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Green building certification and drivers of green premiums: a meta-regression analysis on global housing market

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Abstract

Purpose – Climate change has become a critical challenge, drawing attention to the need for sustainable practices in the built environment. Despite the recognised environmental benefits of green buildings (GBs), research on the economic value of GBs, especially in the housing sector, remains limited, with mixed results documented. To better comprehend the economic value of green residential buildings, this study aims to examine the consistent effects of GB certifications (GBCs) on housing markets and identify factors contributing to the documented mixed results.

Design/methodology/approach – This study applies a meta-regression analysis supplemented by the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol to synthesise findings from past literature in testifying to the existence of green housing (GH) effects and identifying drivers for the varied effects.

Findings – The meta-regression evidence exhibits consistent green premiums in housing markets. In addition, four principal influential factors governing GH premiums are identified, including certification characteristics, data attributes, model specifications and external considerations. The implications of these findings and their practical applications are also discussed.

Originality/value – As the first study to examine price premiums and the reasons for heterogeneous effects related to GB certifications in housing markets, this meta-regression analysis extends the body of knowledge in this research domain. The findings of this study enhance the understanding of the economic value of GH and provide policymakers with some practical guidance aligning with markets.

Keywords Green building certification, Green premium, Housing market, Market value, Meta-regression analysis, SPAR-4-SLR

Paper type Research paper

1. Introduction

With the increasing frequency of weather extremes and the rising global temperature (NOAA, 2023), climate change has garnered attention, being recognised as a critical challenge (Lin and Zhao, 2023). Acknowledging its complex and costly impacts (Hsiang *et al.*, 2017), the public and investors have paid growing interest to energy efficiency, net-zero, and Environmental, Social and Governance (ESG), particularly the environmental pillar (Lee and Liang, 2024). This focus extends to the built environment, which accounts for 30% of global energy consumption (UNEP, 2024) and offers substantial potential for carbon emission reductions (Wang *et al.*, 2024). Green buildings (GBs), which are defined as "the creation and responsible management of a healthy built environment based on resource efficient and ecological principles" (Kibert, 2016), are vital for the built environment as they reduce environmental impact, enhance energy efficiency, conserve resources, and promote healthier living spaces (Lee *et al.*, 2022). Being expected to play increasingly essential roles in fighting climate change and maintaining sustainability, the voice of the demand for green witnesses rapid growth

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(Mesthrige Jayantha and Sze Man, 2013); and a series of GB certification (GBC) systems have been developed and widely adopted at a global scale (See Table 1 for all the abbreviations).

Table 1. List of abbreviations

Abbreviations	
GB	Green building
GBC	Green building certification
SPAR-4-SLR	Scientific Procedures and Rationales for Systematic Literature Reviews
GH	Green housing
ESG	Environmental, social and governance
WLS	Weighted least square
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
CGBL	Chinese green building label
GM	Green mark
LEED	Leadership in energy and environmental design
EEWH	Ecology, energy saving, waste reduction, and health
TGBP	Tokyo green building program
OLS	Ordinary least squares
DID	Difference-in-difference
GDP	Gross domestic product
PET	Precision-effect testing
BREEAM	Building research establishment environmental assessment method

Source(s): Authors' own work

As the environmental benefits of GBs have been deeply explored and understood, many scholars have sought to answer the question of the market value of the green characteristics or the advanced green performance of certified buildings. These investigations primarily focused on commercial property sectors (Eichholtz *et al.*, 2010; Fuerst and McAllister, 2011), while the largest sector of housing (Savills, 2021) seems to be lagging behind, receiving relatively little attention from scholars (Fuerst and Shimizu, 2016). In addition, mixed results regarding the impact of GBCs on housing prices, ranging from negative to positive, and with different magnitudes are documented. Most of the studies prove that certified green housing (GH) is associated with price appreciations (ranging from 0.8% to 54.6%) (e.g. Deng *et al.*, 2012; see the literature review for details), which can be attributed to the increasing demand for eco-friendly living. However, discounts for green-certified housing are also reported by several studies (e.g. Rahman, 2014), suggesting the value of green certifications might not yet be fully recognised by the community as an effort to promote sustainable and environmentally resilient cities. The inconsistent results raise the questions of (1) whether green premiums exist, (2) what factors contribute to these mixed outcomes, and (3) what is the theoretical explanation for the green premium, if any?

Past literature has attempted to explain the variations in green premiums or discounts through comparative studies and submarket analyses, but a consensus has not been reached. Although a few meta-analyses have sought to address these questions, they often combined residential and commercial markets, resulting in diverse outcomes. Different from commercial property markets, having clear mechanisms of why GBCs are valued, the smaller proportion of professional or institutional investors in housing markets results in a lack of disclosure and understanding of the green value (Fuerst and Shimizu, 2016). Additionally, the residential market's susceptibility to policies, regulations, and inefficiencies complicates the measurement of green value (Fuerst and Shimizu, 2016). Therefore, to better understand the price effect of GBCs and drivers of the variations in the housing market, a more focused study is needed. Aiming at answering the above-identified three research questions with a focus on housing market, a meta-regression analysis is conducted supplemented by the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol to recruit observations and identify differences among studies, and a theory explanation is developed by positing a hypothesis linking the relationship between GBCs and housing price variations. Given that the estimated effects reported by previous research cannot be seen as a global effect without considering the study-design characteristics such as study regions, study period, and methods applied for the analysis (Fizaine *et al*., 2018), this study aims to determine a consistent trend in the GBC effects and to explain the variations of GBC effects from the study-design perspective. Additionally, the theoretical rationale for GBCs' impact on housing prices is often overlooked.

