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A Two-Step Fuzzy DEMATEL Analysis of the Barriers to Green Finance in Green Building in Developing Countries

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Abstract

Green buildings (GBs) are a means of achieving sustainable construction. However, they face challenges, such as higher (perceived or actual) investment costs and inadequate capital. Green finance (GF) presents opportunities to address some challenges of GB. Barriers hinder GF-in-GB; however, previous studies identifying barriers to GF-in-GB are limited. Moreover, prior studies have not considered the interrelationships among these barriers. This study aims to identify and prioritize the critical barriers to GF-in-GB in Ghana to inform decision-making by policymakers and stakeholders. This study developed a valid set of barriers and criteria from the literature to ascertain their interactions through two rounds of Delphi surveys with 12 professionals with GF-in-GB experience. A two-step fuzzy decision-making trial and evaluation laboratory (FDEMATEL) method was employed to validate 16 criteria of barriers using linguistic preferences. The findings of this study indicate that split incentives, inadequate private investment, inadequate management support, and limited green projects are critical barriers to GF-in-GB. These criteria deserve critical attention, as they are of high importance cause indices and can give rise to effect barriers. The government can adopt the research findings in policymaking and by other stakeholders that seek to eliminate barriers by focusing on the most influential ones.

Keywords: barriers; fuzzy Delphi method; fuzzy DEMATEL; green finance; green building; sustainable urbanization

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1. Introduction

The floor area of buildings is expected to increase by 75 percent by 2050, 80 percent of which will be in developing countries [1]. The significant rise in buildings and construction activities has brought enormous pressure and challenges to the environment and global economies, especially climate change issues [2]. For example, the operations and materials used in buildings and construction account for approximately 34 per cent of global CO_2 emissions and 32 per cent of the final energy use [3]. Over the past few decades, researchers, climate activists, and national governments have been finding novel ways to decarbonize the built environment sector to promote affordable housing supply towards sustainable urbanization [4]. One such approach is green building (GB) [5].

GB mitigates the negative impacts of buildings on the climate and natural environment throughout the lifecycle stages [6]. For example, GB adopts ecologically sustainable principles from the substructure to the superstructure through decommissioning [7]. With sustainable principles such as energy efficiency, GB can potentially reduce global CO_2 emissions by 43 percent by 2030 [4]. It can also lower the operating cost of buildings, increase occupant comfort, health, and productivity, enhance corporate reputation, and increase the market value of buildings [8]. Although GB has several benefits, its implementation remains minimal. It is faced with barriers such as higher (perceived or actual) investment costs, lack of government support or incentives, lack of market demand, lack of public awareness, and inadequate capital and green finance (GF) [3]. GB and energy efficiency investments in buildings represent less than 4 percent (USD 237 billion) of the global buildings and construction sector value (USD 6.3 trillion) [3]. The literature [3,9,10] suggests that GF presents opportunities to close the GB investment gap.

GF refers to financial instruments supporting the climate-resilient transition through funding activities that protect the environment, such as emissions reductions, reduced energy use, and developing climate-resilient infrastructure [11]. The International Finance Corporation [12] estimates a GF-in-GB investment opportunity of USD 24.7 trillion in emerging economies by 2030. Although GF has received increased attention recently, some adoption and implementation barriers exist [10,13,14]. Identifying and prioritizing the barriers to GF-in-GB would provide critical information to enable policymakers to reduce decision inefficiencies, enhance stakeholder acceptance and investment, and strategically develop novel GF-in-GB initiatives.

Few studies have been conducted on barriers to GF-in-GB using several methods and analytical tools. For example, Ref. [15] identified the key barriers to accessing GF for building energy retrofits by energy service companies (ESCOs) in China. The key barrier identified was limited access to GF, preventing ESCOs from expanding in the country. Agyekum et al. [13] examined professionals' perceptions of the obstacles to GB project finance in Ghana's construction sector. The significant challenges were split incentives, risk-related barriers, capital expenditure, lack of incentives, and initial capital cost. Survey methods and interviews were used in these studies. Ref. [16] adopted a mix of surveys, focus groups, and interviews to assess the barriers to investment decisions for green infrastructure by large European insurance companies. According to the participants from the insurance sector, banks and development finance institutions, regulatory obstacles and a lack of bankable projects and project pipelines are the main barriers to green investment. The analytical tools employed in these studies included descriptive analysis, one-sample t-test, One-Way ANOVA, and content analysis [13,15,16]. Although previous studies have demonstrated that some key barriers are responsible for the slow uptake of GF-in-GB, the interrelationships among the barriers identified were not considered.

It is argued in the literature that adoption and implementation barriers have some interdependencies among them and that one barrier can stimulate the occurrence of other barriers [17–19]. In addition, surveys adopted in previous studies may be prone to subjectivities and ambiguities. In addition, these studies do not consider the existential relationships between the barriers identified. While these subjectivity gaps and challenges persist in survey-based studies, fuzzy approaches used in multicriteria decision-making methods, such as the decision-making trial and evaluation laboratory (DEMATEL) and Delphi methods, can address them [20]. The DEMATEL method provides a more systematic and interactive research process of the judgment of a panel of independent experts on a particular issue [21]. In addition, DEMATEL helps develop mutual relationships of criteria and their correlated mutual relationships and influences of the criteria. This method can analyze total relations and provide a causal-effect diagram to describe the logical and mutual relationships, direct impacts and influences among sets of variables [18,22]. Researchers have adopted the fuzzy set theory to handle uncertainties in the DEMATEL method [23]. Linguistic preference scales used in DEMATEL studies allow experts to easily convert qualitative information into fuzzy numbers. The fuzzy logic is necessary for handling such vagueness and imprecision in human judgment [23]. Hence, there is a need to extend the DEMATEL method with fuzzy logic to make better decisions in fuzzy environments [17–19]. Hence, the fuzzy DEMATEL (FDEMATEL) was adopted in this study. Before applying the FDEMATEL, the fuzzy Delphi Method (FDM), which integrates the fuzzy set theory into the classical Delphi procedure, was used to validate identified factors from the literature [24].

As explained above, the previous studies based on single surveys, interviews or focus groups do not consider the influences and relationships between the barriers of GF-in-GB under fuzzy environments. To address these gaps, this study aims to quantitatively and objectively assess the interactions between the barriers to GF-in-GB using the two-step fuzzy Delphi–DEMATEL. This study is important first because, given the few studies examining GF-in-GB in developing economies, its empirical findings add significantly to the existing GF-in-GB literature. Moreover, this study would be critical to understanding the most important and critical barriers and their cause-and-effect interrelationships. Knowledge of these relationships would be useful to industry practitioners, the government, decision-makers, and other stakeholders in sustainably focusing the limited resources on addressing the influential and critical barriers. Furthermore, this study can be an important reference point for policymakers and advocates interested in promoting GF-in-GB in Ghana and other emerging economies to achieve more sustainable economies and societies.

2. Theoretical Background

2.1. Green Finance

GF has become one of the most significant innovations of the modern era, creating a financial pool to support sustainability goals. Hence, governments, international organizations, and even the public advocate for greening the economic system and global investments. GF is "financing investments that deliver environmental benefits in the broader context of environmentally sustainable development" [25]. It also refers to financial services for economic activities supporting environment improvement, climate change mitigation and more efficient resource utilization. These economic activities include the financing, operation and risk management for green project areas [11]. This form of finance mobilizes resources to support sustainable development, foster green economic growth, and mitigate the impacts of climate change and other environmental risks [26]. Over time, several GF instruments/mechanisms have been developed: green and climate bonds, green and climate loans, green and climate funds, green credits, green banks, sustainability bonds, village funds, green insurance, green mortgages and green stocks [3]. GF proponents believe that to "save our planet" by mitigating climate change and adapting to its effects, the global financial markets should redirect investment from brown activities to green projects. Green projects here refer to sustainability-aligned projects such as environmental protection, energy savings and efficiency, clean energy and fuels, renewable energy, climate-smart agriculture, sustainable water management, green transportation, and green building (which is the focus of the study). Research on green and sustainable finance is increasing, and this is crucial for advancing a GF system and green economic growth [26]. However, while the potential for integrating GF-in-GB is enormous, the literature reveals that the area remains understudied, underdeveloped, and underinvested [3]. Hence, research on GF-in-GB is of immense significance if the Paris Agreement Accord and the UN Sustainable Development Goals within the built environment sector are to be achieved by 2030. In the next section, the potential for GF-in-GB transition is reviewed.

2.2. Potential for GF-in-GB Transition

GF can accelerate GB transition in several ways. The literature suggests that GB finance is essential to implementing climate change mitigation and adaptation actions within the buildings and construction industry as part of nationally determined contributions [27]. Green investment in the built environment sector is rising and is expected to be one of the biggest global investment opportunities of the decade [3,12]. Recently, GF-in-GB research has emerged as a hotspot within global sustainability research, leading to several empirical studies and a few review studies [10,20].

From the literature, the ideal financing models to meet the sustainability objectives for GB have not been thoroughly investigated, developed, and promoted. Traditional financing models come with practical and regulatory limitations, making them inadequate to address the needs of GB completely [10]. For instance, whilst GF models consider sustainability dimensions, conventional building finance focuses primarily on "returns and risks" [28]. GF-in-GB intends to provide long-term capital for financing or refinancing GBs or energy-efficiency retrofits of buildings. In addition, investors and developers have access to better credit terms for financing GB development at lower risk [10]. Aside from addressing sustainability needs, GB investments are expected to yield favorable returns to maximize the stakeholders' wealth, including occupants [29]. In addition, GF-in-GB embraces emerging financial technologies (fintech) such as the Internet of Things (IoT), digital twins, blockchain, big data and mobile transactions [30]. Other studies investigate the impact of carbon trading on emissions reduction in buildings and construction [31,32]. In view of the above benefits and opportunities, several empirical studies exist. Existing GF-in-GB studies have focused on critical driving factors [20,33,34], obstacles [13,15,35], GB fund framework development [36], GB insurance [37], and GBs in commercial mortgage-backed securities [38]. Other studies evaluated the relationship between green property finance and carbon emissions in the building industry [27] and the financial performance of exchange-traded funds (ETFs) investing in sustainable real estate and GBs [39].

Despite the contributions, a few country-specific studies are available on the barriers to GF-in-GB [13,15]. Yet the World Bank Green Infrastructure Finance Framework Report emphasizes that for GF-in-GB to be effective, country-specific government policies and instruments are necessary [40]. The report also highlights that government policies should address Sustainable Development Goals by promoting innovation and managing issues related to carbon markets and taxes, standards and regulations, financial support mechanisms, and policy inconsistencies across different levels of governance [27,40]. In addition, the literature stresses that sustainability solutions, particularly for the built environment, must be highly contextual, considering cultural, country or region-specific dimensions [14]. Hence, it is essential to conduct more country- and region-specific studies. This study addresses this gap by focusing on developing countries, using Ghana as a case study.

GF in Ghana, particularly for GB, is expected to address GB cost barriers, including but not limited to constraints of inadequate long-term funding and lack of dedicated incentives for developers [13,41]. However, GF-in-GB is hindered by barriers. These barriers could be due to the lack of experience in implementation and the peculiarities associated with developing countries such as Ghana. Given the above, the objective of this study is to identify and prioritize the critical barriers to GF-in-GB in Ghana and to model their interrelationships to aid policymakers and stakeholders in decision-making. The following section summarizes the specific barriers to GB-in-GB from the literature.

