; Bhattacharya et al., 2018; Buier, 2020; Caspary, 2009)
	government financing (grants, loans, taxation, and agencies)	State, federal, and local public funding supporting infrastructure projects in the face of natural hazards to reconcile disaster, extreme weather, and environmental concerns	Enable large-scale investment; long-term; a large portion of funding infrastructure projects; easy to make criteria for sustainability	Fiscal funds need to be included in the budget, limited by the scale of fiscal revenue and expenditure at the same level	(Zimmerman, 2017; Brodmerkel et al., 2020; Zimmerman et al., 2019; Kennedy et al., 2016; Abramowicz and Stepniewska, 2020)
Private financing	Business financing	Funding sustainable infrastructure through payments for infrastructure services	Incorporating citizens in sustainable development; more flexible	Sustainable investments are not always profitable; high risk	(Ruiz et al., 2016; Davies et al., 2018)
	Foreign direct investment	Reliable and long-term source of private foreign investment in developing countries for sustainable infrastructure	Effectively improve market awareness, economic stability, quality control, skill/knowledge levels, and technology transfer	High political risks; potentially hinder domestic investment	(Pan et al., 2018; Clark et al., 2018)
	Financial institutions	Institutional investors like insurance companies and investment banks in the context of sustainable infrastructure	Play a much broader role in catalysing private investments into sustainable infrastructure, including enabling financial sector learning, creating trust for projects and taking an early mover role to help projects	Higher credit risks; regulatory uncertainty; preference for projects which provide stable and predictable cash flows like the wind and solar projects	(Mielke, 2019; Geddes et al., 2018)

			gain a track record; long-term		
Public-private partnership	Collaborative partnership and co-financing	Cooperation between the local government and the private investor, typically a Special Purpose Vehicle (SPV) is granted.	Public authorities can share the risk of investment with private companies; more local-focused compared with centrally-lead schemes;	Potential uneven development between poor and rich regions due to the risk aversion from private sectors; higher cost	(Bolton and Foxon, 2015; Polyakova and Vasilyeva, 2016; Mell, 2021; Davies et al., 2017; Tubridy, 2021; Angelstam et al., 2017; Mostafavi et al., 2014; Mell, 2018; Kościelniak and Górka, 2016; Patil et al., 2016; Cui et al., 2020a; Egan and Agyemang, 2019; Pelizzaro, 2015; Toxopeus and Polzin, 2021; Johannessen et al., 2014; Mell, 2020)
Green financing	Green bonds	A directly engaging the public and institutional investors in the sustainable infrastructure	Combine targeted interventions in the short term and support medium term expansion; combine public and private sector expertise; on-going innovative capacity; strengthening market confidence	High regulatory risks; greenwashing problems	(Holmes and Mabey, 2009; Cousins and Hill, 2021; Lu et al., 2015; Partridge and Medda, 2020; Gonzalez-Ruiz et al., 2018)
	Green funds	Long-term with stable returns on sustainability			(Biagini et al., 2014; Schneider and Wiener, 2013; Clark, 2019)
	Green equity	ESG issues reflected in the equity market, including equity indices			(Voica et al., 2015)
	Green investment bank	Policy-driven based; raising funds on the capital market, providing loans and other financial products			(Holmes and Mabey, 2009)

Through this comparison, we see that green financial schemes have their unique strengths across the financing sources for sustainable infrastructure projects. In general, with financial intermediaries in the capital market, green financial mechanisms not only are more flexible than traditional public and private financing sources (Holmes and Mabey, 2009), but also have lower risks and costs compared with typical PPPs (Ruiz et al., 2016; Polyakova and Vasilyeva, 2016). To be specific, in comparison to public funding, green financing is not subject to the budget of local governments and is immune to potential political risks (Mell, 2018; Zimmerman et al., 2019), which means that by financing from green financial schemes (green bonds for example), more flexibility can be achieved for the construction of sustainable infrastructure. It is clearly pointed out by Kumar and Arora (2019) and (Zimmerman, 2017) that although public funds from multilateral lenders and local governments help close some of the financing gaps to specific regions (for example, the under-developed areas), public financing themselves are not sufficient for supporting scaled sustainable infrastructure projects at a long-time basis.

To mitigate the inflexibility and inadequacy of public financing sources, private financing including business financing,

foreign direct investment, and funding from financial institutions are studied in previous literature to find better ways developing sustainability in infrastructure projects. Indeed, private financing sources are endowed with more flexibility and efficiency with the help of more active market participants compared with public funds, but in terms of responsible investing focused on sustainability and green projects, drawbacks are still obvious. One common situation among different types of private financing illustrated by Ruiz et al. (2016) is that private capital is easier to be prevented from sustainable investments as those eco-investments are not always profitable. Another disadvantage of private financing on sustainable infrastructure is their innate characteristic of higher risks and uncertainty (Pan et al., 2018; Clark et al., 2018). Moreover, (Geddes et al., 2018) stated that an unbalanced propensity exists when private capital invests in sustainable infrastructure, projects with stable and predictable cash flows like wind and solar projects are more welcomed.

In this regard, many scholars turned to public-private partnerships for better supporting sustainable infrastructure projects. Polyakova and Vasilyeva (2016) claimed that in the Russian market, PPPs have comparative benefits in the field of infrastructure. Similar points were proved by Pelizzaro (2015) and Cui et al. (2020a) that risks can be shared by public authorities and private participants, allaying the concerns of both parties. However, Patil et al. (2016) also pointed out several drawbacks of PPPs that massive liabilities and costs can be generated due to the long-term commitments and the form of off-balance sheet financing by the governments. Besides, the risk aversion from private sectors can lead to uneven development of sustainable infrastructure projects between different regions (Egan and Agyemang, 2019).