This research makes several contributions to the literature on GH premiums and sustainable buildings. Firstly, to the best of our knowledge, this is the first study applying meta-regression analysis to examine the price effects of GBCs in housing markets. By standardising and integrating the diverse results from multiple studies, meta-regression analysis allows researchers to determine consistent effects across different datasets (Hwang, 2018; Gumz and Fettermann, 2022), deliver a comprehensive quantitative conclusion and confirm the existence of GH premium for the first time. Furthermore, by exploring how sample and data characteristics, model specifications, and contextual elements influence green premiums, this research offers valuable guidance on conducting empirical analysis to quantify green premiums. It can also be referred to as a benchmark for comparing results across studies. This is particularly valuable in fields like GBs and sustainability, where creating a resilient built environment requires understanding how various factors contribute to long-term environmental and economic benefits (Yau, 2012).

Secondly, this study pioneers using the newly developed SPAR-4-SLR systematic review method as a supplemental approach to meta-regression analysis. This innovative combination enhances the rigour and transparency of the literature review process, ensuring that decisions are well-justified and scientifically grounded. The study improves the quality and reliability of research findings by setting a new standard for conducting systematic literature reviews in this field. Thirdly, the study goes beyond empirical analysis by developing a hypothesis that connects the theoretical underpinnings of GBCs with housing market dynamics. It provides a deeper understanding of the mechanisms driving the influence of GBs on housing prices, offering compelling evidence to validate Quigley and Rubinfeld (1989)'s demand for comfort theory. This highlights the importance of often-overlooked unobservable attributes in shaping housing market behaviour. The findings contribute to academic discourse and offer practical guidance for policymakers in promoting environmental policies and regulations that align with market realities.

The remainder of the paper is structured as follows. Section 2 reviews the literature on past studies investigating GH premiums and previous meta-regression analyses exploring the green and energy premiums for housing sectors. Section 3 develops a hypothesis with a background in theory to link the relationship between GBCs and housing markets. Section 4 discusses the methods applied in this study. The findings are reported in Section 5, and the suggestions and policy implications are discussed in the next section. The last section concludes the paper.

2. Literature review

Research on testifying GB premiums and explaining GB premium variations has been limited, with only a few meta-analyses and meta-regression studies conducted. Two meta-analyses confirm the existence of premiums in the real estate market (Brown and Watkins, 2015; Dalton and Fuerst, 2018), while three meta-regression studies explain mixed results (Ankamah-Yeboah and Rehdanz, 2014; Fizaine *et al*., 2018; Cespedes-Lopez *et al*., 2019). Notably, no study specifically focused on GBCs in the residential real estate market. Previous studies usually combined residential and commercial real estate, but it is crucial to split these two markets due to differing buyer behaviours (Lee, 2017; Bangura and Lee, 2022; Bangura and Lee, 2024). Furthermore, past studies have primarily focused on energy-oriented certifications, often overlooking the broader sustainability measures incorporated in GBCs, which assess various aspects of a property's entire lifecycle (Chen *et al*., 2014). While energy performance remains central to GBCs (Shan and Hwang, 2018), these certifications also consider other factors that may incur additional costs or lead to shorter lifespans, thus potentially affecting green premiums (Deng and Wu, 2014; Zhang *et al.*, 2017; Jeddi Yeganeh *et al.*, 2019). In contrast, energy savings are more readily valued due to their direct impact on energy bills (Fuerst *et al.*, 2016; Wahlström, 2016). Thus, further research is needed to examine how the housing market values GBCs.

Brown and Watkins (2015) conducted a meta-analysis of 17 studies on residential GH, finding an average 4.3% green premium for properties with building certifications, including both energy-focused and GBCs. Dalton and Fuerst (2018) expanded the analysis to 42 studies, confirming a 6% and 7.6% price appreciation for rental and sale properties in residential, commercial, and hotel sectors. Subgroup analyses report differences in price premiums between different sectors, emphasising the importance of separating these markets. Ankamah-Yeboah and Rehdanz (2014) looked at 20 papers providing international evidence for the sale and rental price premium of residential and commercial properties with energy performance certifications, finding that study location and certification type influence premiums. Cespedes-Lopez *et al.* (2019) focused on energy performance-related certifications, finding that premiums vary across continents. Fizaine *et al.* (2018) examined both energy-oriented and comprehensive GBCs, confirming that all green certifications led to price appreciation, with variations based on study regions, types, and methods.

While past meta-analyses have established the existence of green premiums in the property market, they do not explain the mixed results for GB premiums or discounts. Meta-regression analyses have identified some reasons for these mixed results but have not reached a consensus on influential factors, often documenting opposite effects for significant variables such as certification type, study region, estimation method, and study period. These inconsistencies may stem from previous studies pooling residential and commercial properties or combining energy-focused certifications with GBCs. Given the unique characteristics of housing markets and GBCs, more targeted research is necessary, especially in the housing sector, where green premiums are underexplored (Chen *et al.*, 2014; Lee, 2017). This gap in understanding the mixed results of green premiums remains largely unanswered, despite its significance in the real estate sector (Fuerst *et al.*, 2016; Savills, 2021). Moreover, previous studies did not incorporate the SPAR-4-SLR systematic review method as a supplementary approach to meta-regression analysis, although this innovative method enhances the rigour and transparency of the literature review process, ensuring that research decisions are well-grounded and scientifically justified (Paul *et al.*, 2021). Lastly, prior studies have not provided a clear theoretical explanation for the relationship between GBCs and housing prices (Khoo *et al.*, 2022). Therefore, this study aims to investigate the influential factors affecting GBC premiums with a focus on the housing market through a meta-regression analysis supported by the SPAR-4-SLR protocol and supplement past literature with theoretical explanations of the potential effects of GBC on housing prices.

3. Hypothesis development

As discussed by Mesthrige Jayantha and Sze Man (2013) and Chuweni *et al.* (2024), homebuyers mainly focus on locations and observable housing attributes when making purchasing decisions, while the less observable “brand-name” attributes of GBCs (Hui and Yu, 2020) may not be aware by homebuyers (Kahn and Kok, 2014). This raises the question of why GBs, which may not exhibit distinguishable performance, command a price premium. A set of hypotheses is developed in this section, providing a theoretical explanation for the implicit relationship between GBCs and property prices.