3. Literature Review of Barriers to GF-in-GB

GF-in-GB models and their implementation differ among economies [41]. As noted, different barriers hinder successful implementation across regions, countries, and even cities. All specific finance-related barriers to GB implementation in Ghana identified in the literature were considered in identifying barriers to GF-in-GB. It is preferable to employ well-known factors in a research study so that respondents can respond efficiently [42]. As such, various barriers to GF in the literature were comprehensively reviewed. Relevant papers were retrieved from Scopus, Web of Science, and Google Scholar using "barriers", "green finance", and "green building" keywords and their variants. The search returned 27 articles discussing the barriers of GF-in-GB. The screening criteria for identifying relevant literature were studies examining GF in sustainable buildings and construction. After thoroughly examining these articles, five barriers to GF-in-GB with 22 indicators were shortlisted (see Table A1, Appendix A). This barrier categorization was based on similar groupings in the literature [43–45]. In addition, two experts with at least ten years of industry and/or academic experience were consulted during the shortlisting of the barriers and the groupings. A summary of the identified barriers is provided below:

3.1. Financial Barriers

Financial barriers relate to when high costs make certain activities problematic to afford [46] (i.e., all cost-related GF barriers). Following the literature review, six financial barriers to GF-in-GB were identified: split incentives, short-termism, limited GF supply, capital adequacy and liquidity issues, costly processes, and economic instability. The main challenge of GF is that of incentives [47]. According to Ref. [48], there is a perception of the uncertain benefits of green bond issuances. For instance, split incentives were identified as a significant barrier to GF in building energy efficiency retrofits in China [15]. Similarly, Ref. [13] found split incentives to be a significant barrier to financing GBs in Ghana. This lack of incentive for GF or to structure green bonds originates from the certification process [49] and its inability to show tangible benefits [50]. A survey revealed that the potential mismatch between investor and issuer expectations poses pricing uncertainty in the Ghanaian market [41]. Maturity mismatches or short-termism remain a critical issue in the global development of GF [51,52]. Again, the underlying liquidity profile of potential GF product issuers is crucial.

Similarly, SMEs lack capital requirements for GF, leading to inadequate financing schemes [13]. Owing to the insufficient capacity of SMEs to develop qualified funding proposals that meet requirements [15], green banks are reluctant to support green projects. In addition, the collateral obligations of SMEs are incredibly high and rigorous [15,53]. For example, it is reported that SMEs require as much as 120% collateral from the total loans obtained and to have a creditworthy sponsor [53]. Usually, a minimum project finance size of at least USD 100 million is also necessary [54], making it more challenging for SMEs to access GF. Other stakeholders perceive GF as a costly process, with higher transaction costs or additional fees [15,48,49]. The high up-front costs related to the perceived high cost of low-carbon technology investments remain critical [47,49]. In addition, poor economic conditions, notably exchange rate volatility and rising inflation, may dissipate interest in GF [13].

3.2. Regulatory Barriers

Regulatory barriers include international, national, state, or local laws, regulations, policies, and structures that may restrict the growth and development of GF. The three major regulatory barriers that affect GF-in-GB are policy and regulatory uncertainty, political instability, and regulatory requirements. The literature shows that policy uncertainty is the biggest concern for investors [54]. After three years, the government of Ghana has yet to implement its 2021 announcement of issuing a green bond [41]. These failed promises do not signal how and to what extent the government intends to support and promote the green transition. Such uncertainties could inhibit private-sector participation in the GF market. In contrast, the Nigerian government created the Green Bond Guidance, leading to its first green bond issued in 2017 [55]. Similarly, the Hong Kong government is famous for its sovereign green bonds in GBs [56]. These government signals have enhanced private investor confidence and interest in GF.

Again, a stable political climate is critical for investors' interest in a specific market. An erratic political atmosphere exposes the financial system to vulnerabilities, given the uncertainties in government policies [57]. Regulatory requirements may lead to regulatory risks that can inhibit GF-in-GB growth. This results in cost increases for project developers regarding the time required to understand the new regulations and additional related costs [58]. For instance, Ref. [53] claims that current regulatory frameworks have limited effectiveness in providing a clear direction for financial institutions to develop sustainable finance action plans capable of mainstreaming it within their business practice. A survey of professionals in Ghana revealed that the lack of guidelines for green bond issuance is responsible for the lack of clarity that market participants experience [41].

3.3. Organizational Barriers

The context in which organizations operate can drive or frustrate development [59]. The identified organizational barriers include greenwashing, inadequate management support, and inadequate private investment. The risk of greenwashing, also known as reputational risk, has been identified in the literature as a key GF barrier and remains a severe risk to all stakeholders [48]. Greenwashing is the issuance of so-called green securities that lack environmental benefits. This emanates from the lack of a clear GF definition, leaving room for misleading claims about green projects [60]. Emerging stories indicate that most GF is issued on greenwashing, a false representation that does not positively impact the environment [55]. Again, the failure of top and middle management to embrace GF in operational activities and an unsupportive organizational structure for green transition impede the growth of GF [10]. Additionally, insufficient private effort was identified in the literature review as a GF barrier. For instance, most renewable energy retailers in New South Wales are semi-privatized and barred from effectively entering into long-term public–private agreements [61]. Dmuchowski et al. [45] indicate a low private sector participation in financing a green economy in Poland. Therefore, private sector efforts in GF are very low and insufficient to meet the growing global need. However, to achieve meaningful, sustainable development, there is a need to leverage private sector investments with the current public spending on GF [62].

3.4. Technical Barriers

The lack of knowledge and technical capacity or expertise of project developers, issuers, and investors has been identified in the literature as a barrier to GF [15,52]. While many experts lack knowledge regarding financial policies or tools for green projects [47], companies often lack the financial management and accounting capacities required for a comprehensive green loan application [15]. Ref. [41] notes the importance of greater technical capacity in the Ghanaian market in enhancing GF. Lack of knowledge about GF is also influenced by inadequate research and development (R&D) support for GF-in-GB [63,64]. In addition, the perceived technology risk associated with uncertain GB technologies and products influences GF [13,41,65].

3.5. Structural Barriers

Structural (or market) barriers are natural or strategic barriers that arise in the market to prevent new entrants. These barriers, either short- or long-term, collectively prevent GF products from gaining traction in the capital market. They include limited green projects, a lack of harmonized global standards and guidelines, risk perception, a lack of a universal definition for "green projects", inadequate transparency and consistency with GF, information asymmetry, and a lack of quality historical data.

So far, few market participants can identify a pipeline of eligible green projects for GF because of the novelty of the product. Despite the rising interest in potential issuers in GF, there is a lack of eligible pipelines [41,48]. Mielke [16] agrees that the lack of bankable projects and project pipelines is a major barrier to GF. Although the Government of Ghana has introduced several initiatives to support its transition to a green economy, GF remains nascent in the country, primarily due to the almost non-existent GBs in Ghana. While there is significant awareness of GF, few market participants have some level of understanding of GF across issuers and investors alike [41]. There is also a lack of existing guidelines and regulations regarding GF. Ref. [41] asserts that a functioning debt capital market is key to GF issuance. Hence, there must be appropriate legislative protection for investors showing a degree of transparency and good governance through credit ratings, market liquidity, and acceptable yields. Ref. [55] argues that the lack of a harmonized system affects GF. This further deepens the challenges posed by the lack of credible historical information or databases on green projects and the various risk perceptions associated with green projects [13]. Similarly, GF is plagued with imperfect information, where parties to a transaction have access to different levels of information [66,67]. Finally, the poor clarity on what can be classified as GF is a barrier to the demand for GF-in-GB [10]. This unending debate on what qualifies as "green" in project financing is a big challenge to GF stakeholders [68].

As presented in Table A1 (Appendix A) and explained above, 22 barriers to GF-in-GB in Ghana were identified and grouped into five categories. From the above literature review, several barriers hinder the adoption and implementation of GF. The few available studies on GB focus on Ghana, Europe, and China [13,15,16]. To complement these studies, some general barriers to GF were also reviewed. While these studies provide significant findings, the interrelationships among the barriers are not considered. To overcome these gaps, a holistic approach that considers barrier interactions is suggested to be more effective than a unilateral approach [17,18]. Hence, this study aims to assess the interactions between barriers to GF-in-GB in Ghana through expert knowledge using the fuzzy Delphi–DEMATEL approach. The FDM was applied to validate the GF-in-GB barriers and indicators. Recent literature favors the FDM due to its simplicity and effectiveness, mainly because it requires a single investigation and does not mandate modification of expert opinions [18,24]. Based on the identified gap of the lack of interrelationships between existing barriers, the two-step fuzzy DEMATEL method employed in this study is explained below.

4. Research Methodology

This study used FDM and FDEMATEL survey methods to collect expert views on barriers to GF-in-GB. The FDM and FDEMATEL methodologies are emerging in sustainability-related research [18,69] and have recently been applied in GF-in-GB research [20] in a related paper as part of a PhD study. This study proposes a three-phase method, as shown in Figure 1.

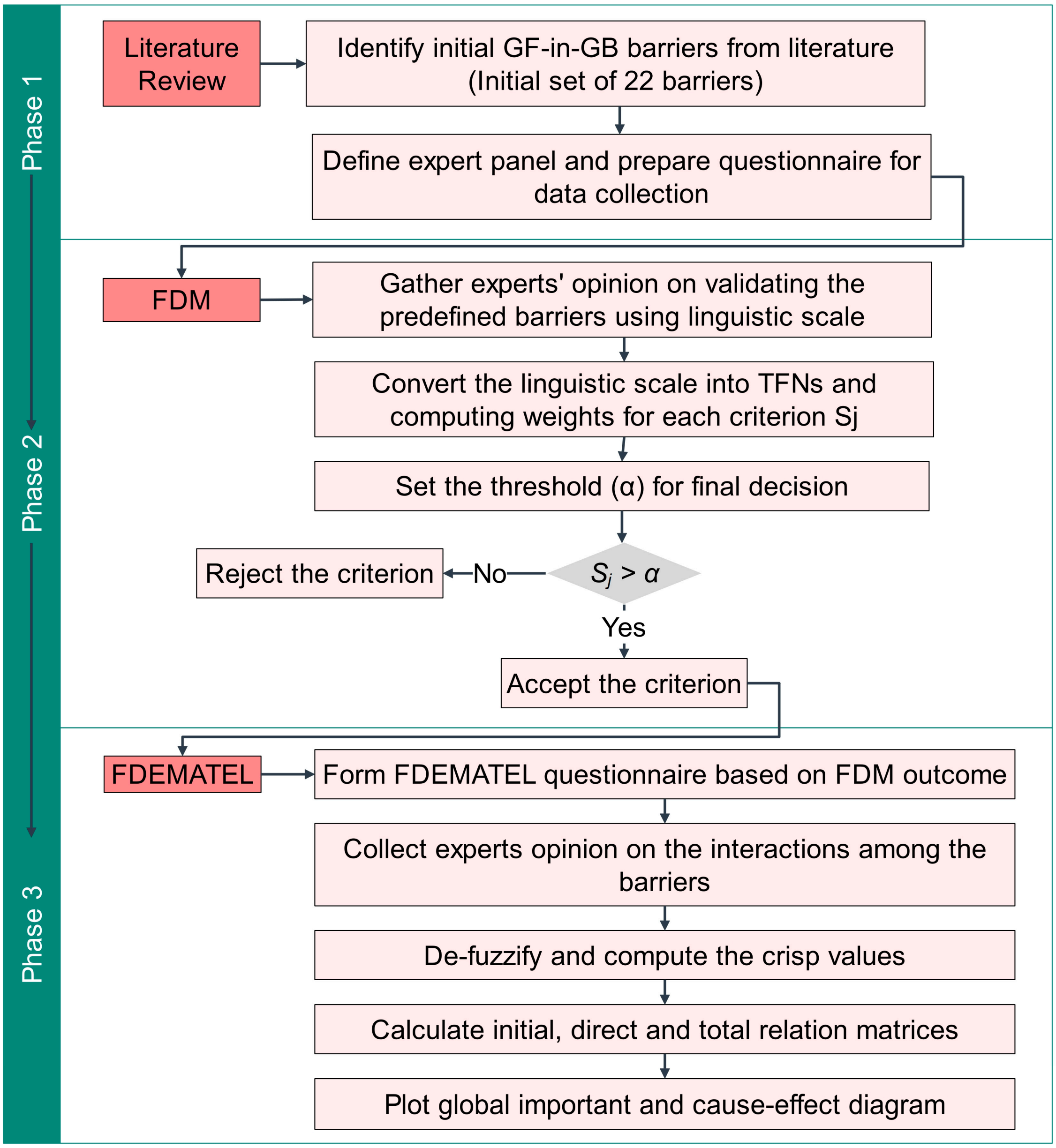

Figure 1. The FDM and FDEMATEL processes were modified from those of Ref. [18]. The arrows indicate the direction of flow in the FDM-FDEMATEL process, with green color denoting the three major phases: literature review, FDM, and FDEMATEL (highlighted in red). The detailed steps for each phase are highlighted in pink.