With the emergence of the concept of green finance, green financing for sustainable infrastructure was noticed by several studies, unsystematic but intriguing. Holmes and Mabey (2009) first introduced the idea of raising new finance through green bonds, affirming this type of new products can raise money from both institutional and retail investors for public financing of low carbon infrastructure and energy efficiency programmes. Other financing products within the context of green financial systems like green funds, green equities, and green investment banks were all mentioned for their potential suitability for sustainable infrastructure projects (Biagini et al., 2014; Voica et al., 2015; Holmes and Mabey, 2009). According to the literature, the superiority of green financing for sustainable infrastructure lies in many aspects. First, with the help of financial intermediaries like banks and mutual funds, green financial systems surpass sole private or public financing in their diverse funding sources and dispersed managerial risks (Davies et al., 2018; Lu et al., 2015). In fact, these intermediaries in green financial markets help to create trust and catalyse private investment for sustainable infrastructure based on the concepts of socially responsible investing and impact investing (Flammer, 2021). Second, acting as a financing supplementary, green financing is more flexible in attracting and absorbing funds and help to promote the project efficiency and equity in PPPs (Geddes et al., 2018). Third, one of the most superior characteristics of green financial systems is that they price sustainable performance by offering lower-cost debt securities, possibly green bonds to firms with better environmental performance, which can be an incentive for sustainable infrastructure projects.

In Table 3, we identified the characteristics of viable financing sources for sustainable infrastructure and highlighted the advantages of green financial schemes. It shows that although evidence proves advantages of green finance in supporting the construction of sustainable infrastructure, these points of view are illustrated in a segment way. In other words, the increased awareness of the importance of promoting sustainable infrastructure has not been effectively integrated with financial markets, and research involving comprehensive green financial systems is extremely lacking. It is reasonable as this body of knowledge is quite new. In order to deepen the understanding of the function played by green finance in supporting sustainable infrastructure projects and to integrate green financial schemes into the infrastructure field, in the next section we develop a conceptual framework.

4. Towards a conceptual framework

Aiming to conceptualise the field of green finance in the infrastructure sectors and to integrate green financial schemes into sustainable infrastructure projects, a form of framework is presented as a way to improve the contribution of green financial

markets to sustainable infrastructure. As shown in Figure 6, the conceptual framework is composed of three pillars: principles for green financial markets, green finance for sustainable infrastructure, and context factors.

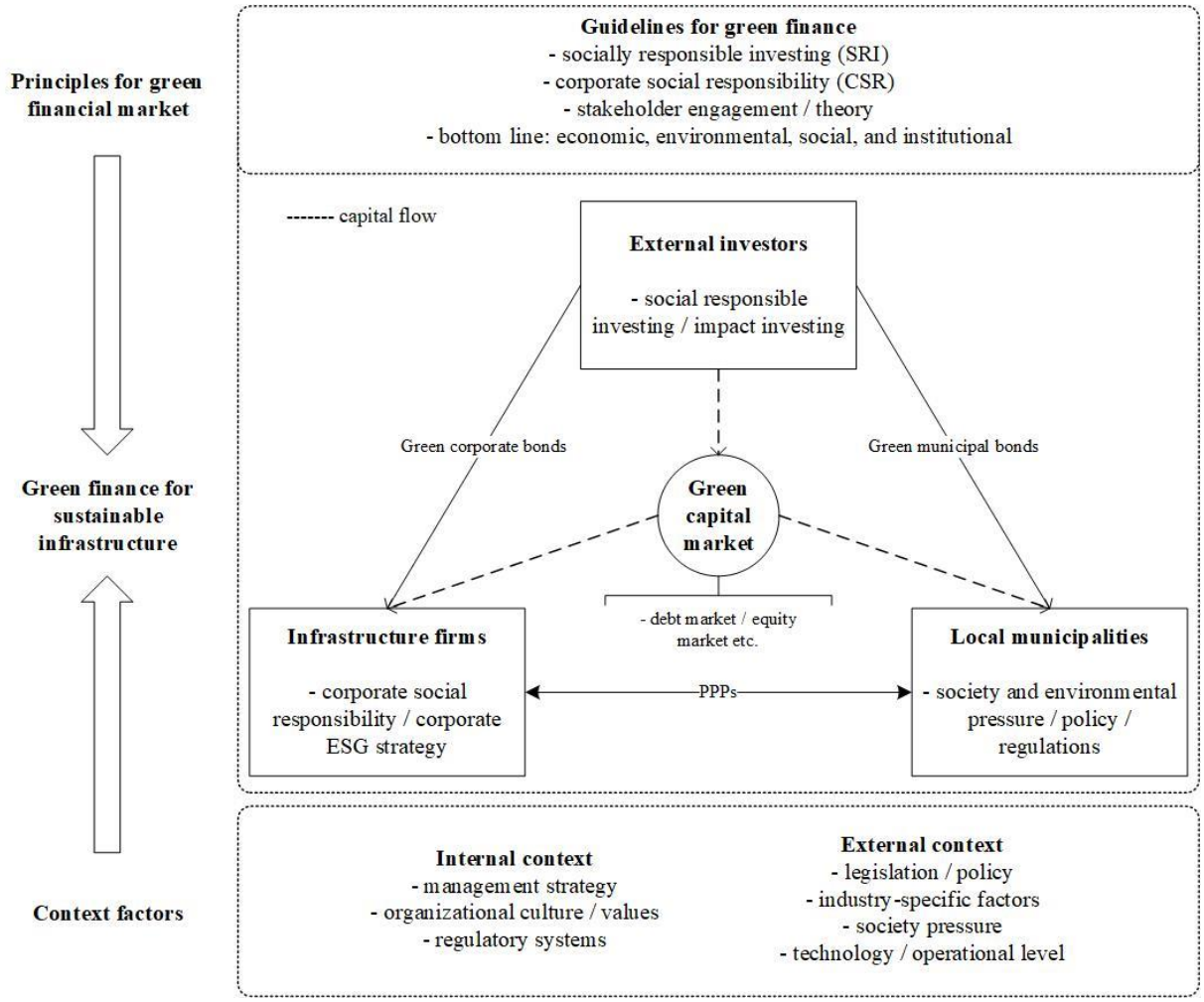

Figure 6 Proposed framework for green finance for sustainable infrastructure

4.1 Supportive aspects of framework

In accordance with Morioka and de Carvalho (2016), the supportive aspects for the integration of green finance into sustainable infrastructure are composed of the principles of green financial markets and related context factors. To be specific, the principles of green financial markets are introduced in the proposed conceptual framework to serve as keynotes and guidelines for decisions towards financing sustainable infrastructure through green financial mechanisms. And the context factors, both internal and external, are illustrated to provide a declaration of the importance of financing sustainable infrastructure within the green financial schemes.