Housing, as a type of good with a combination of attributes, its price is usually measured by a series of features related to the dwelling. In addition to these housing features showing observable benefits, Quigley and Rubinfeld (1989) suggest that those unobservable attributes serve as inputs in improving the comfort of the residences and significantly affect housing prices. Certified GBs are evaluated based on sustainability measures that align with these unobservable attributes discussed by Quigley and Rubinfeld (1989), improving indoor and outdoor environmental quality and energy efficiency (Kahn and Kok, 2014; Fang *et al*., 2018). The Demand for Comfort Theory posits that consumers prioritise physical and psychological comfort when making purchasing decisions, highlighting the importance of comfort and quality-of-life considerations in economic models of housing demand (Quigley and Rubinfeld, 1989). Therefore, although GBCs may not be known by potential homebuyers, the features linked with GBCs, reflected in the attributes of the final goods of comfort, attract homebuyers to pay a price premium. Thus, the hypothesis 1a is proposed as follows:

H1a. GBCs are valued by homebuyers as the comfort features related to GBCs are measured, supported by Quigley and Rubinfeld (1989)'s demand for comfort theory.

On the other hand, despite the growing emphasis on sustainability, market responses to GBCs can be dynamic due to the market for lemons problem proposed by Akerlof (1978) based on the information asymmetry theory (Vickrey, 1961). Asymmetry information is a common problem in real estate markets, especially those emerging markets like the GH market (Wu *et al*., 2019; Jiang *et al*., 2024) where homebuyers are not fully aware of the green features and associated benefits even if the property is certified by GBC. The information asymmetry is associated with inefficiency transactions and underestimation of the green features (Chan *et al*., 2017; Xu *et al*., 2022), which leads to the market for lemons problems, that GH may be undervalued because buyers cannot distinguish them from properties without those green features. Therefore, under Akerlof and Vickrey's information asymmetry theory, Hypothesis 1b is posited as follows:

H1b. Homebuyers may not fully value GBCs, as GBCs' features could be undervalued due to the market for lemons problem, as supported by information asymmetry theory.

4. Methodology

To testify to the existence of GH premiums and identify factors contributing to the mixed results among GH premiums, a meta-regression analysis [1], which serves as an effective tool to investigate impactful factors in explaining the differences among existing literature (Zheng and Lee, 2025), is conducted. Unlike meta-analysis, which is originally designed for integrating findings from medical experiments, meta-regression analysis with different focuses is more commonly used in empirical-based economics studies (Stanley and Doucouliagos, 2012), where controlling all influential factors is impossible for observational data (Stanley *et al*., 2013). Furthermore, meta-regression analysis can test and correct for the potential publication selection effects that are often detected in empirical studies, identifying the genuine effect of an economic phenomenon (Stanley, 2008). Therefore, meta-regression analysis is the most appropriate method to explore factors influencing GH premiums without being affected by the potential publication selection bias. The analysis involves four key steps: recruiting observations, coding meta-data, testing genuine effects, and identifying influential factors (Wang *et al*., 2021). To enhance the reliability and eliminate estimation bias, this study integrates the SPAR-4-SLR for recruiting observations to ensure transparency and rigour of data collection and applies the weighted least squares (WLS) regression for addressing heteroscedasticity and publication selection bias. The following section will provide a detailed description of the complete research process.

Step 1: Recruiting observations-SPAR-4-SLR protocol

The SPAR-4-SLR [2] protocol developed by Paul *et al*. (2021) is employed to obtain observations for the meta-dataset. Unlike Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), SPAR-4-SLR expends the PRISMA flow with more detailed guidance on conducting a review for specific research domains and further provides justifications for the rationales from both logical and practical perspectives (Paul *et al*., 2021), which helps to make more rigours decisions for each step of the entire process. Figure 1 explains the three stages and six substages of the SPAR-4-SLR protocol.

In the “assembling,” stage, the research domain is defined as the value of the GBCs reflected in housing sale prices, and two research questions are specified. To gather comprehensive studies with sufficient sample size in this emerging research domain, instead of only focusing on journal articles, several types of publications are considered by this study, including journal articles, conference papers, working reports, and theses. However, the quality and reliability of the study will be further assessed, and peer-reviewed studies are preferred. The “acquisition” substage employs Web of Science, Scopus, and Google Scholar