First, barriers to GF-in-GB were extracted from an extensive literature review. Then, an interview was conducted with two experts with at least ten years of industry and/or academic experience in GB finance. This was intended to refine the barriers regarding their clarity, relevance, practicality, and validity in the study context [24]. Secondly, the FDM was employed to select the critical barriers based on the case of Ghana. The FDM approach presented here was structurally designed to assess the list of pre-screened barriers extracted from the literature review and through the expert panel interview. Finally, the cause–effect interrelationship of the barriers was obtained by using the FDEMATEL.

Research has shown that the accuracy and effectiveness of the Delphi studies do not depend on the number of panelists alone, but on the qualities of experts [21,70]. Hence, the expert selection process was based on Ref. [71]'s approach. They include experience and knowledge of the issues under investigation, willingness and capacity to participate, sufficient time to participate, and effective communication skills. The literature recommends a sample size of eight to 16 panelists for a Delphi panel [21,70]. In this study, 30 panelists from Ghana with an average of five years of experience in either GF and/or GB projects were contacted. Twelve valid expert opinions were obtained. Online and face-to-face methods were used in the data collection process. The relatively large Delphi sample of expert panelists considered issues such as some panelists dropping out due to other commitments or disinterest [21]. The professional backgrounds of the respondents included Project/Construction Managers, Quantity Surveyors, Engineers, and Finance Experts. It should be noted that some respondents had multiple professional backgrounds. While the study was based in Ghana, some experts had international experience in countries such as the US, Australia, Hong Kong, Kenya, and Nigeria. Table 1 summarizes the profile of the experts involved in this study.

Table 1. Summary of experts' profiles.

Attribute	Sub-Attribute	Frequency (N = 12)	Percentage (N = 100%)
Education level	PhD degree	4	33.3
	Master's degree	8	66.7
	Total	12	100.0
Professional background [a]	Chattered Accountant	1	8.3
	Investment manager	1	8.3
	Quantity Surveyor	5	41.7
	Academic/Researcher	8	66.7
	Project/Construction Manager	8	66.7
	Engineer	2	16.7
Years of experience	1–5 years	6	50.0
	6–10 years	4	33.3
	>10 years	2	16.7
	Total	12	100.0
Area of related expertise	Green finance	3	25.0
	Green building	2	16.7
	Both	7	58.3
	Total	12	100.0
Organization	Academic or research institute	6	50.0
	Green certification firm	1	8.3
	Contractor firm	2	16.7
	Consultant firm	1	8.3
	Development/commercial banks	2	16.7
	Total	12	100.0
Professional membership [a]	Association of Certified Chartered Accountants (ASCE)	1	8.3
	American Society of Civil Engineers (ASCE)	1	8.3
	Australian Institute of Project Managers (AIPM)	1	8.3
	Ghana Institute of Construction (GIOC)	6	50.0
	Ghana Institute of Surveyors (GhIS)	3	25.0
	Project Management Professional (PMP-Ghana)	3	25.0
	Institute of Engineering Technology Ghana (IETG)	1	8.3
	International Finance Corporation Excellence in Design for Greater Efficiencies (IFC EDGE) Expert	3	25.0
Type of GB certification involved in [a]	Green Star South Africa-Ghana	4	33.3
	IFC EDGE	6	50.0
	US LEED	5	41.7
GF certification/standards involved in [a]	Climate Bonds Initiative	3	25.0
	ICMA Green Bond Principles	6	50.0
	GRESB Green Bond Guidelines	1	8.3
Journal or book publications	≥3 publications	8	66.7
Presented in conferences	Yes	4	33.3
Type of GB supply involved in [a]	Commercial, public, and institutional buildings	6	50.0
	Residential buildings or homes	5	41.7
	Healthcare facilities and laboratories	1	8.3
	Green retrofitting of existing buildings	1	8.3
	All the above	2	16.7

Table 1. *Cont.*

Attribute	Sub-Attribute	Frequency (N = 12)	Percentage (N = 100%)
Extent GF impact investment decision in GB [b]	Prefer GF such as green bonds where available and where competitively priced	7	58.3
	Mandates or targets	1	8.3
Preferred channels of green fixed-income investments for GBs [b]	Development bank green bonds	5	41.7
	Corporate green bonds	8	66.7
	Private placement of green bonds	1	8.3
	Green loans	8	66.7
	Sovereign green bonds	3	25.0

[a] Some experts possess multiple professional backgrounds and memberships; hence, percentages may exceed 100%. [b] Multiple answers were allowed.

The FDM and FDEMATEL methods employed in this study are explained below.

4.1. Fuzzy Set Theory

Human judgments are not definitive and are usually considered vague. Expressions like "very low," "a bit better," and "very likely" are common in daily conversations, leading to fuzziness, uncertainties, and ambiguities in expert judgment [72]. The fuzzy set theory introduced by Zadeh [23] uses linguistic variables to address such uncertainties and ambiguities. The fuzzy set theory employs fuzzy numbers, a fuzzy subset of real numbers, based on confidence intervals. Linguistic variables are words or sentences in a natural language for which no specific value exists [73]. Linguistic variables, like "very likely" or "not likely", can be indicated by a triangular fuzzy number (TFN) within a defined scale, like 0–10. A TFN is a fuzzy set with three membership functions or parameters: l, m, u. While the parameters l and u represent the lower and upper limits of a TFN, m denotes the center of the fuzzy number. This implies that a fuzzy number is approximately "m" and cannot be less than "l" or greater than "u" [24,72]. TFNs are easily understandable and, hence, are preferred by decision-makers. For instance, the linguistic variable "not likely" can be represented as a TFN (say 1, 2, 3), where a higher number means more likelihood.

4.2. Fuzzy Delphi Method (FDM)

The FDM is an improved and modified version of the traditional Delphi method, which is useful in obtaining consensus among a group of experts through multiple rounds of surveys [74]. While the FDM preserves the benefits of the conventional Delphi method, such as consensus building, it addresses other disadvantages, such as low convergence of experts' opinions, high execution costs due to multiple rounds, and the possibility of filtering out particular experts' opinions [24]. Compared to classical Delphi surveys, FDM is advantageous for its "simplicity" and "efficiency." In addition, FDM requires a single investigation and does not require experts to modify their extreme opinions [24]. It also helps experts clarify their optimistic, pessimistic, and realistic opinions based on TFNs. Generally, the FDM is considered a systematic, interactive and predictive process where experts express their opinions using only one linguistic variable [24,75]. The FDM process adapted from Refs. [18,24] is detailed below:

Step 1: Gathering experts' opinions through questionnaire surveys:

A group of 12 GF-in-GB experts in Ghana was invited to organize and determine the direct interactions between pairwise barriers. The experts used the linguistic operators in Table 2 to evaluate the interactions between each pair of barriers using one of five lingual expression hierarchies: extreme, demonstrated, strong, moderate, and equal.

Table 2. Fuzzy interpretation for lingual expression.

Lingual Expression	Corresponding TFNs		
Extreme	0.75	1.00	1.00
Demonstrated	0.50	0.75	1.00
Strong	0.25	0.50	0.75
Moderate	0.00	0.25	0.50
Equal	0.00	0.00	0.25

Source: Ref. [18].

The primary data collection instrument was a structured matrix questionnaire. Since Ghana has no experience in GF-in-GB and no open data on the interactions between the barriers, expert knowledge, which is more useful in such circumstances, is utilized. Although more experts were anticipated, few were found because of the novelty of the subject in the country.

Step 2: Aggregation and defuzzification of experts' opinions:

The following procedures were used for aggregation and defuzzification. The geometric mean was used to aggregate the respondent scores, and the fuzzy weight (w_j) of each criterion was determined.

$$w_j = \{a_j = min(a_{ij}), b_j = \left(\sum_{i=1}^{n}(b_{ij})\right)^{\frac{1}{n}}, c_j = max(c_{ij})\}, \tag{1}$$

where j represents the significance evaluation score of the indicator j, i represents the expert-rated criterion j, n represents the number of experts and a, b and c represent the lower, middle, and upper values of the TFNs, respectively. Additionally, m represents the number of indicators/barriers. The aggregated weights of each criterion are defined as follows:

$$s_j = \frac{a_j + b_j + C_j}{3} \; j = 1, 2, 3 \ldots m. \tag{2}$$

The threshold (α) was chosen to screen out non-significant barriers/indicators: if $s_j \geq \alpha$, then the jth barrier is accepted; otherwise, if $s_j \leq \alpha$, the jth barrier is rejected.

The literature reveals four approaches to estimating the threshold values: strict, mean, moderate, and conservative. For more details, the reader is referred to Ref. [76]. Similar to related studies [18,24], this study used the consensus among experts to set the threshold value at the average of TFNs.

4.3. Fuzzy Decision-Making Trial and Evaluation Laboratory (FDEMATEL)

In the second phase of the Delphi survey with the same experts, the FDEMATEL method was used to evaluate the cause-and-effect relationships among the barriers. While DEMATEL was employed to evaluate the causal-effect link between the barriers, the fuzzy set theory was utilized to resolve the fuzziness in expert judgements. Hence, the FDEMATEL can address such uncertainties and ambiguities during decision-making. In this study, Table 3 was used to convert linguistic terms into equivalent TFNs after qualitative judgments were gathered.

Table 3. TFNs for FDEMATEL assessment.

Linguistic Terms	Corresponding TFNs		
Very high (VH)	0.70	0.90	1.00
High (H)	0.50	0.70	0.90
Medium (M)	0.30	0.50	0.70
Low (L)	0.10	0.30	0.50
Very low (VL)	0.00	0.10	0.30

Source: Ref. [18].

For n members in a decision group, $\tilde{z}_{ij}^{f}$ denotes the fuzzy weight of the ith barrier impacting the jth barrier assessed by the fth evaluator.

The FDEMATEL approach implemented in this study is described in Appendix B. The FDM and FDEMATEL analytical process, summarized below, was used to obtain the results [18,20]:

1. An initial set of 22 GF-in-GB barriers (Table A1, Appendix A) was identified from the literature and analyzed using FDM based on 12 experts from Ghana. Based on the FDM, Equations (1) and (2) were used to estimate the acceptable threshold at 0.525. Using the FDM threshold, non-critical barriers are removed. Table A2 (Appendix C) presents the FDM for the barrier weights and their thresholds. Table 4 lists the 16 acceptable/critical barriers and aggregated fuzzy weights after deleting the defuzzied weights below the threshold.
2. Experts' qualitative assessments were converted into equivalent TFNs (see Table 3). Based on acceptable barriers or indicators, a new set of questions was examined using FDEMATEL. The same experts provided the data, and (Equation (A1), Appendix B) was used to normalize the assessed TFNs. (Equations (A2)–(A4), Appendix B) were used to determine the normalized values, total normalized crisp values, and crisp values for each expert.
3. The IDRM and normalized direct relationship matrix were generated using (Equations (A5) and (A6), Appendix B). (Equation (A7), Appendix B) was used to compute the influence or significance level of the complete interdependence matrix.
4. (Equations (A8) and (A9), Appendix B) were used to calculate the horizontal axis $(D + R)$ and vertical axis $(D - R)$. The driving barriers in the first quadrant have causal features and are of higher importance. If a barrier is in the second quadrant, it is a voluntary barrier with a causal function but lesser importance. The third quadrant is made up of less important and independent barriers. Core problems are those mapped into quadrant four, indicating higher importance. The core problems rely on the driving barriers in the first quadrant, are unable to be improved by themselves, and require addressing the root problems [18]. The analytical steps proposed in this study are summarized in Figure 1.

Table 4. Validated FDM barriers to GF-in-GB in Ghana.