As an initial step, principles for green financial markets are identified to lay the foundations for arguing the feasibility of green financial schemes when aiming for sustainable development in the infrastructure sectors. In this sense, the framework shows the importance of socially responsible investing (Pástor et al., 2021) and corporate social responsibility (Flammer, 2021). Socially responsible investing (SRI), sharing similarity with the term ‘impact investing’, is broadly defined as an investment process that involves identifying a portfolio which optimizes environmental, social and governance (ESG) criteria (Auer and Schuhmacher, 2016; Henke, 2016). In SRI strategies, ESG criteria portfolios with social attributes are screened to seek for the promotion of social benefits apart from the financial returns. In the meantime, corporate social responsibility

(CSR) has been proved to have positive effects on firm performance, from both financial and environmental aspects, through the role of capital market (Gillan et al., 2021; Albuquerque et al., 2018; Brooks and Oikonomou, 2018; Chen et al., 2018). In this regard, sustainable infrastructure projects are encouraged not only for the benefits of social attributes, but also for the financial gains that infrastructure companies may make through green financial markets.

Another important element of supportive aspects is the stakeholder engagement. In definition, stakeholders include shareholders, employees, financers, government, suppliers, customers, community, etc (Fernando and Lawrence, 2014; Freeman and Dmytriyev, 2017). Stakeholder theory, consistent with value maximization or value-seeking behaviour, implies that firms should pay attention to all constituencies that can affect the value of the firm (Jensen, 2010). Supported by the stakeholder theory, CSR practice is proved to play a key role in reducing information asymmetry, mitigating conflicts between stakeholders, and enlightening value maximization (Ng and Rezaee, 2015). In this sense, sustainable infrastructure projects, acting as a type of CSR strategy, can have positive impacts on corporate management within infrastructure firms.

Apart from the principles of green financial markets, the context factors, including both internal and external aspects, have crucial influences on financing sustainable infrastructure within green financial schemes. The internal context factors which provide a declaration of the importance of green finance for sustainable infrastructure are the management strategies of both infrastructure companies (Morioka and de Carvalho, 2016) and local municipalities (Seuring and Müller, 2008; Ye et al., 2022), their organizational culture/values as well as their organizational regulations (Baumgartner and Zielowski, 2007; Meng et al., 2022; Liu and Liu, 2022). As for the external factors that affect green finance for sustainable infrastructure, legislation/policy for financial markets (Zhang et al., 2021), society and environmental pressure (Kolk and Mauser, 2002), industry-specific factors (Richter et al., 2021; Díaz and Escribano, 2021), as well as technology and operation level aspects (Kemp, 1994).

4.2 Core participants of framework

The core participants of the framework are three key actors within green financial markets for sustainable infrastructure: local municipalities, infrastructure companies, and external investors. Specifically, these participants are coordinated in the green capital market to promote investments in sustainable infrastructure.

Municipal authorities are key players in infrastructure investment. Infrastructure, especially for urban maintenance and construction, is closely related to the welfare of local residents as regional externalities can be achieved (Meng et al., 2022). In the meantime, innovative use of capital market by the governments helps finance infrastructure investment (Ye et al., 2022). When focused on sustainable infrastructure, alongside the economic growth illustrated by many studies, positive environmental externalities provide municipalities with better incentives to expand their investments. In terms of the financing sources from governments, borrowing is widely used as a key method, especially relies on a system of municipal bond rating. Local taxes, together with grants and subsidies are also available sources.

Due to the capital-incentive nature of infrastructure, privatization is regarded as a possible solution to perceived under-investment in the public sector (Helm, 2009) and a way to shift future financial risk to the private contractor (Dannin, 2011). In this regard, infrastructure companies are encouraged to take part in infrastructure financing. Meanwhile, the forms of 'public-private partnerships (PPPs)' have also witnessed a growing portion in infrastructure projects. In the form of PPPs, governments are moving towards the role of regulator rather than provider of infrastructure service, leaving ownership and provision of services to the private sector, by which the investment risks partially transferred from the public to private sector. In other words, the involvement of the financing support from infrastructure companies relieve the pressure of local governments. When it comes to the concept of sustainable infrastructure, related firms label their social responsibility by delivering sustainable infrastructure projects or other ESG strategies. Such private capital investments are traditionally dependent on bank loans in most countries (Inderst, 2016).

External investors, apart from infrastructure firms and governments, contribute to infrastructure finance by a range of investment vehicles, through capital market, covering equity and debt for listed infrastructure companies, infrastructure funds, and direct investment to projects (Inderst, 2016). Over the years, infrastructure has been regarded as an alternative asset class in investment portfolios, which offers long-term, stable, and predictable cash flows with limited downside risk, and protects the investors from inflation(Newell and Peng, 2008; Rothballer and Kaserer, 2012; Ben Ammar and Eling, 2015). With the development of innovative financial instruments like publicly traded infrastructure real estate investment trusts (REITs), external investors participate more in infrastructure investments, enhancing the diversity of infrastructure investments and ensuring the activeness of capital market. As for the investment towards sustainable infrastructure, those external investors with great social responsibility are offered an option of investing in the green capital market, utilizing negative or positive screening strategies for impact investing (Ormiston et al., 2015). Among available financing sources of sustainable infrastructure in the green capital market, literature places great emphasis on green bonds (Cousins and Hill, 2021; Hallauer et al., 2019), by which the proceeds can be exclusively applied to projects with clear environmental benefits, i.e., sustainable infrastructure projects in the context of this paper.

4.3 The green capital market of framework

As illustrated in the previous section, the green capital market is playing the key role in supporting sustainable infrastructure, performing a vital function in attracting and coordinating the participation of the core participants of the framework mentioned before, i.e. local municipalities, infrastructure firms, and external investors.

Overall, the green capital market incorporates sustainability considerations and helps to recognize the long-term benefits of a more sustainable economy (Gutterman, 2021). The superior characteristic of green capital market lies in pricing sustainable performance by offering preferential interest rate and providing higher credit-rating level. With the green-related innovation in capital markets, various financial instruments have developed significantly.