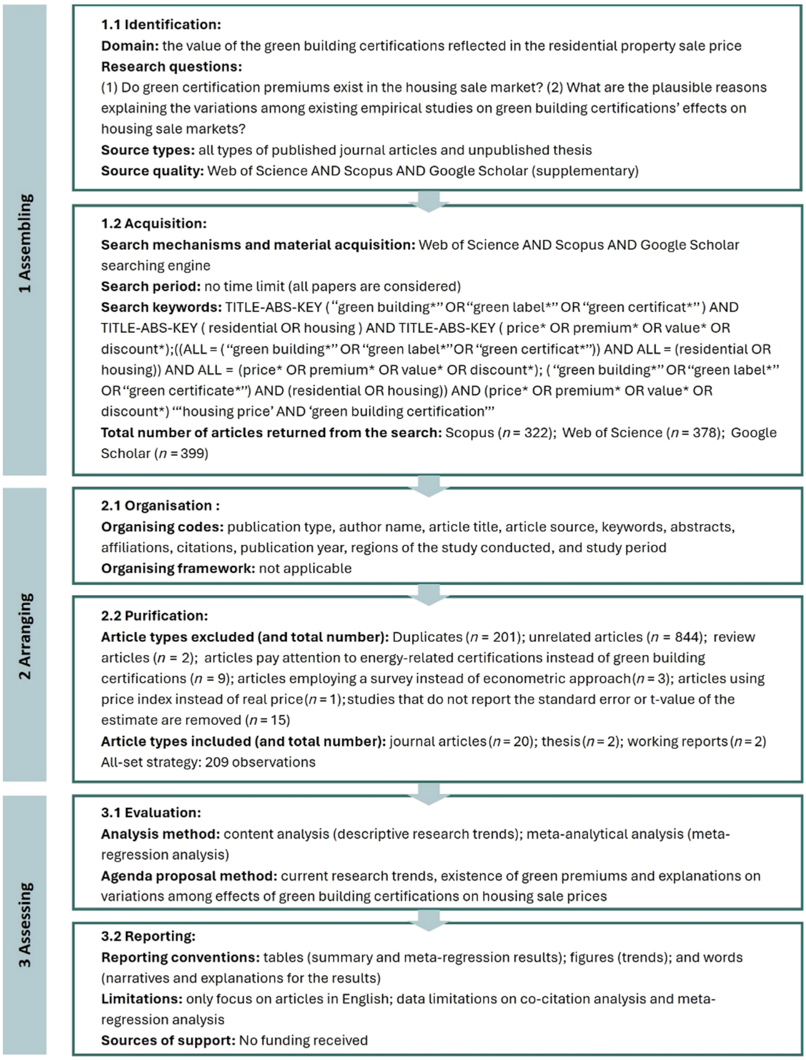

Figure 1. Summary of the three steps in SPAR-4-SLR. Source: Authors’ own work

databases. Following the keywords searching strategies without setting time limitations, 1,099 records were returned and were exported to an Excel file for further analysis. During the "arranging" stage, all records are organised and purified; specifically, 201 duplicates and 844 unrelated records, as well as nine papers on energy-related certifications, are removed. Only econometric models based on actual price data are considered to maintain sample homogeneity, leading to the removal of 4 additional papers. Additional screening at the observation level is required for meta-regression analysis. Studies must report the standard error or t-value measure publication bias; 15 papers are excluded. Following Wang *et al.* (2021)'s work, the all-set strategy is applied, to include all estimates in the meta-dataset, which helps to identify differences within and between studies. The final dataset comprises 209 observations from 24 papers, which is generally an acceptable sample size for detecting reliable and meaningful conclusions with sufficient statistical power (Bruns, 2017; Glisic *et al.*, 2023). At the "assessing" stage, the dataset is analysed with meta-regression and supplemented by content analysis to identify some research trends for coding meta-data. Results are presented through tables, figures, and narrative explanations for clarity. Limitations include the restriction to English-language papers and data limitation of meta-regression analysis.

Step 2: Coding meta-data

Coding meta-data aims to identify differences among studies and observations, and it is the crucial and the hardest part of a meta-regression analysis (Stanley and Doucouliagos, 2012). This process should be comprehensive and insightful, covering factors related to data focus, model construction, and method selection. In addition, previous literature also highlights that scenario and contextual factors also exert impacts (Chen *et al.*, 2019; Chaikumbung, 2023). To identify differences comprehensively, step 2 analyses research trends and characteristics at both study and observational levels and develops a conceptual framework to summarise and organise all the characteristics identified.

4.1 Study-level summary and trends

Table 2 summarises the 24 studies included in the meta-dataset with the following details: study region, study period, certifications and property focused by the study, as well as the major results reported by the study. Firstly, the time span of this research domain spans over 10 years (2010–2024), with data covering an even longer span of 22 years (from 2000–2022). As awareness of climate change grows and governments' attitude shifts over time, the GBCs' effects may also vary (Brown and Watkins, 2015; Aroul and Rodriguez, 2017). Another characteristic of the data is single-year data or multiple-year data. Without panel data to account for year effects, the estimated effects represent the average green premiums over the entire period, potentially overestimating or underestimating the impact. Secondly, the cases cover eight countries across America, Asia, and Europe, revealing heterogeneous effects of green premiums influenced by diverse regulatory and socioeconomic contexts (Ankamah-Yeboah and Rehdanz, 2014; Fizaine *et al.*, 2018). Additionally, twelve certification systems, both mandatory and voluntary, are examined, with policies affecting the perceived value of GBs (Lee *et al.*, 2022).

4.2 Observational-level features

To maintain sample homogeneity, studies remaining in the meta-dataset employ the Hedonic Price Model, which is a commonly applied economic framework that assumes that housing price is made up of a bundle of implicit prices of individual housing attributes (Rosen, 1974). In this case, at the observation level, differences arise in model construction and econometric method selection. Model construction varies in control variables and functional forms. Firstly, variations in control variables, particularly regarding "unit" and "building" characteristics, are crucial when applying the hedonic model to avoid biased outcomes (Cropper *et al.*, 1988).