Barriers	BC1	Indicators	Weights
Financial barriers (B1)	BC1	Split incentives	0.527
	BC4	Capital adequacy and liquidity issues	0.531
	BC6	Economic instability	0.555
Regulatory barriers (B2)	BC7	Policy and regulatory uncertainty	0.530
	BC9	Regulatory requirement	0.525
Organizational barriers (B3)	BC10	Greenwashing	0.526
	BC11	Inadequate management support	0.525
	BC12	Inadequate private investment	0.539
Technical barriers (B4)	BC15	Technological uncertainty	0.526

Table 4. *Cont.*

Barriers	BC1	Indicators	Weights
Structural barriers (B5)	BC16	Limited green projects	0.534
	BC17	Lack of harmonized global standards and guidelines	0.528
	BC18	Risks perception	0.531
	BC19	Lack of a universal definition for "green projects"	0.526
	BC20	Inadequate transparency and consistency with GF	0.542
	BC21	Information asymmetry	0.534
	BC22	Lack of quality historical data	0.538

5. Results

5.1. The FDM Results

As previously discussed, the FDM was utilized to select the critical barriers from the ones identified in the literature. FDM was used to assess 22 GF-in-GB barrier indicators identified from the literature. Based on Equations (1) and (2), the acceptance threshold was estimated at 0.525. Table A2 (Appendix C) presents the FDM results comprising the indicator weights and thresholds. All indicators with defuzzied weights less than the acceptable threshold were excluded. The results of the FDM are presented in Table 4.

5.2. The FDEMATEL Results

As per the FDM results, the FDEMATEL questionnaire was presented to the same experts to evaluate the cause–effect relationship between the barriers and the indicators. Based on the TFNs in Table 3, the 12 experts assessed the valid barrier set in Table 4 to determine their interrelationships. The data collected from the experts were normalized, defuzzied, and aggregated using (Equations (A1)–(A5), Appendix B) and are provided in Table 5. An illustration of the defuzzification process of the results of one of the experts (referred to as Expert A) is provided in Appendix D.

Table 5. Synthetic crisp values for the barriers.

	B1	B2	B3	B4	B5	Sum
B1	0.000	0.703	0.616	0.745	0.656	2.724
B2	0.659	0.000	0.967	0.701	0.716	3.042
B3	0.457	0.748	0.000	0.620	0.590	2.415
B4	0.423	0.575	0.664	0.000	0.748	2.410
B5	0.494	0.796	0.787	0.664	0.000	2.742
					Max	3.042

The synthetic values in Table 5 are standardized using (Equation (A6), Appendix B), and the total interrelationship matrix for the barriers is computed using (Equation (A7), Appendix B). The driving and dependent powers are calculated using (Equations (A8) and (A9), Appendix B), as shown in Table 6.

Table 6. Total interrelationship matrix of GF-in-GB barriers.

	B1	B2	B3	B4	B5	*D*	*R*	*D* + *R*	*D* − *R*
B1	(0.150)	0.078	0.020	0.103	0.062	0.114	0.048	0.162	0.066
B2	0.099	(0.233)	0.163	0.061	0.070	0.159	0.125	0.284	0.034
B3	0.037	0.122	(0.203)	0.068	0.054	0.077	0.141	0.218	(0.063)
B4	0.025	0.039	0.067	(0.176)	0.129	0.084	0.122	0.206	(0.038)
B5	0.037	0.119	0.095	0.066	(0.201)	0.116	0.115	0.230	0.001

The negative ($D - R$) values for B3 and B4 indicated that these two barriers were identified as the effect group and could only be improved indirectly. The ($D - R$) values are positive for B1, B2, and B5, indicating that these aspects belong to the causal group and impede the adoption and growth of the GF-in-GB system. Finally, the results were used to determine whether the relationships were weak, medium or strong. Figure 2 is a causal interrelationship diagram of GF-in-GB barrier categories.

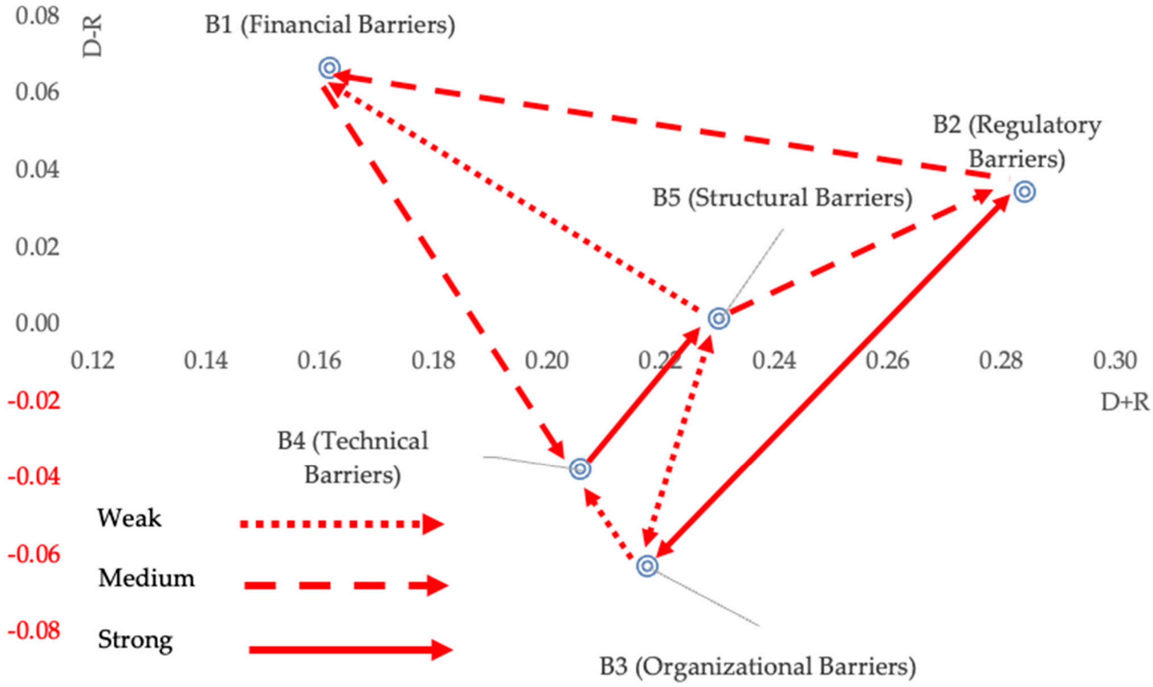

Figure 2. Barriers causal effect diagram. The diagram shows the causal relationships among these five barriers. All double-headed arrows show two-way relationships or interdependence among each other. For instance, weak relationships exist between structural and organization barriers. This means that they exhibit the same effect on each other; thereby focusing on either of the two will yield the same results.

The results from Figure 2 indicate that financial barriers (B1), regulatory barriers (B2), and structural barriers (B5) belong to the causal group barriers on the positive side of the $(D - R)$ axis. Technical barriers (B4) and organizational barriers (B3) belong to the effect group on the negative side of the $(D - R)$ axis. The regulatory barrier category (B2) is the most significant type of barrier and can lead to the existence or elimination of other GF-in-GB barriers. This implies that it has the most powerful influence on the entire GF-in-GB system.

Similarly, Table 7 provided the causal interrelationships matrix among the barrier indicators.

Table 7. Total interrelationship matrix of the indicators.

	BC1	BC4	BC6	BC7	BC9	BC10	BC11	BC12	BC15	BC16	BC17	BC18	BC19	BC20	BC21	BC22	D
BC1	1.345	1.493	1.485	1.472	1.472	1.373	1.463	1.498	1.532	1.498	1.586	1.667	1.519	1.592	1.527	1.541	24.062
BC4	1.358	1.372	1.438	1.411	1.411	1.318	1.429	1.434	1.480	1.446	1.545	1.602	1.476	1.530	1.497	1.491	23.239
BC6	1.381	1.455	1.368	1.416	1.416	1.315	1.425	1.437	1.490	1.445	1.554	1.591	1.464	1.518	1.486	1.491	23.251
BC7	1.357	1.445	1.425	1.370	1.386	1.308	1.419	1.442	1.456	1.452	1.563	1.634	1.454	1.456	1.458	1.346	22.969
BC9	1.375	1.449	1.452	1.372	1.372	1.330	1.447	1.453	1.499	1.476	1.579	1.638	1.489	1.550	1.523	1.524	23.528
BC10	1.321	1.384	1.386	1.370	1.370	1.231	1.398	1.403	1.439	1.402	1.520	1.549	1.433	1.501	1.476	1.469	22.651
BC11	1.396	1.480	1.468	1.452	1.452	1.347	1.398	1.471	1.518	1.484	1.607	1.648	1.505	1.577	1.528	1.545	23.876
BC12	1.439	1.501	1.493	1.486	1.486	1.377	1.491	1.442	1.557	1.518	1.628	1.677	1.541	1.608	1.575	1.571	24.389
BC15	1.308	1.373	1.383	1.350	1.350	1.268	1.367	1.390	1.362	1.393	1.502	1.550	1.419	1.468	1.436	1.429	22.349
BC16	1.385	1.451	1.454	1.434	1.434	1.329	1.433	1.469	1.492	1.400	1.573	1.614	1.500	1.542	1.516	1.513	23.540
BC17	1.388	1.486	1.475	1.445	1.445	1.382	1.470	1.477	1.536	1.481	1.538	1.663	1.520	1.591	1.554	1.535	23.987
BC18	1.350	1.441	1.436	1.420	1.420	1.309	1.424	1.441	1.481	1.436	1.564	1.532	1.456	1.530	1.497	1.504	23.243
BC19	1.336	1.412	1.420	1.405	1.405	1.297	1.410	1.416	1.468	1.441	1.538	1.590	1.389	1.512	1.482	1.480	23.004
BC20	1.417	1.495	1.480	1.458	1.458	1.377	1.473	1.492	1.537	1.510	1.628	1.662	1.523	1.523	1.565	1.566	24.164
BC21	1.358	1.424	1.413	1.411	1.411	1.343	1.433	1.445	1.486	1.444	1.567	1.606	1.461	1.538	1.438	1.522	23.302
BC22	1.279	1.361	1.349	1.351	1.351	1.255	1.344	1.347	1.393	1.364	1.483	1.513	1.396	1.446	1.442	1.358	22.031
R	21.794	23.022	22.927	22.624	22.639	21.158	22.824	23.060	23.726	23.189	24.974	25.737	23.545	24.483	23.998	23.886	1.459

Table 8 summarizes the prominence and importance values of the GF-in-GB barrier indicators.

Table 8. Prominence and importance values of GF-in-GB indicators.

	BC1	BC4	BC6	BC7	BC9	BC10	BC11	BC12	BC15	BC16	BC17	BC18	BC19	BC20	BC21	BC22
D	24.062	23.239	23.251	22.969	23.528	22.651	23.876	24.389	22.349	23.540	23.987	23.243	23.004	24.164	23.302	22.031
R	21.794	23.022	22.927	22.624	22.639	21.158	22.824	23.060	23.726	23.189	24.974	25.737	23.545	24.483	23.998	23.886
$D + R$	45.856	46.261	46.178	45.593	46.167	43.808	46.700	47.448	46.075	46.728	48.961	48.980	46.549	48.647	47.300	45.917
$D - R$	2.268	0.216	0.325	0.345	0.889	1.493	1.052	1.329	(1.377)	0.351	(0.987)	(2.493)	(0.541)	(0.319)	(0.697)	(1.854)

Figure 3 presents the cause–effect diagram of the indicators of GF-in-GB.