Green credit, referring to the practice of banks taking into account of environmental factors in their lending operations and loan issuance (Thompson and Cowton, 2004). By providing preferential intertest rates to environmentally-friendly enterprises and imposing penalized intertest rates on polluting enterprises, green credit adjusts the flow of funds through credit resources and ultimately promotes the green transformation and sustainable development (Xu and Li, 2020). However, in terms of the high upfront costs and long investment duration, bank loans are limited in infrastructure sectors, resulting in the less involvement of green credit in financing sustainable infrastructure.

Another innovative financial instrument in the green capital market, green bond, however, has been emphasized by many scholars for the development of sustainable infrastructure (Lu et al., 2015; Flammer, 2021; Richter et al., 2021). Green bond, raising capital for green eligible projects, supports the issuers with large amount of proceeds and longer investment horizons. Meanwhile, from the perspective of investors, tax incentives are applied on the investment of green bonds. In terms of the green bond issuers, similar to non-green bonds, governments, business entities, and banking institutions are the main actors. For funding sustainable infrastructure projects, green corporate bonds and green municipal bonds are highlighted in supporting projects of renewable energy, clean transportation, and biodiversity conservation etc. (Partridge and Medda, 2020; Díaz and Escribano, 2021). By issuing green bonds, both local municipalities and infrastructure firms can raise money in developing sustainable infrastructure projects.

With the emphasis on corporate ESG/CSR issues, green equity including exchange-traded funds (ETFs) (Voica et al., 2015) is playing a more active role in the green capital market. Green equity, associated with corporate ESG rating systems, is functioned through strategies of socially responsible investing (SRI). Literature ensures a positive correlation between ESG scores and corporate financial performance (Gangi et al., 2020; Wang and Sarkis, 2017), supporting the SRI strategies where firms with better ESG performance attract more investments. In addition, as the issuance of green bond is an important factor

of ESG performance, price co-movements between green bond and stock have also been investigated to promote the development of the green capital market(Richter et al., 2021; Reboredo, 2018; Reboredo and Ugolini, 2020). In this way, listed infrastructure firms with a focus on sustainable infrastructure projects can attract more investors, whose aims are either to obtain abnormal returns from ESG investing (responsible-profit seekers) or simply doing good to the society (value-driven investors). Meanwhile, these investors in the green capital market in turn promote the environmental awareness of listed infrastructure firms, eventually facilitating the construction of sustainable infrastructure.

Admittedly, the development of innovative financial instruments diversifies the green capital market. Apart from green credit, green bond, and green equity, derivatives like futures contracts and procurement auctions have emerged recently. However, many challenges still exist. To ensure the market success, liquidity improvement of sustainable financing instruments, collaboration of related institutions, and universally accepted reporting benchmarks are required.

5. Discussion

5.1 Making sense of the literature

Financing sustainable infrastructure is considered important, in line with the goals of sustainable growth. However, in practice the vague definition and loose classification of sustainable infrastructure erects some obstacles for studies in this field. Meanwhile, although existing research has made significant progress regarding infrastructure investment in the context of sustainability, literature on utilizing green financial framework to enhance the development of sustainable infrastructure has not attracted adequate attention. Our critical review identifies an uneven research status in this field that most of the studies had a geographic preference in Europe and North America, overlooking the situations in developing countries. What is more, among these reviewed studies, few of them utilize quantitative data to develop a more empirical understanding towards financing sustainable infrastructure. Instead, most of them are based on evidence from interviews and case studies, although helpful to some extent, lacking commonality in hypothesis tests. Most importantly, we notice that there is no integrated framework addressing green finance into the development of sustainable infrastructure, which reflects an insufficient connection between infrastructure investment and financial markets in the study of green finance domains.

Such findings indicate an initial stage of development of sustainable infrastructure and there is no unified green financing framework towards sustainable infrastructure. Among which, one of the most obvious features of the research characteristics is the large difference in the number of studies for developed and developing countries respectively. This phenomenon revels that green financial markets in developing countries have not been utilized yet and sustainable investments towards infrastructure field are fragmented, only a small fraction of green financing sources is realized for funding sustainable infrastructure projects, with a clear regional preference. The possible explanation is that in developing countries, mobilizing green financial markets can be challenging because of weak institutions, unsubstantial governance, and transparent systems.

Admittedly, the interdisciplinary nature relating to infrastructure, finance, and sustainable development makes studies on financing sustainable infrastructure complicated. Also, the broad range of infrastructure projects increases the complexity of evaluating their financing strategies. However, we managed to conduct a comparison between different financing sources for sustainable infrastructure projects illustrated by the selected literature and then provide a consolidated conceptual framework for integrating green finance schemes with sustainable infrastructure projects. When compared with other studies, this work is done to address the challenges of accessing diverse financing sources for sustainable infrastructure and the feasibility of integrating green financial markets with sustainable infrastructure under the increase of publications focusing on sustainability. At the same time, this study recognizes the lack of quantitative evidence for this field as well as the absence of a common conceptual framework for sustainable infrastructure within green finance.

This systematic literature review results in the identification of research trends and research characteristics of existing papers on this topic. In order to fully understand the advantages of green financial schemes in supporting sustainable infrastructure, we compare different viable financing sources mentioned in the reviewed papers. By providing the consolidated conceptual framework for financing sustainable infrastructure, we addressed the call for a holistic and integrative process to guide infrastructure firms, local governments and financial markets in adopting green financial schemes within the principles and context factors. This innovative framework can promote studies in the field of financing sustainable infrastructure and presents a relatively complete system for green finance in the infrastructure domains. While other studies including Holmes and Mabey (2009) and Ruiz et al. (2016) have also attempted to highlight the function of green finance in sustainable infrastructure projects, the mechanism has not been fully proposed.

For businesses and practitioners, this framework offers some clarity on the processes of implementation of sustainable infrastructure projects and identifies appropriate financing channels for support. By addressing a clearer pathway for financing sustainable infrastructure, this study may remove some ambiguity for practitioners on the concepts of sustainability, contribute to the sustainable reformation of infrastructure firms and accelerate the development of green financial markets.

5.2 Limitations and recommendations

The main limitations of this paper lie in the research methods and the field of study. In terms of the research methods, according to Morioka and de Carvalho (2016), the critical steps of selecting the paper samples are directly affected by the trade-off between the number of studies and the depth of analysis of the samples. In addition, this paper describes the whole population of papers on financing sustainable infrastructure based on a sample study. Although the process of sample selection is well constructed, limitation still exists because the main term ‘sustainable infrastructure’ has a broad meaning and application in several areas. By focusing on the term ‘sustainability’, there may have been an exclusion of relevant papers. Furthermore, as this paper does not encompass grey literature and is only focused on English language studies, a geographic bias may exist due to this specific language and the publication context of this research.