Table 2. Summary of the research in this domain

Reference	Study region	Study period	Certification	Certification type	Property type	Effect direction	Major findings
Chuweni *et al*. (2024)	Malaysia	2014–2022	Green Building Index	V	M	+	16.2%–43%
Jiang *et al*. (2021)	China	2018	Chinese Green Building Label (CGBL)	V	M	+	4.46%–11.7%
Jeddi Yeganeh *et al*. (2019)	USA	2000–2019	EarthCraft	V	S	+	14%–16.9%
Liao and Zhao (2019)	Singapore	2002–2015	Green Mark (GM)	C	M	+	1.8%–5.5%
Fang *et al*. (2018)	China	2012–2014	Green Building Evaluation Label	V	M	+	1.32%–17.82%
Zhang *et al*. (2017)	China	2013	CGBL	V	M	+	4.25%–8.34%
Kempf (2016)	Switzerland	2009–2016	Minergie	V	M & S	+	21.34%–21.5%
Couch *et al*. (2015)	USA	2007–2013	Leadership in Energy and Environmental Design (LEED)	V	M	+	9%
Depratto (2015)	Canada	2006–2014	LEED	V	M	+	5.7%–14.9%
Freybote *et al*. (2015)	USA	2011	LEED	V	M	+	3.8%
Chen *et al*. (2014)	Taiwan	2008–2012	Ecology, Energy Saving, Waste Reduction, and Health (EEWH)	V	M	+	3.54%–5.84%
Deng and Wu (2014)	Singapore	2000–2010	GM	C	M	+	1.3%–14.5%
Mesthrige Jayantha and Sze Man (2013)	Hong Kong	2003–2008	Hong Kong Building Environmental Assessment Method and Hong Kong Green Building Council Award	V	M	+	3.4%–6.4%
Deng *et al*. (2012)	Singapore	2000–2010	GM	C	M	+	0.8%–21.12%
Huang (2022)	Taiwan	2012–2017	EEWH	V	M	mixed	−0.6%–5.9%
Tsai (2022)	Taiwan	2013–2021	EEWH	V	M	mixed	−112~5441 New Taiwan Dollar (TWD)/m^2
Dell'Anna and Bottero (2021)	Singapore	2013–2017	GM	C	M	mixed	−5.9%–48.7%
Aroul and Rodriguez (2017)	USA	2002–2009	Local residential green building program	C	M & S	mixed	−0.76%–2.91%
Fuerst and Shimizu (2016)	Japan	2004–2011	TGBP	C	M	mixed	−1.32%–5.89%
Kahn and Kok (2014)	USA	2007–2012	LEED and Green Point	V	S	mixed	−2%–4.1%
Yoshida and Sugiura (2015)	Japan	2002–2009	Tokyo Green Building Program (TGBP)	C	M	mixed	−5.63%–26.26%
Yuan *et al*. (2022)	China	2018	CGBL	V	M	–	−10.31%~-38.98%
Yoshida and Sugiura (2015)	Japan	2002–2009	TGBP	C	M	–	−4.2%~-12.2%
Rahman (2014)	Canada	2013	LEED	V	S	–	−1.08%~-2.48%

Note(s): C refers to compulsory, V refers to voluntary, M refers to multifamily, S refers to single-family,/refers to not specified property type, + refers to positive and – refers to negative
Source(s): Authors' own work

Secondly, the dataset reveals two functional forms in estimations: semi-log and linear. While semi-log can address extreme values, it may introduce data bias (Osborne, 2008); whereas linear models minimise mean percentage error but are sensitive to extreme values (Cropper *et al.*, 1988). Moreover, various econometric methods have been applied including ordinary least squares (OLS), difference-in-difference (DID) and spatial models (Fesselmeyer, 2018; Dell'Anna and Bottero, 2021). However, advanced models offer more powerful controls for other potential impacts while being very sensitive to the selection of treatment groups and spatial outliers (Anselin, 2003). Besides, GBC systems typically have multiple levels based on sustainable performance, with higher levels indicating better performance. Some studies have reported differences in the magnitude of the effects among levels (Deng *et al.*, 2012; Jiang *et al.*, 2021; Tsai, 2022); however, the direct comparison does not confirm statistical significance.

4.3 Other potential factors affecting the green premiums

Apart from the basic factors identified from the original studies, some insightful factors can be recognised by understanding other factors that are influential to GH premiums. The purchasing behaviour for GH is affected by a number of aspects (Zhang *et al.*, 2019). Key green features, showing tangible benefits, such as energy saving, water saving, soundproofing and high greenery ratio, are preferred by customers (Yau, 2012). Homebuyers' personal characteristics and psychological factors, including education level, marital status, and responsibility ascription, also play a role (Liu *et al.*, 2018; Wu *et al.*, 2022). Moreover, environmental awareness, shaped by public information and government attitudes, impacts green demand and willingness to pay (Zhang *et al.*, 2016; Yu *et al.*, 2019). Lastly, broad economic conditions are also key influential factors contributing to variations in green value (Portnov *et al.*, 2018).

4.4 Explanatory variables

Based on study features, characteristics, and other influential factors, three groups of differences are coded: sample and data factors, model and methodological factors, and contextual and scenario factors. Figure 2 illustrates the conceptual framework of these factors explaining variations in GH premiums; Table 3 defines each variable. Among these identified variables, most of the variables are dummy variables (except for the two contextual factors), which represent the absence of a particular characteristic and testify to whether the specific characteristic affects the estimated green premiums (Wooldridge, 2016).

Sample and data factors examine study characteristics and original data, including study period, property type, and publication year. A "multiple-year" dummy variable checks if long-term averages misestimate green premiums, while the publication year variable tracks GBC effects over time. A "property type-multifamily" variable isolates impact by property type. Model and methodological factors address model construction and methods. Dummy variables for "unit" and "building" test whether their omission causes overestimations, while "OLS" and "semi-log" dummies assess method and functional form effects. Scenario and contextual factors consider study context and certification types. Regional dummies ("Asia" and "Europe") highlight geographic disparities. Limited by data, environmental awareness (carbon emissions) and economic conditions gross domstic product (GDP) proxies gauge GH premium influences. The certification type and level variables assess their impacts.

Step 3: Precision-effect testing (PET)

To objectively understand an economic phenomenon, it is necessary to evaluate scientific knowledge unbiasedly (Stanley and Doucouliagos, 2012). However, the widely detected publication selection preference leads to a publication bias, which distorts findings and inflates effect sizes (Glass, 1981; Begg and Berlin, 1988; Stanley and Doucouliagos, 2012). Therefore, it is necessary to test the publication bias before conducting a meta-regression analysis and address the publication bias issue if it does exist (Stanley and Doucouliagos, 2012). A funnel