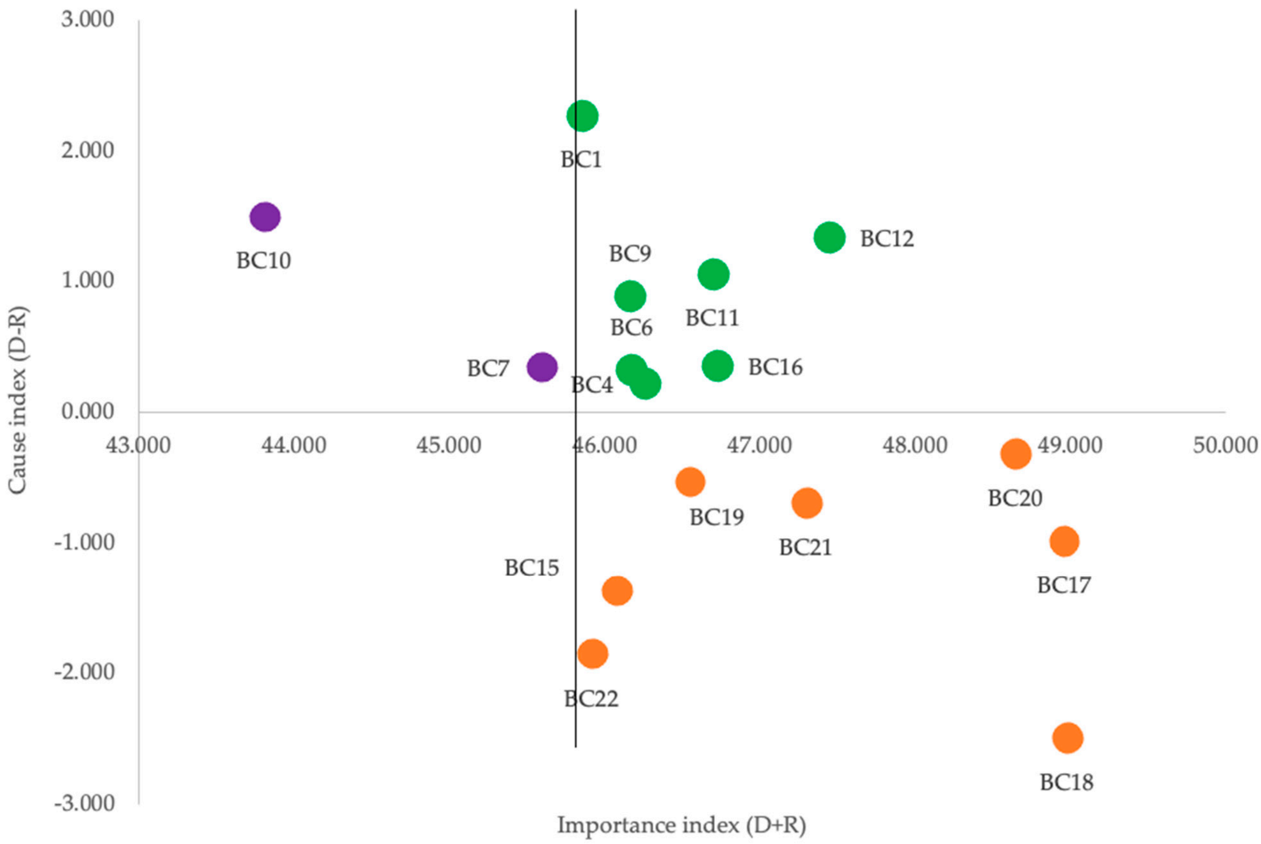

Figure 3. Indicators causal effect diagram. The green-colored barriers are known as linkage/critical barriers, characterized by strong driving power and high dependence. The orange-colored ones are the dependent barriers, characterized by high dependence but weak driving power. These barriers can only be indirectly addressed by removing the linkage barriers. The violet ones are referred to as driving barriers, have high driving power but weak dependence.

Figure 3 shows that the ($D - R$) axis differentiates between the cause-and-effect groups, while ($D + R$) indicates the importance or prominence of the indicators. The causal group indicators are on the positive side of the ($D - R$) axis, while those on the negative side are effect groups. The barrier indicators include inadequate private investment (BC12), inadequate management support (BC11), and limited green projects (BC16).

6. Discussion

This section elucidates the critical findings of the study. In Section 6.1, barriers with higher global importance indexes are discussed. Then, the barriers that belong to the cause–effect group are expounded in Section 6.2. Finally, the indicators that showed both highly important and causal indexes are discussed (Section 6.3).

6.1. Barriers with Higher Global Importance Index

Barriers with high global importance indexes are also referred to as high prominent index barriers. These barriers have the potential to influence or be influenced by other barriers and, hence, need critical attention, particularly in the short term [17,20]. Regulatory (0.284) and structural barriers (0.230) emerged as the two barriers with the highest global importance indexes.

Regulatory barriers have the highest global importance index among all the barriers. This implies it has the most potent influence on the entire GF-in-GB system. Regulations impact the adoption of sustainability in construction and GF-in-GB [18] and appear to drive other barriers, such as organizational and technical barriers. The lack of existing guidelines and regulations has been stressed as a critical constraint on GF in Ghana. In addition, the country's lack of credit risk rating requirements remains a challenge to the issuance of GF products such as green bonds in the country [41]. Ref. [13] also identified changing government policy as a key obstacle to GB project financing in Ghana. These regulatory barriers lead to policy uncertainties [54], restraining private sector participation in GF. Addressing regulatory barriers, such as a lack of existing guidelines or regulations [41] and changing government policies [54], will, in effect, impact organizational and technical barriers. The government and other stakeholders must assess how regulations and policies can positively impact the development of GF-in-GB. In so doing, the development of local guidelines and regulations for GF is key, particularly for GBs. This means the government must actively regulate the green capital market. Considering the current economic conditions, best practices from other developed countries and those in the subregion can be adapted to the peculiar case in Ghana. As a result, the uncertainties of implementing GF in a novel Ghanaian capital market will be lessened, and investors will eventually be more confident.

The second most important global barrier was structural barriers. They include limited green projects [41,48], a lack of harmonized global standards and guidelines [41,55], risk perception [13], a lack of a universal definition for "green projects" [10,68], inadequate transparency and consistency with GF, information asymmetry [66,67], and a lack of quality historical data [13]. For instance, Ghana lacks a pipeline developed for eligible green projects [41,48]. In agreement, Ref. [13] stresses that the lack of credible historical information or databases on green projects and the various risk perceptions are responsible for the low green project financing in Ghana. Since these structural barriers (also known as market barriers) prevent new entrants into the GF market in Ghana, addressing them is critical for promoting GF-in-GB. For example, the result suggests that GF-in-GB is hindered by a lack of a quality historical database, which may further lead to information asymmetry among investors and suppliers of GF. To overcome this, the government of Ghana could create a public repository or database to track future sovereign green bonds to finance GBs and their performance. With such transparency from the government, commercial developers, non-private building owners, corporate building owners, and private green banks could also be encouraged to share data on their corporate green bonds for GBs in the database to increase access to information on GF. This proposed Ghana GF-in-GB database could be a comprehensive resource on GB and GF cost, which includes cost breakdowns for GB, indices, and location-adjustment factors, GF data (such as issuer, size, tenor, financing costs, verifier and/or external review reports, green certification reports, use of and management of proceeds, etc.). Similarly, structural barriers could also lead to the emergence of other obstacles, such as technical and organizational barriers to GF-in-GB (see Figure 2).

Regarding the barrier indicators in Table 8, risk perception (BC18) emerged with the highest global importance index. This was followed by a "lack of harmonized global standards and guidelines" (BC17), "inadequate transparency and consistency with GF" (BC20), "inadequate private investment" (BC12) and "information asymmetry" (BC21), respectively. These were the top five indicators with the highest global importance indexes. By comparison, it is observed that indicators belonging to structural barriers have higher importance indexes. This underscores the urgent need to address these structural barriers, which should be prioritized in the short term when promoting the development and growth of GF-in-GB.

6.2. Cause–Effect Barriers

The second category includes barriers that belong to the cause–effect group. The cause group barriers are those with positive cause indexes that tend to affect the entire GF-in-GB system, thereby leading to other barriers [17,19]. The barriers with negative cause indexes belong to the effect group. The cause barriers are deemed critical because of their potential influence on the effect barriers. As indicated in Table 6, financial, regulatory, and structural barriers were found in the cause group barriers; hence, they have the potential to give rise to additional barriers, such as technical and organizational barriers. Among the cause group barriers, financial barriers had the highest cause index, highly impeding the entire GF-in-GB system. These barriers arise when high costs make it challenging to afford green activities. Since financial difficulties hinder GB implementation, favorable macroeconomic conditions, such as stable inflation and foreign exchange rates, should be created for GF-in-GB to thrive [10,77,78]. In addition, the perception of the uncertain benefits of GB [13] creates a mismatch between issuers' and investors' expectations [41]. This could be addressed by structuring GF products through a certification process that shows the tangible benefits of GF-in-GB [49,50]. Issues such as green bond pricing premiums are achievable through corporate green bonds and long-term institutional investors [79]. In the long term, developing countries may experience the pricing benefit of highly rated issuers in developed countries. Again, the inability of institutional investors in Ghana to identify and quantify credit and market risks associated with investment in debt instruments [41] can be improved through GF workshops. The government must take the initiative of organizing training for both government officials and finance and investment experts to increase awareness and knowledge of GF. Lessons from successful green bond issuances from sub-Saharan African countries such as Nigeria, Kenya, Namibia and South Africa [41,55] would be pivotal to developing the Ghanaian GF market and training experts. Hence, regulations must consider the collateral and liquidity requirements and the ability of SMEs in Ghana to participate in the GF market. Increasing green loans—which are usually smaller in volume and performed privately [80]—and green securitization could be the starting point. Green securitization, for instance, is now required to access debt capital markets financing for small-scale, low-carbon and climate-resilient assets, particularly GBs [81]. They provide avenues to increase capital access and decrease capital costs for SMEs. As explained above, adopting the above strategies to eliminate the financial barriers identified would address the underlying cause and lead to the reduction in barriers such as inadequate private investment (organizational barrier) and technological uncertainty (technical barrier). Other cause group barriers, such as the regulatory and structural barriers, have been discussed above. Altogether, cause group barriers should be addressed in the long term to prevent the occurrence of effect group barriers.

6.3. Indicators with High Importance and Cause Indexes

The third category of barriers that require special attention is the indicators that show both high importance and cause indexes. The following indicators met both requirements and therefore require critical attention: "split incentives" (BC1), "inadequate private investment" (BC12), "inadequate management support" (BC11), and "limited green projects" (BC16). The uncertain benefits of GB [13] create a mismatch between issuers' and investors' expectations [41]. Due to pricing benefit uncertainties, this may hinder adequate private investment [41,55]. Similarly, there is inadequate management support owing to the lack of urgency to embrace green practices [10]. This could be attributed to fear of loss of investment and uncertainty about the returns of GB [10], lack of building and finance models [82], and technological uncertainty [13,41]. Engagement with investors is key to developing an appetite for GF [41]. Increasing investors' appetite for GF-in-GB will lead to the development of a pipeline for eligible green projects. Addressing these barriers with both high importance and cause indexes is very critical to addressing effect barrier indicators, such as inadequate transparency and consistency with GF (BC20), lack of universal definition for "green projects" (BC19), information asymmetry (BC21), lack of harmonized global standards and guidelines (BC17), technological uncertainty (BC15), lack of quality historical data (BC22), and risk perception (BC18). For example, GF-in-GB could be championed through public demonstration projects, which call for the government of Ghana to revisit its green bond issuance promise. These green-financed projects could be helpful in assessing the performance of GF-in-GB in a novel Ghanaian market. Lessons from the demonstration projects could be shared with the private sector. Again, the experience gathered from such projects could serve as the basis for training other professionals and private developers. The success stories from the GF-in-GB demonstration projects could motivate the private sector to explore and adopt the concept to promote a sustainably financed built environment.

7. Conclusions

The aim of this study was to identify and prioritize the critical barriers to GF-in-GB in Ghana and analyze the findings to guide policymakers' and stakeholders' decision-making. Experts' opinions were used to validate a pool of barriers to GF-in-GB from the literature, which was then refined using FDM. The cause–effect relationships between the critical barriers were then evaluated using FDEMATEL.