Despite these limitations, the contributions of this paper remain valid. This review identifies different financing sources for sustainable infrastructure from a wide geographic range of studies, increasing the understanding of investments in sustainable infrastructure in the context of socially responsible and impact investing. Based on the comparison of viable financing sources, green finance is proved to surpass other financing methods by pricing sustainable performance into the market. Our proposed framework conceptualizes the field of green finance for sustainable infrastructure and illustrates a relatively comprehensive model for applying green financial schemes in the infrastructure context. In terms of future research, studies on green finance in the context of infrastructure sectors are limited, especially in developing countries, and this could be a focus for future studies. What is more, as we have proposed a consolidated conceptual framework for this field, future research could assist in the further validation of this framework by providing empirical evidence based on quantitative data analysis.

For related recommendations, first of all, a clear standard of sustainable infrastructure is needed, clarifying the scope of sustainability and types of infrastructure projects, which can lay the basic foundation for research in this field. In addition, the effect of green finance for sustainable infrastructure should be examined empirically from reliable datasets. A centralized platform within both project-level and firm-level information over the world should be built for projects, investors and advisory services. Furthermore, environmental performance disclosure and transparency in reporting risks and policies need to be improved. Advanced policies need to be introduced for better guidance and oversight of investments in sustainable infrastructure in order to ‘unlock’ private investments for sustainable development. In detail, corporate sustainable performance and related natural resources should be accurately valued and priced. In addition, private investments should be supported by aligned incentives such as subsidies and risk mitigation schemes. Finally, communication, coordination, and collaboration between public and private sectors need to be encouraged for supporting sustainable development projects.

6. Conclusion

Recent years have brought focus to addressing climate change, green transition, and sustainable development with the ratification of the Paris Agreement and the commitment to the Sustainable Development Goals (SDGs). This in turn has highlighted the need for financing sustainable infrastructure. With greater attention to this field, a consensus has been achieved that investments in sustainable infrastructure not only have the potential to boost productivity (Fernald, 1999; G. Duggal et al., 1999; Deng, 2013), but they also generate various benefits for the environment, social welfare and economy (Frischmann, 2012). However, we found a large research gap in the studies on financing sustainable infrastructure. Throughout the systematic literature review, this study has not only developed a comprehensive understanding of sustainable infrastructure by identifying different types of infrastructure projects and their focused dimensions of sustainability, but also highlighted the superiority of green finance in supporting sustainable infrastructure, based on a comparison of pros and cons between traditional financing sources. A consolidated conceptual framework has been proposed for the integration of green financial schemes and sustainable infrastructure projects, which underpins the research in this field.

While a well-established financing system for sustainable infrastructure has not been developed, some rewarding attempts have been made and innovative financing schemes have been utilized such as the green finance framework. Innovative partnerships and collaboration have catalysed private investments in the transition to sustainable infrastructure, which can be crucial for sustainable development. Despite the limitations of this systematic literature review, we contribute to this field by clarifying the initial implicit and vague understanding of sustainable infrastructure and promoting academic research and practical solutions for integrating green finance into financing sustainable infrastructure projects.

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Section 2. Preliminary Results of Green Bonds for Infrastructure

1. Research Question and Hypothesis

1.1 Research questions

So far, studies on sustainable infrastructure investments and financing are quite inadequate, as hardly any empirical papers on green finance mentioned the infrastructure context and only 45 studies were found from thousands of articles during the systematic review. However, there are still valuable findings from the combination of the narrative literature review and the systematic literature review. It is worth noticing that green finance framework has been incorporated in the development of sustainable infrastructure: green investment banks as public investors; green bonds, green funds, as well as green equity for private investors.

However, empirical analysis of supporting sustainable infrastructure projects by green finance is extremely lacking. This vast research gap stems from the insufficient understanding of green finance and sustainable infrastructure, as they are both nascent and incipient concepts, waiting for further research. This research is designed to bridge this research gap by studying the empirical impact of utilization of green finance for sustainable infrastructure investments.

Although studies have illustrated that green bond markets are increasingly playing important roles in supporting construction of sustainable infrastructure, few of them fully study the impact of green bond. Although some empirical results are found towards corporate green bonds, there is still far from truly understanding the utilization of green bonds in infrastructure context for several reasons. For one reason, only focusing on corporate green bonds are not suitable for analysing sustainable infrastructure projects, as green municipal bonds are quite important funding sources which cannot be neglected. However, the number of previous researches on green municipal bonds is very scarce. Second, no empirical research on corporate green bonds and related green financial markets have targeted at the infrastructure context, with little attention on the characteristics of this alternative asset class. This lack of intuition can lead to potential biased conclusion of corporate green bond markets. What is more, studying on one specific area like infrastructure context can avoid some undesired “noise” from other industries in the analysis, for example, bonds with the same credit rating but from different industries have different performance and risk premiums (Díaz and Escribano, 2021). Third, the empirical results on the effects of green financial markets and socially responsible investing strategies are mixed, providing opportunities for studying in this not yet fully researched field.

Among viable green financial instruments for sustainable infrastructure, this research will be focused on the private investing sector, i.e. green bonds and green equity. In other words, green investment banks are not included in this study. The reason for this choice can be listed as follows: First, private sectors are gaining a rise of interests in infrastructure investments compared with public sectors. In addition, the green finance framework is mainly developed in the private sectors.

As it is mentioned before that in the green bond markets, which are the most popular green funding sources for sustainable infrastructure, green municipal bonds and green corporate bonds are sharing the predominant positions. Thus, here comes the first question:

(1) Will green bonds reduce issuers’ financing cost compared with conventional bonds? What are the advantages of issuing green bonds (both green municipal bonds and green corporate bonds)?

Alongside the impact of financing cost for green bonds, their theoretically believed potential positive effects on sustainability are also necessary to be examined. So, the second question is:

(2) Do green bonds help improve the sustainable performance, for the municipality and for the firms?