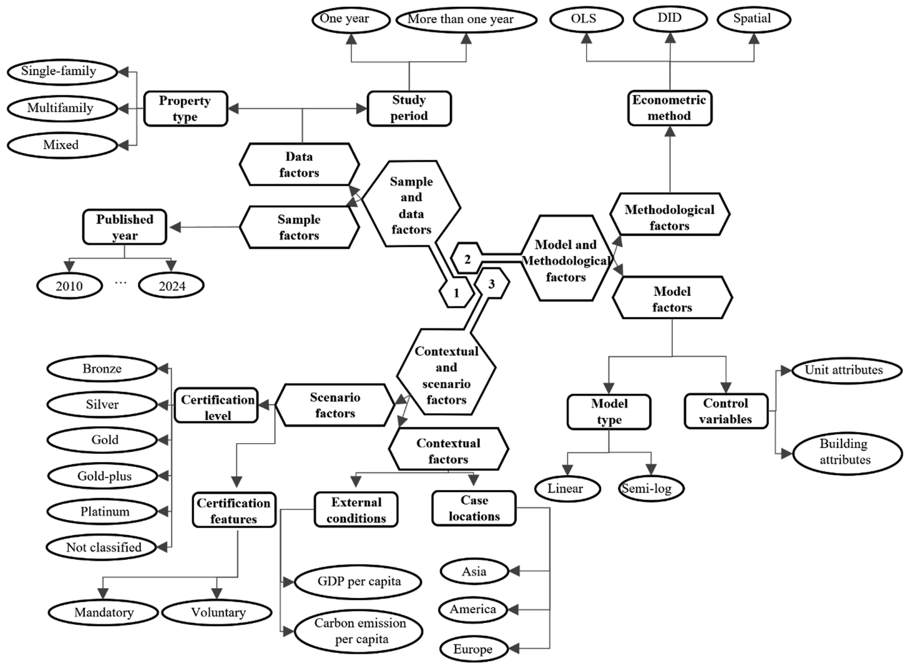

Figure 2. A conceptual framework for identifying the explanatory variables. Source: Authors' own work

plot is generated to detect potential bias and errors in the meta-data (Sutton *et al.*, 2000). Following Stanley and Doucouliagos (2012)'s work, PET, is also conducted to assist the funnel plot in testing the publication bias and the genuine effect of GBCs beyond the publication bias. The PET test is performed according to Equation (1), shown as follows:

$$t_i = \beta_0 + \beta_1(1/SE_i) + \mu_i \tag{1}$$

where t_i refers to the t-statistics of the observation i, β_0 is the constant and β_1 is the parameter of the regressor, SE_i is the standard error of observation i, μ_i is the residual.

Step 4: Meta-regression analysis

Semi-elasticity, representing the percentage change of the dependent variable with a change in the independent variable (Cropper *et al.*, 1988), is selected as the effect size for comparison. It is commonly reported in empirical studies on GBC effects and has been applied to past meta-regression studies (Ankamah-Yeboah and Rehdanz, 2014; Cespedes-Lopez *et al.*, 2019). For studies not reporting the estimated effect in semi-elasticity format, data transformations are needed based on the average housing price, and the percentage of change is calculated.

After identifying the effect size and explanatory variables, a basic regression model is developed as Equation (2). However, due to the differing residuals [3], OLS is inappropriate. In terms of the Fixed effect and random effect models, which are widely used in the meta-analysis, they are either inefficient in identifying influential factors (Braden *et al.*, 2011; Klemick *et al.*, 2018) or reintroducing the publication bias into the estimation (Bergstrom and Taylor, 2006; Thalib and Doi, 2011; Stanley and Doucouliagos, 2012). The fixed effect model only allows within-study comparisons, which significantly restricts the explanatory power of the meta-regression analysis (Dettori *et al.*, 2022). The random effect model, which is capable of analysis between-study factors, may reintroduce selection bias into estimations, especially

Table 3. Definition of the variables

Variable	Dimension	Definition	Reference case
Data and sample factors			
D_my	Multiple years	= 1 if the dataset covers multiple-year data	One year
D_pm	Property type: multifamily	= 1 if the dataset focuses on multifamily housing = 2 if the dataset focuses on single-family housing	No specific property types
py	Published year	published year	–
Model and methodological factors			
D_u	Unit characteristics	= 1 if the model controls the unit characteristic(s)	Not control any unit characteristics
D_b	Building characteristics	= 1 if the model controls the building characteristic(s)	Not control any building characteristics
D_OLS	OLS	= 1 if the model estimated by OLS	Other econometrics approaches
D_semi	Functional form: semi-log	= 1 if the model is in the form of the semi-log	Linear
Contextual and scenario factors			
D_as	Asia	= 1 if the study case focuses on the Asian context	American context
D_eu	Europe	= 1 if the study case focuses on the European context	
gpdpc	Gross domestic product GDP per capita	The average GDP per capita data of the study region over the study period	–
epc	Carbon emissions per capita	The average Carbon emissions per capita data of the study region over the study period	–
D_cl	Certification level	= 1 refers to the bottom level = 2 refers to the second level from the bottom = 3 refers to the third level from the bottom = 4 refers to the fourth level from the bottom = 5 refers to the fifth level from the bottom	No specific levels
D_cm	Certification mandatory	= 1 if the certification system is mandatory	Voluntary

Note(s): The unit characteristics are those attributes for a certain unit, such as the number of bedrooms, garage, floor level, etc.; the building attributes include the age of the building, total floor, etc., but exclude the green certification
Source(s): Authors' own work

when confounding factors are not adequately controlled (Senn *et al.*, 2019; Cao *et al.*, 2021). Therefore, to address the publication bias issue and effectively estimate the effects of potential factors, this study employs a Weighted Least Square (WLS) approach with the inverse value of the standard error of each observation as the weight (Stanley and Doucouliagos, 2012). The WLS model is shown in Equation (3):

$$ES_i = \beta_0 + \sum_k \beta_k D_{ik} + \mu_i \tag{2}$$

$$ES_i/SE_i = \beta_0/SE_i + \sum_k \beta_k D_{ik}/SE_i + \epsilon_i \tag{3}$$

where ES_i is the effect size of each observation; D_k refers to the three groups of meta-regressors identified in the previous section; β_k represents the parameter of each regressor; SE_i denotes the standard error of each observation; β_0 is the constant.