7.1. Research Implications

This study offers several theoretical and management implications and insights. First, the findings highlight five critical barriers and 16 indicators that decision-makers and other stakeholders must address through best practices to successfully adopt and implement GF-in-GB in Ghana. The combined use of FDM and FDEMATEL methods clearly identifies the barriers that need immediate attention to mitigate risks and uncertainties with GF-in-GB. Furthermore, the findings underscore the importance of regulatory and structural barriers, which had high important indexes and belonged to the cause group barriers. These barriers were deemed to have a high impact and influence, and without addressing them both in the short- and long-term, the overall GF-in-GB system will not thrive in emerging economies. In addition, if not addressed immediately, these barriers could lead to other effect group barriers, such as organizational and technical barriers. In terms of the indicators, our findings reveal specific barriers such as "split incentives" (BC1), "inadequate private investment" (BC12), "inadequate management support" (BC11), and "limited green projects" (BC16) that impede the growth and development of GF-in-GB in developing countries. Hence, they require special attention. Altogether, if these barriers and the indicators are not addressed in the long term, they can lead to the emergence of other effect group barriers and indicators in Ghana. Consistent with the literature, this study reveals that addressing regulatory and structural barriers is more critical to meeting global sustainability goals than other barriers [17,18,20]. Hence, the Government of Ghana can collaborate with other stakeholders to devise strategies that directly address the most influential barriers to GF-in-GB projects, as identified in this study. Given the limited resources available in a developing context like Ghana, a result-oriented two-step fuzzy DEMATEL offers managers and policymakers a more resource-efficient decision-making framework to ensure Ghana develops and promotes GF-in-GB projects. This method enables government agencies, private investors, and other stakeholders to allocate resources more strategically, focusing on areas that will yield the greatest impact [17]. For example, the Government of Ghana agency heads and other stakeholders need to focus on providing more management support (BC11, cause group barrier) to increase the pool of green projects (BC16, cause group barrier), which can effectively and concurrently address the challenge of the lack of quality historical data (BC22, effect group barrier).

Secondly, this study addresses academic calls to examine the interrelationships between the factors influencing GF-in-GB [10,13,14]. As a result, the study significantly contributes to existing knowledge, being one of the few to prioritize and rank GF barriers in the GB context and developing countries alike. Furthermore, while the empirical focus is on Ghana, the insights extend beyond this case. For countries seeking to promote GF-in-GB in a world of resource constraints, the study provides a practical response to critical questions: How can barriers to GF-in-GB be identified? How do these barriers interact? How can they be prioritized? And how can strategic decision-making be enhanced through these insights? This is the first comprehensive study to identify, evaluate, and rank the barriers to GF-in-GB, analyzing these barriers as having multifaceted relationships. The results revealed that, at the moment, technical and organizational barriers are less significant, primarily due to the need for regulations guiding the overall GF-in-GB architecture and a streamlined structure for such markets. It is expected that once the regulatory and structural or market conditions of GF-in-GB are well-defined, organizations may face fewer challenges and resistance in adopting GF-in-GB. Hence, future studies should focus more on developing policies and regulations to promote GF-in-GB. This is because a poor regulatory environment leads to an ineffective system adopted by key stakeholders [18]. In addition, developing strategies to streamline and position the GF-in-GB market structure in developing countries needs equal attention.

7.2. Limitations and Future Research

Although the objectives of this study were achieved, there are still some limitations. First, given the early GF applications in GB research and practices [20], the analysis was based on the opinions of 12 experts with GF and GB experience in Ghana. Hence, the expert opinions may be biased towards academia and industry. Since the data is specific to the Ghanaian context, attention should be paid to the analysis results compared to those of other emerging and advanced economies with different economic conditions. However, the insights from this study could be adaptable to countries with comparable economic conditions to Ghana. Apart from this, caution should also be given when the results are interpreted and generalized because of the relatively small sample size. Future research should, therefore, involve many respondents and extend the scope to include other emerging and advanced economies. Additionally, incorporating the distinct perspectives of different stakeholders, such as issuers, investors, developers, governments, and non-governmental organizations, could provide a deeper understanding of both the supply- and demand-side barriers to GF-in-GB. Again, to expand this study, future research should consider more barriers and indicators.

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Appendix A

Table A1. Proposed barriers to GF-in-GB in Ghana.

Barriers	Indicators	Description	References
Financial barriers (B1)	BC1—Split incentives	Expected returns of financial suppliers differ from the GB firms' or green investors' goals	[13,15,48–50]
	BC2—Short-termism	Maturity mismatch between short-term bank loans and long-term GB	[41,51,52]
	BC3—Limited GF supply	Inadequate financing schemes	[13,15,41]
	BC4—Capital adequacy and liquidity issues	High and rigorous collateral requirements of SMEs, limited assets and weak balance sheets, limited capital and liquidity of SMEs	[15,41,53,54]
	BC5—Costly process	Higher transaction costs or additional fees associated with "green"	
	BC6—Economic instability	Uncertain economic conditions; high interest rate; high inflation rates; unstable currency or exchange rates	[13]
Regulatory barriers (B2)	BC7—Policy and regulatory uncertainty	Conflicting government policy signals/framework to promote green transition	[54,60]
	BC8—Political instability	Unstable political atmosphere exposing the financial system to vulnerabilities	[57]
	BC9—Regulatory requirement	Lack of guidelines for green bond issuance	[41,53,58]

Table A1. *Cont.*

Barriers	Indicators	Description	References
Organizational barriers (B3)	BC10—Greenwashing	Reputational risk due to misleading information on environmental performance of green firms	[48,55,60]
	BC11—Inadequate management support	Failure of top and middle management to embrace GF in operation activities, unsupportive organization structure for green transition	[10,41]
	BC12—Inadequate private investment	Low involvement of the private sector in GF	[45,61,62]
Technical barriers (B4)	BC13—Limited knowledge and technical expertise	Lack of knowledge or expertise regarding financial policies or tools towards green projects	[15,41,47,52]
	BC14—R&D challenges	Inadequate research and development on GF-in-GB	[63,64]
	BC15—Technological uncertainty	Technology-risk associated with uncertain GB technologies	[13,41,65]
Structural barriers (B5)	BC16—Limited green projects	Lack of identifiable GF/bankable green projects	[41]
	BC17—Lack of harmonized global standards and guidelines	Lack of standardized framework/guidelines or global standards to structure green projects.	[41,55]
	BC18—Risks perception	Risk factors such as climate-related risk, reputational risk, systemic risk	[13,41,68]
	BC19—Lack of universal definition for "green projects"	Lack of a clear definition of what is GF-in-GB.	[10,68]
	BC20—Inadequate transparency and consistency with GF	Absence of adequate accountability and transparency in assessing green projects, lack of reporting/disclosure regulations.	[41,83]
	BC21—Information asymmetry	Imperfect information where parties to a transaction have access to different levels of information.	[66,67]
	BC22—Lack of quality historical data	Problems of data accessibility, lack of clear and reliable data to inform decisions.	[13,66]

Appendix B

Fuzzy decision-making trial and evaluation laboratory (FDEMATEL) Approach

Step 1: Normalize the fuzzy numbers:

The fuzzy numbers are normalized using Equation (A1):

$$S = \left(s\tilde{z}^f_{lij}, s\tilde{z}^f_{mij}, s\tilde{z}^f_{uij}\right) = \left[\frac{\left(\tilde{z}^f_{lij} - min\tilde{z}^f_{lij}\right)}{\left(max\tilde{z}^f_{uij} - min\tilde{z}^f_{lij}\right)}, \frac{\left(\tilde{z}^f_{mij} - min\tilde{z}^f_{mij}\right)}{\left(max\tilde{z}^f_{uij} - min\tilde{z}^f_{lij}\right)}, \frac{\left(\tilde{z}^f_{uij} - min\tilde{z}^f_{mij}\right)}{\left(max\tilde{z}^f_{uij} - min\tilde{z}^f_{lij}\right)}\right], \tag{A1}$$

where $\left(s\tilde{z}^f_{lij}, s\tilde{z}^f_{mij}, s\tilde{z}^f_{uij}\right)$ reflects the normalized values of the TFNs.

Step 2: Compute normalized values, total normalized crisp values and crisp values:

Compute the left $\left(s\tilde{z}^f_{ltij}\right)$ and right $\left(s\tilde{z}^f_{rtij}\right)$ normalized values Equation (A2), the total normalized crisp values Equation (A3) and the crisp values Equation (A4).

$$\left(S^f_{ltij}, S^f_{rtij}\right) = \left[\frac{s\tilde{z}^f_{mij}}{\left(1 + s\tilde{z}^f_{mij} - s\tilde{z}_{lij}\right)}, \frac{s\tilde{z}^f_{uij}}{\left(1 + s\tilde{z}^f_{uij} - s\tilde{z}^f_{mij}\right)}\right] \tag{A2}$$

$$\tilde{w}^f_{ij} = min\tilde{z}^f_{lij} + S^f_{ij}\left(max\tilde{z}^f_{uij} - min\tilde{z}^f_{lij}\right) \tag{A3}$$

$$\tilde{w}^f_{ij} = min\tilde{z}^f_{lij} + S^f_{ij}\left(max\tilde{z}^f_{uij} - min\tilde{z}^f_{lij}\right) \tag{A4}$$

Step 3: Define the initial direct relation matrix (IDRM) to calculate synthetic values:

Define an IDRM that aggregates the subjective assessments of n evaluators and finds the synthetic value using Equation (A5).

$$\tilde{w}_{ij}^{f} = \frac{1}{n}\left(\tilde{w}_{ij}^{1} + \tilde{w}_{ij}^{2} + \tilde{w}_{ij}^{3} + \ldots + \tilde{w}_{ij}^{f}\right), \quad \text{(A5)}$$

where w_{ij} specifies how much the criterion i influences the criterion j.

Step 4: Normalize direct relationship matrix:

Standardize the IDRM to generate the normalized direct relationship matrix (U) based on Equation (A6).

$$U = w \otimes IDRM, \quad \text{(A6)}$$

where w $= max\left(\sum_{j=1}^{n} w_{ij}^{f}\right)$ for every i ranging from 1 to n.

Step 5: Calculate total relation and interrelationship matrix:

Calculate the total relation matrix and use the matrix U to estimate the total interrelationship matrix (Y) using Equation (A7).

$$Y = U(I - U)^{-1}, \quad \text{(A7)}$$

where I represents the size n and an identity matrix.

Vector D represents the total of the rows, while the vector R is the sum of the columns. Equations (A8) and (A9) were used to compute the importance indexes $(D + R)$ and cause indexes $(D - R)$.

$$D = \sum_{j=1}^{n} U_{ij}\, for\ all\ j\ from\ 1\ to\ n \quad \text{(A8)}$$

$$R = \sum_{i=1}^{n} U_{ij}\, for\ every\ i\ ranging\ from\ 1\ to\ n \quad \text{(A9)}$$

The inner dependency matrix was obtained to determine the strength of the cause–effect link. This was used to determine the global importance score of the indicators. Here, the horizontal axis $(D + R)$ reflects "prominence" and denotes significance. In contrast, the vertical axis $(D - R)$ represents the causal qualities and signifies "relation". The value $(Di + Ri)$ represents all effects generated and received by $barrier_i$, indicating both $barrier_i$'s influence on the overall system and other system barriers' influence on $barrier_i$. When $(D - R)$ is negative, the barrier is recognized as the effect group, and when it is positive, they are identified as the cause group. The $(D - R)$ criteria show the net effect that $barrier_i$ has on the system. The importance index represents the significance of the barriers, whereas the cause index is the degree to which a barrier has the potential to affect the entire system and give birth to other barriers. The cause index is positive if the barrier affects other barriers (i.e., the cause group) and negative if other barriers influence the barrier (i.e., the effect group). The barriers in the "cause group" are deemed very critical since they have the potential to impact those in the "effect group" [17].

Appendix C

Table A2. FDM—Indicators screening out.