In terms of considering the potential connectedness of socially responsible investing strategies between corporate green bond markets and stock performance, research on the equity market focused on listed infrastructure firms is indispensable. To be specific, the third question can be raised:

(3) Will the issuance of corporate green bonds affect stock performance of listed infrastructure firms?

Further research on the socially responsible investing in sustainable infrastructure leads to the fourth question:

(4) What are the association between ESG score of listed infrastructure firms and their stock performance?

Answers to the above questions can provide some valuable insights for the participators in the green financial market, including the governments, infrastructure firms, and investors. For example, there are three types of investors in the financial markets (Auer and Schuhmacher, 2016): value driven investors (focus merely on high ESG ratings for their investments and are willing to accept a financial loss in exchange for that), responsible profit-seekers (are concerned with both high ESG ratings and financial profits for their portfolio choice), and irresponsible profit-seekers (simply interested in profitable investments without considering the social benefits). This research can help these various kinds of investors achieve their goals accordingly.

1.2 Hypothesis

What are the rationales for issuing green bonds? According to the previous studies, several possible theories can be applied for understanding. The first theory is that investors are willing to "trade off" financial returns for social benefits. As for the issuance of green bonds, this can be known as "green premium", which is measured by the yield spread between green bonds and the conventional bonds. Based on this theory, here comes the first hypothesis:

H1: Both the green municipal bonds and green corporate bonds reduce the issuer's financing cost.

As for the theory related to the environmental performance post-issuance of green bonds, greenwashing argument has gained much attention these days, which means that bond issuers make some unsubstantiated or misleading claims on their environmental commitments. In other words, bond issuers make environmental commitments by issuing green bonds without taking tangible actions towards sustainability.

In terms of green municipal bonds, governments act as credit guarantee so greenwashing is less likely to happen in green municipal bonds. What is more, the issuing of green municipal bonds represents the government commitments towards an environmentally friendly society, which potentially encourage related institutions and firms to engage in sustainable development.

As for the green corporate bonds in the infrastructure context, there will be less incentive for greenwashing when compared with other industries like manufacturing industry. For one reason, infrastructure projects involve more types of stakeholders and stricter regulations, making it more difficult for infrastructure firms to involve in greenwashing. What is more, as infrastructure industry is generally accepted as inflation hedging and low-risk accompanied with low-return compared with other industries in the equity market, infrastructure firms have less potential to attract responsible profit-seekers than other industries with higher risk and returns by enhancing their corporate social performance. The above analysis leads to the second hypothesis:

H2: Green municipal bonds and green corporate bonds help improve the sustainable performance of municipality and firms, respectively.

Speaking of the reaction of stock performance towards the issuance of green bonds, the signalling argument and investor attention argument (Tang and Zhang, 2020) can be used for analysis. According to the signalling argument, green bonds may serve as a credible signal of commitments towards the environment, which can be of great value under the circumstance of information asymmetry. Thus, the issuance of green bonds may bring about more investments from value driven investors and responsible profit-seekers, leading to a better performance in the equity market. In terms of the investor attention argument, green bonds announcement increases the media exposure and attracts investors' attention for the firms, resulting in a larger investor base and better performance in the equity market. So, the third hypothesis is listed as follows:

H3: Green bond issuance improves the infrastructure firms' performance in equity market.

2. Research Methodology (Corporate Green Bonds)

2.1 Event study methodology

In order to examine the stock price reaction around the announcement of green bonds, the event study methodology will be utilized. Event study method is a widely used method to examine the stock reaction around the announcement of the event. The announcement date rather than the issuance date will be selected as the related information will be provided to the market on the announcement day, and corresponding action will be conducted by this date. In contrast, on the issuance day, there will be no new information for the market participators.

2.2 Difference-in-difference methodology

In order to examine the environmental effects after the issuance of green bonds, matching approach and difference-in-difference (DID) model are utilized in this research. As the issuance of green bonds is endogenous with respect to the environmental outcomes, in other words, some unobserved and undetected factors may drive a spurious relation between the issuance of green bonds and environmental outcomes. Ideally, to resolve this endogenous issue, a suitable instrument variable (IV) would be the best choice. However, it is difficult to find such an instrument variable according to the previous literature: the issuance of green bonds is not random, and it is hard to find an empirical setting in which green bonds are randomly issued. Thus, matching methodology is used in this part, which is to obtain a plausible counterfactual of how green bond issuers would have fared had they issued a conventional bond. The matching procedure is designed to ensure that control firms are highly similar to the treated firms ex ante.

3. Data Description (Corporate Green Bonds)

To compile a database of infrastructure corporate green bonds, I extract all corporate bonds in Bloomberg's fixed income database that are labelled as 'green bonds' (more precisely, bonds for which the field 'Green Instrument Indicator' is 'Yes'). Given that this part of the thesis is focused on the corporate green bonds in infrastructure sector, I exclude bonds whose issuer's BICS (Bloomberg Industry Classification System) is 'Government' and 'Financials'. Given the comprehensive coverage of Bloomberg's fixed income database, the resulting data set is likely to closely map the full universe of corporate green bonds.

According to Flammer (2021) and Tang and Zhang (2020), corporate green bonds essentially existed in 2013, when the total amount issued reached $5 billion. So, my data on corporate green bonds is collected from the

beginning of the year 2013 to the end of 2022. According to these criteria, a compiled database of corporate green bonds, issuing from January 1, 2013 to December 31, 2022, yields a total of 2749 bonds.

For each bond, Bloomberg contains a wide range of information including the amount, currency, coupon, maturity, and credit rating. To facilitate comparisons, I covert all amounts into US dollars and delete the bonds whose issue amount and mark for public firms are missing. In the end, a compile of 2722 bonds covering nine BICS industries are collected for further study. In the following part, some stylized facts based on these data are provided to better understand the status quo of worldwide green bond issuance.

3.1 Corporate green bonds across years, industries, and countries

To understand the evolution of corporate green bonds over time, I report the issuance amount and number of the issued green bond by years. Table 1 shows the rapid growth in corporate green bonds over the past few years. Although the issuance of green bonds was merely seven in 2013, it has experienced an approximate tenfold increase over the past two years, accompanied by an amount surge from $5.92 billion to $622.03 billion.