In terms of the model-building strategy [4], it follows a stepwise approach, where three groups of variables are introduced progressively into the model. This strategy is particularly appropriate for exploratory research, as it allows for a systematic investigation of potential factors influencing green premiums (Nazarpour *et al.*, 2016) and enables assess the robustness of the model. By adding or removing variables incrementally, we can verify that the regression results remain stable across different model specifications, ensuring consistency in the findings (Li *et al.*, 2024). All three models will be reported to demonstrate the results of the stepwise approach and to testify to the robustness of the results across various stages of variable inclusion. Both significant and insignificant factors provide valuable insights, as suggested by Cespedes-Lopez *et al.* (2019), and their inclusion aligns with best practices in meta-regression analysis.

5. Results

5.1 Existence of green premiums and publication bias

As shown in Figure 3, the funnel plot is asymmetric toward positive, demonstrating the existence of publication among the dataset (Stanley, 2005, 2008). Although the funnel plot might have limited power in identifying publication selection bias (Chaikumbung, 2023), the PET test results, which serve as an effective tool (Portnov *et al.*, 2018), further confirm the existence of publication bias on estimated GH premiums. The results of the PET test are reported in Table 4, and the PET results not only confirm the publication selection bias but also prove the existence of a genuine effect of GH premiums beyond the publication selection bias. Table 4 shows that b_0 is significant at 1%, suggesting that publication selection bias is found. In addition, the b_1 also rejects the null hypothesis, which represents the existence of the actual empirical effect beyond the publication selection bias (Stanley, 2005, 2008). In other words, although past literature tends to be biased in reporting significant results of GH values, a genuine green premium is evident in housing markets, reflecting that home buyers price GBs.

The findings highlight the relevance of the demand for comfort hypothesis, as posited in the previous subsection and supported by Quigley and Rubinfeld (1989). The existence of green premiums for GBs confirms the connection between those sustainable but unobservable features that contributed to the comfort of the property and their valuation of such attributes in real estate. This finding is also in line with the outcomes of the prior empirical studies of Mesthrige Jayantha and Sze Man (2013), Yoshida and Sugiura (2015), etc., reporting

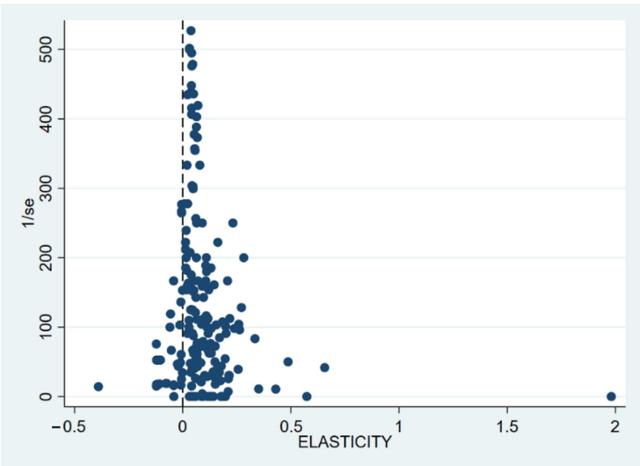

Figure 3. Funnel plot. Source: Authors' own work

Table 4. Precision-effect testing (PET)

Variables	t-value
1/se	0.036*** (7.16)
Constant	4.384*** (4.92)
Observations	209
R-squared	0.198

Note(s): t-statistics in parentheses (***p < 0.01, **p < 0.05, *p < 0.1)
Source(s): Authors' own work

significant price premiums associated with GBCs and past studies that green premiums do exist in real estate markets, including both residential and commercial markets (Ankamah-Yeboah and Rehdanz, 2014; Dalton and Fuerst, 2018). By proving the existence of the genuine effect of GBCs, the finding further suggests that GBCs, with a series of green attributes, are recognised as a form of amenity that not only contributes to ecological sustainability but also carries tangible economic implications, reflected in their pricing dynamics. Considering this, a convincing argument arises among stakeholders in urban development (e.g. developers and policymakers), highlighting the significance of those environmentally friendly design elements in residential properties. Specifically, GHs, offering both economic and ecological benefits, meet the growing demand for sustainable living spaces and align with broader societal and environmental goals, which provides a win-win situation for residents and communities by fostering economic resilience and enhancing the overall quality of urban living environments.

5.2 Factors contributing to the variations

Table 5 [5] reports the regression results of the meta-regression. A stepwise approach is applied to gradually introduce the three groups of factors, which have been identified in section 4, into the model to explore influential factors affecting the estimated green premiums and testify to the robustness of the models. As shown in Table 5, Models 1, 2 and 3 introduce the data and sample, methodological and model, contextual and scenario variables, with increasing R-squared values, suggesting the continuous increase in the model's explanatory power. The F test rejects the null hypothesis, indicating that all three models are significant. Furthermore, the stepwise results also demonstrate that the effect of each variable is comparatively constant, without any variables showing significant changes in statistical significance or directions, confirming the robustness of the model. Given that Model 3 [6] [7] includes the most variables and has the highest explanatory power, the following subsection will focus on the outcomes of Model 3 and interpret the findings from the meta-regression analysis.

5.2.1 Data and sample factors. The analysis reveals that "multiple years" and "published year" significantly influence green-certified housing premiums, while "multi-family" has no significant effect. Studies using multi-year data report higher premiums than those based on single-year data; however, as non-panel data, these averages may not fully reflect year-to-year effects. The "published year" factor is associated with a 0.5% annual increase in premiums, indicating that more recent studies report higher values. This trend aligns with findings that green premiums are inconsistent and tend to rise over time, likely due to increased public awareness and recognition of buildings' carbon emissions (Brown and Watkins, 2015; Aroul and Rodriguez, 2017; Mahmoud, 2020; Lee *et al.*, 2024). In contrast, the "multi-family" variable shows an insignificant correlation with green premiums, indicating similar market responses to GBCs as single-family homes, suggesting a uniform market reaction across different housing types.