Indicators	a_j	b_j	c_j	s_j	Decision
BC1	0.000	0.582	1.000	0.527	Accepted
BC2	0.000	0.518	1.000	0.506	Unaccepted
BC3	0.000	0.566	1.000	0.522	Unaccepted
BC4	0.000	0.592	1.000	0.531	Accepted
BC5	0.000	0.557	1.000	0.519	Unaccepted

Table A2. *Cont.*

Indicators	a_j	b_j	c_j	s_j	Decision
BC6	0.000	0.665	1.000	0.555	Accepted
BC7	0.000	0.590	1.000	0.530	Accepted
BC8	0.000	0.533	1.000	0.511	Unaccepted
BC9	0.000	0.573	1.000	0.525	Accepted
BC10	0.000	0.575	1.000	0.526	Accepted
BC11	0.000	0.568	1.000	0.525	Accepted
BC12	0.000	0.617	1.000	0.539	Accepted
BC13	0.000	0.528	1.000	0.509	Unaccepted
BC14	0.000	0.556	1.000	0.519	Unaccepted
BC15	0.000	0.577	1.000	0.526	Accepted
BC16	0.000	0.602	1.000	0.534	Accepted
BC17	0.000	0.584	1.000	0.528	Accepted
BC18	0.000	0.593	1.000	0.531	Accepted
BC19	0.000	0.577	1.000	0.526	Accepted
BC20	0.000	0.627	1.000	0.542	Accepted
BC21	0.000	0.603	1.000	0.534	Accepted
BC22	0.000	0.613	1.000	0.538	Accepted
Threshold (α)				0.525	

Appendix D

Table A3. Defuzzification Procedure from Expert A.

	B1		B2		B3		B4		B5	
B1	[0.000 0.000 0.250]		[0.750 1.000 1.000]		[0.250 0.500 0.750]		[0.500 0.750 1.000]		[0.750 1.000 1.000]	
B2	[0.250 0.500 0.750]		[0.000 0.000 0.250]		[0.750 1.000 1.000]		[0.500 0.750 1.000]		[0.000 0.000 0.250]	
B3	[0.750 1.000 1.000]		[0.250 0.500 0.750]		[0.000 0.000 0.250]		[0.500 0.750 1.000]		[0.000 0.000 0.250]	
B4	[0.000 0.000 0.250]		[0.500 0.750 1.000]		[0.750 1.000 1.000]		[0.000 0.000 0.250]		[0.750 1.000 1.000]	
B5	[0.500 0.750 1.000]		[0.750 1.000 1.000]		[0.750 1.000 1.000]		[0.500 0.750 1.000]		[0.000 0.000 0.250]	
	$\tilde{sz}^f_{lij}$ $\tilde{sz}^f_{mij}$ $\tilde{sz}^f_{uij}$		$\tilde{sz}^f_{lij}$ $\tilde{sz}^f_{mij}$ $\tilde{sz}^f_{uij}$		$\tilde{sz}^f_{lij}$ $\tilde{sz}^f_{mij}$ $\tilde{sz}^f_{uij}$		$\tilde{sz}^f_{lij}$ $\tilde{sz}^f_{mij}$ $\tilde{sz}^f_{uij}$		$\tilde{sz}^f_{lij}$ $\tilde{sz}^f_{mij}$ $\tilde{sz}^f_{uij}$	
B1	[0.000 0.000 0.000]		[0.750 1.000 0.750]		[0.250 0.500 0.500]		[0.500 0.750 0.750]		[0.750 1.000 0.750]	
B2	[0.250 0.500 0.500]		[0.000 0.000 0.000]		[0.750 1.000 0.750]		[0.500 0.750 0.750]		[0.000 0.000 0.000]	
B3	[0.750 1.000 0.750]		[0.250 0.500 0.500]		[0.000 0.000 0.000]		[0.500 0.750 0.750]		[0.000 0.000 0.000]	
B4	[0.000 0.000 0.000]		[0.500 0.750 0.750]		[0.750 1.000 0.750]		[0.000 0.000 0.000]		[0.750 1.000 0.750]	
B5	[0.500 0.750 0.750]		[0.750 1.000 0.750]		[0.750 1.000 0.750]		[0.500 0.750 0.750]		[0.000 0.000 0.000]	
	S^f_{ltij}	S^f_{rtij}	S^f_{ltij}	S^f_{rtij}	S^f_{ltij}	S^f_{rtij}	S^f_{ltij}	S^f_{rtij}	S^f_{ltij}	S^f_{rtij}
B1	0.000	0.000	0.800	1.000	0.400	0.500	0.600	0.750	0.800	1.000
B2	0.400	0.500	0.000	0.000	0.800	1.000	0.600	0.750	0.000	0.000
B3	0.800	1.000	0.400	0.500	0.000	0.000	0.600	0.750	0.000	0.000
B4	0.000	0.000	0.600	0.750	0.800	1.000	0.000	0.000	0.800	1.000
B5	0.600	0.750	0.800	1.000	0.800	1.000	0.600	0.750	0.000	0.000
	$\tilde{w}^f_{ij}$		$\tilde{w}^f_{ij}$		$\tilde{w}^f_{ij}$		$\tilde{w}^f_{ij}$		$\tilde{w}^f_{ij}$	
B1	0.000		0.967		0.445		0.698		0.967	
B2	0.445		0.000		0.967		0.698		0.000	
B3	0.967		0.445		0.000		0.698		0.000	
B4	0.000		0.698		0.967		0.000		0.967	
B5	0.698		0.967		0.967		0.698		0.000	
	$\tilde{w}^f_{ij}$		$\tilde{w}^f_{ij}$		$\tilde{w}^f_{ij}$		$\tilde{w}^f_{ij}$		$\tilde{w}^f_{ij}$	
B1	0.00		0.70		0.62		0.75		0.66	
B2	0.66		0.00		0.97		0.70		0.72	
B3	0.48		0.75		0.00		0.62		0.59	
B4	0.42		0.56		0.66		0.00		0.75	
B5	0.49		0.80		0.79		0.66		0.00	

References

1. IEA. Net Zero by 2050—Analysis—IEA. 2021. Available online: https://www.iea.org/reports/net-zero-by-2050 (accessed on 24 February 2023).
2. Debrah, C.; Chan, A.P.C.; Darko, A.; Akowuah, E.; Amudjie, J.; Asare, K.A.B.; Ghansah, F.A. A bibliometrix-based scientometric-systematic analysis and visualization of the global outlook on post-occupancy evaluation of green building. *Build. Res. Inf.* **2025**, 1–17. [CrossRef]
3. UNEP. Global Status Report for Buildings and Construction 2024/2025. 2025. Available online: https://globalabc.org/sites/default/files/2025-03/Global-Status-Report-2024_2025.pdf (accessed on 16 July 2025).
4. World GBC. WGBC ANZ Status Report 2022. 2022. Available online: https://viewer.ipaper.io/worldgbc/wgbc-anz-status-report-2022/?page=1 (accessed on 14 January 2023).
5. Debrah, C. Lifecycle Economic Feasibility Assessment Model for Green Finance in Green Building in Ghana. 2024. Available online: https://theses.lib.polyu.edu.hk/handle/200/13099 (accessed on 1 September 2024).
6. HK GBC. What Is Green Building? 2025. Available online: https://www.hkgbc.org.hk/eng/about-us/what-is-green-building/index.jsp (accessed on 3 September 2025).
7. Zuo, J.; Zhao, Z.-Y. Green building research–current status and future agenda: A review. *Renew. Sustain. Energy Rev.* **2014**, *30*, 271–281. [CrossRef]
8. Zhang, L.; Wu, J.; Liu, H. Turning green into gold: A review on the economics of green buildings. *J. Clean. Prod.* **2018**, *172*, 2234–2245. [CrossRef]
9. Debrah, C.; Darko, A.; Chan, A.P.C.; Owusu-Manu, D.G.; Edwards, D.J. Green finance in green building needs under the Paris Agreement. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2022; p. 012033.
10. Akomea-Frimpong, I.; Kukah, A.S.; Jin, X.; Osei-Kyei, R.; Pariafsai, F. Green finance for green buildings: A systematic review and conceptual foundation. *J. Clean. Prod.* **2022**, *356*, 131869. [CrossRef]
11. ICMA. Sustainable Finance High-Level Definitions. 2020. Available online: https://www.icmagroup.org/sustainable-finance/icma-publications/ (accessed on 3 September 2025).
12. IFC. *Green Buildings: A Finance and Policy Blueprint for Emerging Markets*; The World Bank: Washington, DC, USA, 2019.
13. Agyekum, K.; Opoku, A.; Oppon, A.J.; Opoku, D.-G.J. Obstacles to green building project financing: An empirical study in Ghana. *Int. J. Constr. Manag.* **2022**, *22*, 2922–2930. [CrossRef]
14. Debrah, C.; Chan, A.P.C.; Darko, A. Green finance gap in green buildings: A scoping review and future research needs. *Build. Environ.* **2022**, *207*, 108443. [CrossRef]
15. Zhang, M.; Lian, Y.; Zhao, H.; Xia-Bauer, C. Unlocking green financing for building energy retrofit: A survey in the western China. *Energy Strategy Rev.* **2020**, *30*, 100520. [CrossRef]
16. Mielke, J. Signals for 2 C: The influence of policies, market factors and civil society actions on investment decisions for green infrastructure. *J. Sustain. Financ. Investig.* **2019**, *9*, 87–115. [CrossRef]
17. Addae, B.A.; Zhang, L.; Zhou, P.; Wang, F. Analyzing barriers of Smart Energy City in Accra with two-step fuzzy DEMATEL. *Cities* **2019**, *89*, 218–227. [CrossRef]
18. Negash, Y.T.; Hassan, A.M.; Tseng, M.-L.; Wu, K.-J.; Ali, M.H. Sustainable construction and demolition waste management in Somaliland: Regulatory barriers lead to technical and environmental barriers. *J. Clean. Prod.* **2021**, *297*, 126717. [CrossRef]
19. Lin, K.-P.; Tseng, M.-L.; Pai, P.-F. Sustainable supply chain management using approximate fuzzy DEMATEL method. *Resour. Conserv. Recycl.* **2018**, *128*, 134–142. [CrossRef]
20. Debrah, C.; Chan, A.P.C.; Darko, A.; Ries, R.J.; Ohene, E.; Tetteh, M.O. Driving factors for the adoption of green finance in green building for sustainable development in developing countries: The case of Ghana. *Sustain. Dev.* **2024**, *32*, 6286–6307. [CrossRef]
21. Hallowell, M.R.; Gambatese, J.A. Qualitative Research: Application of the Delphi Method to CEM Research. *J. Constr. Eng. Manag.* **2010**, *136*, 99–107. [CrossRef]
22. Giri, B.C.; Molla, M.U.; Biswas, P. Pythagorean fuzzy DEMATEL method for supplier selection in sustainable supply chain management. *Expert Syst. Appl.* **2022**, *193*, 116396. [CrossRef]
23. Zadeh, L.A. Information and control. *Fuzzy Sets* **1965**, *8*, 338–353.
24. Petrudi, S.H.H.; Ghomi, H.; Mazaheriasad, M. An Integrated Fuzzy Delphi and Best Worst Method (BWM) for performance measurement in higher education. *Decis. Anal. J.* **2022**, *4*, 100121. [CrossRef]
25. G20 Green Finance Study Group. G20 Green Finance Synthesis Report. September, 2016. Available online: https://www.g20.utoronto.ca/2018/g20_sustainable_finance_synthesis_report.pdf (accessed on 3 September 2025).
26. Qadri, H.M.U.D.; Ali, H.; Abideen, Z.U.; Jafar, A. Mapping the Evolution of Green Finance Research and Development in Emerging Green Economies. *Resour. Policy* **2024**, *91*, 104943. [CrossRef]
27. Gholipour, H.F.; Arjomandi, A.; Yam, S. Green property finance and CO_2 emissions in the building industry. *Glob. Financ. J.* **2022**, *51*, 100696. [CrossRef]