Table 1 Corporate green bonds by years

Year	#Bonds	$Amount (billion)
2013	7	4.92
2014	34	12.31
2015	183	18.84
2016	90	27.01
2017	192	43.11
2018	191	33.86
2019	314	85.51
2020	317	92.20
2021	748	175.49
2022	646	128.77
Total	2722	622.03

Notes: This table reports the total issuance amount and the number of corporate green bonds issued on an annual basis, using corporate green bonds dataset from Bloomberg.

As my research is focused on the infrastructure industries, a breakdown of corporate green bonds by industries and countries is helpful for me to grasp the key information on the distribution of green bonds, selecting and settling the most suitable categories for the infrastructure firms. Industries are partitioned according to the two-level Bloomberg's BICS (Bloomberg industry Classification System) criterion.

Table 2 presents the green bonds issuers' industrial breakdown, indicating a popularity of corporate green bonds in the infrastructure industries such as utilities and energy. This validates the previous section of my study that green bond market is a feasible source for financing sustainable infrastructure. To be specific, environmentally sensitive sectors take up the largest portion of the issued green bonds, including the power generation, utilities, and renewable energy. This is reasonable as the proceeds of a green bond can be exclusively applied to environmentally-friendly fields according to the regulation.

Table 2 Corporate green bonds by industry

BICS1	BICS2	#Bonds	$Amount (billion)
Communications	Cable & Satellite (3)	42	26.12
	Internet Media (4)		
	Wireless Telecommunications Services (14)		

	Wireline Telecommunications Services (21)		
Energy	Coal Operations (3)	451	40.35
	Exploration & Production (3)		
	Integrated Oils (6)		
	Pipeline (9)		
	Refining & Marketing (25)		
	Renewable Energy (405)		
Health Care	Biotechnology	16	5.48
	Health Care Facilities & Services		
	Medical Equipment & Devices Manufacture		
	Pharmaceuticals		
Industrials	Electrical Equipment Manufacturing	425	65.63
	Industrial Other		
	Machinery Manufacturing		
	Manufactured Goods		
	Railroad (20)		
	Transportation & Logistics (82)		
	Waste & Environment Services & Equipment (69)		
Materials	Chemicals	168	44.51
	Construction Materials Manufacturing		
	Containers & Packaging		
	Forest & Paper Products Manufacturing		
	Metals & Mining		
Technology	Communications Equipment	65	22.48
	Design, Manufacturing & Distribution		
	Hardware		
	Semiconductors		
	Software & Services		
Utilities	Power Generation (666)	1,201	339.37
	Utilities (537)		
Consumer Discretionary	Airlines	295	67.57
	Apparel & Textile Products		
	Auto Parts Manufacturing		
	Automobiles Manufacturing		
	Consumer Services		
	Department Stores		
	Distributors - Consumer Discretionary		
	Educational Services		
	Entertainment Resources		
	Home Improvement		
	Homebuilders		
	Retail - Consumer Discretionary		
	Travel & Lodging		
Consumer Staples	Consumer Products	59	16.39
	Food & Beverage		
	Mass Merchants		
	Retail - Consumer Staples		
	Supermarkets & Pharmacies		
Total	N.A.	2722	622.03

Notes: This table reports the total issuance amount in $billion and the number of corporate green bonds by industry, using corporate green bonds dataset from Bloomberg. Industries are partitioned according to Bloomberg's BICS codes.

Table 3 presents a breakdown by countries. As is shown, green bonds are especially important in US and Europe, being the larger issuers in issuance amount. Also, it is noticeable that green bonds are prevalent (in

numbers) in Asia, despite a lower overall amount in dollar terms.

Table 3 Corporate green bonds by country

Country	#Bonds	$Amount (billion)
United States	335	117.40
Netherlands	112	88.01
France	85	65.84
Germany	102	56.07
United Kingdom	77	28.31
South Korea	204	26.19
Spain	85	23.52
Italy	40	23.25
China	580	20.40
Denmark	28	12.25
Japan	124	10.57
Chile	17	8.50
Sweden	105	7.56
India	25	7.20
Hong Kong	41	7.01
Luxembourg	21	6.50
Canada	32	6.44
Portugal	9	6.35
Austria	14	6.14
Ireland	12	6.06
Finland	18	4.87
Norway	84	3.37
Australia	9	2.66
New Zealand	29	2.64
Brazil	81	2.39
Singapore	11	2.23
Others	443	71.29
Total	2722	622.03

Notes: This table reports the total issuance amount in $billion and the number of corporate green bonds by country, using corporate green bonds dataset from Bloomberg. Industries are partitioned according to Bloomberg's BICS codes.

3.2 Summary statistics at the bond level

Table 4 provides summary statistics of corporate green bonds from 2013 to 2018. It is not uncommon that a given company issues several green bonds on a given day, which results in the differences number of green bonds in total, issuer-days, issuer-years, and the unique green bond issuers. In this research, the total 2722 green bonds correspond to 1891 unique issuer-days, 1460 unique issuer-years, and 990 unique issuers.

Meanwhile, I also distinguish between green bonds that are issued by public firms and private firms by the Bloomberg indicator (Is Private Co. or not). It shows that public firms issue larger bonds, which tend to have longer maturities and less coupons. There are no obvious differences between the credit ratings of private firms and public ones.

Table 4 Summary statistics at the green bond level

	All	Private	Public	Event study
#Green bonds	2722	1868	854	827

#Green bond issuer-days	1891	1234	657	642
#Green bond issuer-years	1460	924	536	523
#Green bond issuers	990	619	371	361
Amount	228.52 (354.4)	206.81 (312.6)	276.0 (428.5)	
Maturity	10.63 (51.7)	8.82 (24.5)	14.56 (84.61)	
Coupon (%)	3.36 (2.6)	3.59 (2.2)	2.87 (3.4)	
S&P rating (med.)	BBB+	BBB+	BBB+	
Moody's rating (med.)	Baa1	Baa1	Baa1	
Bloomberg's composite rating (med.)	BBB+	BBB+	BBB	

Notes: This table provides summary statistics for all corporate green bonds.

4. Stock Market Reaction

To examine the stock market reaction to the issuance of green bonds, the event study methodology is utilized. I use the announcement date, instead of the issuance date from the Bloomberg database, since it captures the day when the information is provided to the market. In contrast, no new information is conveyed on the issuance date.

To conduct the event study, I obtain the stock market data from daily security section of Compustat North America and Compustat Global. As the model relies on the actual returns of a reference market and the correlation of the company's stock return with the reference market, unique country's leading stock market indexes are used. For example, the S&P500 for US, CAC40 for France, IBEX35 for Spain, CSI300 for China, Nikkei225 for Japan, etc.). To capture the cumulative abnormal returns, I define the announcement date of green bonds as the event date (day 0). Due to the potential for information to be known by the public prior to the declaration date and the possibility of market reaction lag on the announcement date, I consider the event window [-5, 10].

To compute the abnormal returns, I use the market model:

$$Rit=\alpha i+\beta i\times Rmt+\varepsilon it \quad (1)$$

$$\hat{R}it=\hat{\alpha}i+\hat{\beta}i\times Rmt \quad (2)$$

$$ARit=Rit-\hat{R}it \quad (3)$$

where Rit is the stock return of firm i on day t, Rmt is the market return on day t, εit is the error term, $\hat{R}it$ is the estimated stock return of firm i on day t, $ARit$ is the abnormal daily return of firm i on day t.The coefficients of the market model are estimated by ordinary least square (OLS) regression based on the trading days related to estimation window [-220, -21]. I compute the cumulative abnormal returns (CAR) for each company in several event windows [-5, 5], [-3,3], [-2,2], [-1,1], [0,1], [0,2].

Table 5 Stock market reaction to the announcement of green bond issuance

Event time	Number of firms	CAR (%)	t_test
[-1;1]	332	-0.379	-1.4090107
[-3;3]	342	-0.430	-1.0773354
[-5;5]	337	-0.334	-.6579001
[-2;2]	330	-0.512	-1.4803703
[0;1]	329	-0.475***	-2.1451102
[0;2]	327	-0.606***	-2.2298417

[-5;10]	336	-0.305	-.49033556

Notes: This table shows the CAR results of the first announcement date.

5. Firm-level Outcome

To examine the firm-level outcomes following the issuance of green bonds, I choose to compare the corporate environmental, social, and governance (ESG) performance. One empirical challenge is that the issuance of green bonds is endogenous to firm performance. However, there is difficult to find an instrument for the issuance of green bonds and utilize IV model. Hence, I use a matching approach to build a plausible counterfactual of how firm-level outcomes would evolve absent the green bond issuance. Specifically, for each of the 536 green bond issuer-years (marked as 'treated' firms), I match a 'control' firm which is similar to the 'treated' firm prior to the issuance of green bond.

To build the matched control group, I use the Mahalanobis distance to find the nearest neighbour by several matching criteria. First, for public firms, I only consider those that are bond issuers (but not green bond issuers) in the same year. Second, I control the firms which from the same country and same two-digit SIC industry. Third, I match the remaining candidates based on six firm-level characteristics: firm size, ROA, leverage, environmental score, social score, and governance score of the year preceding the green bond issuance (i.e. at t-1).

Data of corporate financial information are obtained from Fundamental annual of Compustat North America and Compustat Global. Data on corporate ESG performance are obtained from Refinitive database. The matching procedure is to ensure that control firms are highly similar to the treated firms prior to the green bond issuance. Specifically, the three pillars of ESG score ensures a similar environmental performance. ROA ensures a similar performance on profitability. Size and leverage to ensures a similar access to capital markets. Matching these firms based on the same country, industry, and year ensures that the treated and control firms have the similar conditions in their business environment, including economic, regulatory, and other conditions.

As the issuance of green bonds are not part of Refinitive ESG assessment grid in the Refinitive ESG database, it is reasonable to limit the concerns that the green bond issuance itself is the reason for the tangible ESG score improvements. In other words, there is no mechanical link between the green bond insurance and the higher ESG performance scores.

The Refinitive ESG database does not cover all public firms. For firms that are not covered by Refinitive ESG scores, the matching is done based on other three characteristics.

Table 6 Matching results

Variables	Green bond	Mean1	Matched control	Mean2	MeanDiff	p-Value
logat1	400	9.492	401	8.934	0.558	0.000***
roa	395	0.0330	400	0.0300	0.00300	0.317
leveg	400	1.403	401	1.254	0.149	0.083*
escore	266	60.83	215	61.06	-0.229	0.919
sscore	266	59.66	215	59.48	0.180	0.936
gscore	266	57.57	215	57.56	0.00800	0.997
Variables	Green bond	Median1	Matched control	Median2	Diff	p-Value
logat1	400	9.461	401	8.828	19.51	0.000***
roa	395	0.0290	400	0.0300	0.213	0.645
leveg	400	1.150	401	0.989	2.997	0.083*

escore	266	65.80	215	65.54	0.113	0.737
sscore	266	64.79	215	64.32	0.113	0.737
gscore	266	58.89	215	58.89	0.00300	0.960

Notes: This table reports the matching results based on the lowest Mahalanobis distance to the treated firms across six firm characteristics. Means, medians, and p-values of the difference-in-means test and the difference-in-medians test are reported.

To examine the firm-level outcomes, I utilize the DID model:

$$y_{it} = \alpha_i + \alpha_c \times \alpha_t + \alpha_s \times \alpha_t + \beta \times Green\ Bond_{it} + \varepsilon_{it} \qquad (4)$$

where y is the dependent variable: environmental performance of firms, i represents firms or cities, c represents country, t represents year, s represents two-digit SIC industries (infrastructure is not a sole industry based on this measurement), α_i are firm fixed effects (constant over time), $\alpha_c \times \alpha_t$ are country by year fixed effects, $\alpha_s \times \alpha_t$ are industry by year fixed effects, $Green\ Bond$ is a dummy variable (treatment dummy) which equals to 1 if firm or city i has issued a green bond by the year t and 0 otherwise, ε_{it} is the error term.

The results are showed as below:

Table 7 ESG performance after the issuance of green bonds

	(1) escore	(2) sscore	(3) gscore
Green bond	0.3637*	-0.1608	-0.0647
	(1.9968)	(-0.5422)	(-0.1641)
Firm fixed effects	Y	Y	Y
Country-year fixed effects	Y	Y	Y
Industry-year fixed effects	Y	Y	Y
Observation	2152	2152	2152
R-square	0.9399	0.9312	0.8202

Notes: This table reports the results of DID models.

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