28. Sachs, J.D.; Woo, W.T.; Yoshino, N.; Taghizadeh-Hesary, F. *Why Is Green Finance Important?* Social Science Research Network: Rochester, NY, USA, 2019. [CrossRef]
29. Wang, W.; Tian, Z.; Xi, W.; Tan, Y.R.; Deng, Y. The influencing factors of China's green building development: An analysis using RBF-WINGS method. *Build. Environ.* **2021**, *188*, 107425. [CrossRef]
30. Taghizadeh-Hesary, F.; Yoshino, N. The way to induce private participation in green finance and investment. *Financ. Res. Lett.* **2019**, *31*, 98–103. [CrossRef]
31. Kukah, A.S.K.; Xiaohua, J.; Osei-Kyei, R.; Perera, S. How carbon trading contributes to reduction in emission of greenhouse gases: A narrative literature review. *J. Facil. Manag.* **2024**, *ahead-of-print*. [CrossRef]
32. Kukah, A.S.K.; Jin, X.; Osei-Kyei, R.; Perera, S. Theoretical framework for carbon trading in the built environment. *J. Eng. Des. Technol.* **2024**, *ahead-of-print*. [CrossRef]
33. Agyekum, K.; Goodier, C.; Oppon, J.A. Key drivers for green building project financing in Ghana. *Eng. Constr. Archit. Manag.* **2021**, *29*, 3023–3050. [CrossRef]
34. Christensen, P.H.; Robinson, S.; Simons, R. Institutional investor motivation, processes, and expectations for sustainable building investment. *Build. Res. Inf.* **2021**, *50*, 276–290. [CrossRef]
35. Lee, S.; Lee, B.; Kim, J.; Kim, J. A Financing Model to Solve Financial Barriers for Implementing Green Building Projects. *Sci. World J.* **2013**, *2013*, 240394. [CrossRef]
36. Siew, R.Y.J. Alternative framework for assessing sustainable building funds: Green Building Fund. *Build. Res. Inf.* **2015**, *43*, 160–169. [CrossRef]
37. Alabady, H.S.; Abu Ghazaleh, S.N. Green building insurance. *JL Pol'y Glob.* **2017**, *66*, 137.
38. An, X.; Pivo, G. Green Buildings in Commercial Mortgage-Backed Securities: The Effects of LEED and Energy Star Certification on Default Risk and Loan Terms. *Real Estate Econ.* **2020**, *48*, 7–42. [CrossRef]
39. Dugo, I. Finance Embraces Sustainability: An Empirical Analysis of the Financial Performances of ETFs Investing in Sustainable Real Estate and Green Building. 2021. Available online: http://dspace.unive.it/handle/10579/20153 (accessed on 22 July 2024).
40. Rocca, R.L.; Baietti, A.; Bank, T.W. *Green Infrastructure Finance: Framework Report*; World Bank Publications: Herndon, VA, USA, 2012.
41. Africa, F.S. Feasibility Study for Development of a Green Bonds Market in Ghana. 2021. Available online: https://www.fsdafrica.org/publication/feasibility-study-for-development-of-a-green-bonds-market-in-ghana/ (accessed on 19 April 2022).
42. Chan, A.P.C.; Darko, A.; Olanipekun, A.O.; Ameyaw, E.E. Critical barriers to green building technologies adoption in developing countries: The case of Ghana. *J. Clean. Prod.* **2018**, *172*, 1067–1079. [CrossRef]
43. Glemarec, Y.; Bardoux, P.; Roy, T. The Role of Policy-Driven Institutions in Developing National Financial Systems for Long-Term Growth. 2015. Available online: https://www.unep.org/resources/report/role-policy-driven-institutions-developing-national-financial-systems-long-term (accessed on 3 September 2025).
44. Falcone, P.M.; Sica, E. Assessing the Opportunities and Challenges of Green Finance in Italy: An Analysis of the Biomass Production Sector. *Sustainability* **2019**, *11*, 517. [CrossRef]
45. Dmuchowski, P.; Dmuchowski, W.; Baczewska-Dąbrowska, A.H.; Gworek, B. Green economy–growth and maintenance of the conditions of green growth at the level of polish local authorities. *J. Clean. Prod.* **2021**, *301*, 126975. [CrossRef]
46. Hamel, G. What Are Financial Barriers? Sapling. 2021. Available online: https://www.sapling.com/7952653/financial-barriers (accessed on 12 July 2021).
47. Donastorg, A.D.; Renukappa, S.; Suresh, S. Financing renewable energy projects in the Dominican Republic: An empirical study. *Int. J. Energy Sect. Manag.* **2021**, *16*, 95–111. [CrossRef]
48. Deschryver, P.; De Mariz, F. What future for the green bond market? How can policymakers, companies, and investors unlock the potential of the green bond market? *J. Risk Financ. Manag.* **2020**, *13*, 61. [CrossRef]
49. Yamahaki, C.; Felsberg, A.V.; Köberle, A.C.; Gurgel, A.C.; Stewart-Richardson, J. Structural and specific barriers to the development of a green bond market in Brazil. *J. Sustain. Financ. Investig.* **2020**, 389–406. [CrossRef]
50. Shishlov, I.; Morel, R.; Cochran, I. Beyond transparency: Unlocking the full potential of green bonds. *Inst. Clim. Econ.* **2016**, 1–28. Available online: https://www.i4ce.org/en/publication/unlocking-the-potential-of-green-bonds/ (accessed on 3 September 2025).
51. Zheng, G.-W.; Siddik, A.B.; Masukujjaman, M.; Fatema, N.; Alam, S.S. Green Finance Development in Bangladesh: The Role of Private Commercial Banks (PCBs). *Sustainability* **2021**, *13*, 795. [CrossRef]
52. Hafner, S.; Jones, A.; Anger-Kraavi, A.; Pohl, J. Closing the green finance gap—A systems perspective. *Environ. Innov. Soc. Transit.* **2020**, *34*, 26–60. [CrossRef]
53. Setyowati, A.B. Mitigating Energy Poverty: Mobilizing Climate Finance to Manage the Energy Trilemma in Indonesia. *Sustainability* **2020**, *12*, 1603. [CrossRef]
54. Nelson, D.; Pierpont, B. *The Challenge of Institutional Investment in Renewable Energy*; Climate Policy Initiative: San Francisco, CA, USA, 2013.

55. Taghizadeh-Hesary, F.; Zakari, A.; Alvarado, R.; Tawiah, V. The green bond market and its use for energy efficiency finance in Africa. *China Financ. Rev. Int.* **2022**, *12*, 241–260. [CrossRef]
56. HKSAR. *Green Bond Report 2021*; Hong Kong Special Administrative Region of the People's Republic of China: Hong Kong, China, 2021; Volume 34.
57. Wyman, O. *Accelerating Emerging Capital Markets Development, Corporate Bond Markets*; World Economic Forum: Geneva, Switzerland, 2015; pp. 1–60.
58. Setyowati, A.B. Governing sustainable finance: Insights from Indonesia. *Clim. Policy* **2020**, *23*, 108–121. [CrossRef]
59. Darko, A.; Zhang, C.; Chan, A.P.C. Drivers for green building: A review of empirical studies. *Habitat Int.* **2017**, *60*, 34–49. [CrossRef]
60. Berensmann, K.; Lindenberg, N.; Finance, G. *Challenges and Policy Recommendations*; Social Science Research Network: Rochester, NY, USA, 2016. Available online: https://papers.ssrn.com/abstract=2881922 (accessed on 2 July 2021).
61. Kann, S. Overcoming barriers to wind project finance in Australia. *Energy Policy* **2009**, *37*, 3139–3148. [CrossRef]
62. Clark, R.; Reed, J.; Sunderland, T. Bridging funding gaps for climate and sustainable development: Pitfalls, progress and potential of private finance. *Land Use Policy* **2018**, *71*, 335–346. [CrossRef]
63. Chen, D.B. Chapter 15—Central Banks and Blockchains: The Case for Managing Climate Risk with a Positive Carbon Price. In *Transforming Climate Finance and Green Investment with Blockchains*; Marke, A., Ed.; Academic Press: Cambridge, MA, USA, 2018; pp. 201–216. [CrossRef]
64. Toxopeus, H.; Polzin, F. Reviewing financing barriers and strategies for urban nature-based solutions. *J. Environ. Manag.* **2021**, *289*, 112371. [CrossRef]
65. England, B.O. Transition in Thinking: The Impact of Climate Change on the UK Banking Sector. 2018. Available online: https://www.bankofengland.co.uk/prudential-regulation/publication/2018/transition-in-thinking-the-impact-of-climate-change-on-the-uk-banking-sector (accessed on 1 March 2022).
66. Cheung, H.; Baumber, A.; Brown, P.J. Barriers and enablers to sustainable finance: A case study of home loans in an Australian retail bank. *J. Clean. Prod.* **2022**, *334*, 130211. [CrossRef]
67. Schuetze, F. *Transition Risks and Opportunities in Residential Mortgages*; Social Science Research Network: Rochester, NY, USA, 2020. [CrossRef]
68. Paranque, B.; Revelli, C. Ethico-economic analysis of impact finance: The case of Green Bonds. *Res. Int. Bus. Financ.* **2019**, *47*, 57–66. [CrossRef]
69. Negash, Y.T.; Hassan, A.M.; Lim, M.K.; Tseng, M.-L. Sustainable supply chain finance enablers under disruption: The causal effect of collaboration value innovation on sustainability performance. *Int. J. Logist. Res. Appl.* **2024**, *28*, 449–473. [CrossRef]
70. Rowe, G.; Wright, G. The Delphi technique as a forecasting tool: Issues and analysis. *Int. J. Forecast.* **1999**, *15*, 353–375. [CrossRef]
71. Adler, M.; Ziglio, E. *Gazing into the Oracle: The Delphi Method and Its Application to Social Policy and Public Health*; Jessica Kingsley Publishers: London, UK, 1996.
72. Akdag, H.; Kalaycı, T.; Karagöz, S.; Zülfikar, H.; Giz, D. The evaluation of hospital service quality by fuzzy MCDM. *Appl. Soft. Comput.* **2014**, *23*, 239–248. [CrossRef]
73. Wu, W.-W.; Lee, Y.-T. Developing global managers' competencies using the fuzzy DEMATEL method. *Expert Syst. Appl.* **2007**, *32*, 499–507. [CrossRef]
74. Dalkey, N.; Brown, B.; Cochran, S. Use of self-ratings to improve group estimates: Experimental evaluation of delphi procedures. *Technol. Forecast.* **1970**, *1*, 283–291. [CrossRef]
75. Rejeb, A.; Rejeb, K.; Keogh, J.G.; Zailani, S. Barriers to Blockchain Adoption in the Circular Economy: A Fuzzy Delphi and Best-Worst Approach. *Sustainability* **2022**, *14*, 3611. [CrossRef]
76. Petrudi, S.H.H.; Tavana, M.; Abdi, M. A comprehensive framework for analyzing challenges in humanitarian supply chain management: A case study of the Iranian Red Crescent Society. *Int. J. Disaster Risk Reduct.* **2020**, *42*, 101340. [CrossRef]
77. Kats, G. *Green Building Costs and Financial Benefits*; Massachusetts Technology Collaborative: Boston, MA, USA, 2003.
78. Tolliver, C.; Keeley, A.R.; Managi, S. Drivers of green bond market growth: The importance of Nationally Determined Contributions to the Paris Agreement and implications for sustainability. *J. Clean. Prod.* **2020**, *244*, 118643. [CrossRef]
79. Wang, J.; Chen, X.; Li, X.; Yu, J.; Zhong, R. The market reaction to green bond issuance: Evidence from China. *Pac. Basin Financ. J.* **2020**, *60*, 101294. [CrossRef]
80. IFC. What You Need to Know About Green Loans, World Bank. 2021. Available online: https://www.worldbank.org/en/news/feature/2021/10/04/what-you-need-to-know-about-green-loans (accessed on 2 June 2022).
81. CBI. Green Securitisation: Unlocking Finance for Small-Scale Low Carbon Projects. Climate Bonds Initiative. 2018. Available online: https://www.climatebonds.net/resources/reports/green-securitisation-unlocking-finance-small-scale-low-carbon-projects (accessed on 12 July 2022).

82. Porumb, V.-A.; Maier, G.; Anghel, I. The impact of building location on green certification price premiums: Evidence from three European countries. *J. Clean. Prod.* **2020**, *272*, 122080. [CrossRef]
83. Febi, W.; Schäfer, D.; Stephan, A.; Sun, C. The impact of liquidity risk on the yield spread of green bonds. *Financ. Res. Lett.* **2018**, *27*, 53–59. [CrossRef]