Table 5. Stepwise results of meta-regression analysis

Variables	Dimensions	(1) Semi-elasticity	(2) Semi-elasticity	(3) Semi-elasticity
Data and sample factors				
D_my	Multiple years	0.056***	0.081***	0.092***
		(2.96)	(4.45)	(4.83)
D_pm	Property type; multifamily	−0.013	0.008	−0.007
		(−0.70)	(0.45)	(−0.31)
py	Published year	0.003**	0.003*	0.005**
		(2.20)	(1.94)	(2.31)
Model and methodological factors				
D_u	Unit characteristics		−0.080***	−0.095***
			(−3.51)	(−4.16)
D_b	Building characteristics		−0.083***	−0.068***
			(−4.08)	(−3.01)
D_OLS	OLS		0.001	0.019
			(0.09)	(1.34)
D_semi	Functional form: semi-log		−0.052	−0.100
			(−0.06)	(−0.12)
Contextual and scenario factors				
D_as	Asia			−0.102***
				(−3.30)
D_eu	Europe			0.101
				(0.96)
gpdpc	GDP per capita			−0.000
				(−1.62)
epc	Emission per capita			−0.007*
				(−1.94)
D_cl	Certification levels			0.012***
				(2.63)
D_cm	Certification mandatory or not			0.026**
				(2.03)
Constant		−6.655**	−6.630*	−8.990**
		(−2.19)	(−1.82)	(−2.17)
Observations		209	209	209
R-squared		0.070	0.276	0.379
F test		0.0019	0.0000	0.0000
F		5.13	10.95	9.16

Note(s): *t*-statistics in parentheses (***$p < 0.01$, **$p < 0.05$, *$p < 0.1$)
Source(s): Authors' own work

5.2.2 Model and methodological factors. Both model factors are significant, while the methodological factors are not. "Unit" and "Building" are negatively correlated to the value of GBC at the 1% significance level, associated with a 9.5% and 6.8% decrease in effect size. In other words, the GBC effect declines after controlling the impacts of the unit and building characteristics, reflected in smaller magnitudes of the estimates. Unit and building characteristics are major housing attributes and have been widely discussed (Rosen, 1974; Cropper *et al.*, 1988; Cespedes-Lopez *et al.*, 2019), and having these attributes controlled when estimating influential factors' effects on housing prices helps to eliminate model bias (Cropper *et al.*, 1988; Osborne, 2008). Failure to isolate "unit" and "building" characteristics when measuring GBC effects on housing prices leads to overestimated price premiums. Similar findings on model construction have also been discussed and proved by Smith and Huang (1993) and Wang *et al.* (2021). The "OLS" and "semi-log" are statistically insignificant, indicating that the choice of functional form and econometric methods does not affect GBC effects. Regardless of the functional forms, all estimations are reliable or without significant bias. Although DID and spatial models can control spatial dependence and time trends and improve model fit (Anselin, 2003; Bertrand *et al*., 2004), basic regression results do not significantly differ from advanced methods, confirming the robustness of GBC green premiums.

5.2.3 Contextual and scenario factors. Contextual and scenario factors demonstrate several interesting findings. The “Asia” location variable is significant, showing that Asian studies are associated with a 10.2% lower premium than American studies. European studies, however, show no significant difference from American ones, suggesting regional disparities primarily between Asia and other regions. The regional differences might be attributed to several reasons such as economic and environmental conditions, awareness and adoption of GB and market maturity (Zhang *et al*., 2017). Regarding economic and environmental factors, “GDP per capita” is statistically insignificant, suggesting that economic conditions do not significantly affect green premiums. The non-significant GDP coefficient suggests that income levels may not be the primary determinant of willingness to pay for sustainable housing. This could be explained by the increasing recognition of the inevitable and unaffordable impacts of climate change (Hsiang *et al*., 2017). Climate change is a universal concern, but awareness does matter. Developing regions, which have traditionally prioritised economic growth over environmental considerations, are now placing greater emphasis on sustainability, partly due to international policies like the Sustainable Development Goals (Hossin *et al*., 2024). Further research is needed to explore how these factors interact in shaping the demand for sustainable housing. Environmental awareness, measured by “carbon emissions per capita,” shows a weak negative correlation with green premiums. This surprising result could be attributed to several reasons, including differing government attitudes, environmental conditions and local policies and regulations, which should be further investigated. Firstly, due to the UN’s “common but differentiated responsibilities” principle (UN, 1998; Lee and Liang, 2024), government attitudes may vary across countries under different obligations for developed and developing countries, which might lead to differing public awareness (Zhang *et al*., 2016; Portnov *et al*., 2018). In addition, countries like China, with high total emissions and severe environmental issues, although have considerably low emissions per capita statistics, exhibit a higher awareness and willingness to pay for green improvements (Crippa *et al*., 2022). Further, another possible explanation is that carbon pricing initiatives and regulatory approaches vary across countries, influencing housing market responses differently. Some governments may impose stricter carbon pricing policies, which could be reflected in property markets, while others may have more lenient approaches (Lee and Liang, 2024). However, these could be potential avenues for further exploration.

In addition, the GBC development and market development conditions also help explain these regional differences. Western countries pioneered GBC systems like Building Research Establishment Environmental Assessment Method (BREEAM) and LEED in the 1990s, supported by regulations and incentives (Han *et al*., 2018), which resulted in higher awareness and better adoption of GH. Besides, western countries tend to have more mature and established housing markets, which results in more robust demands and informed purchasing decisions for emerging housing features like GBs (Massimo *et al*., 2022). In contrast, with less developed GBC systems and less mature housing markets, facing challenges like limited awareness and regulatory support (Azeem *et al*., 2017; Wadu Mesthrige and Kwong, 2018), both developers and homebuyers in Asia market tend to be hesitant to GH (Zhang *et al*., 2017). Certification-related factors are also significant, and each increase in certification level corresponds to a 1.2% rise in green premiums, aligning with Jiang *et al*. (2021) and Tsai (2022). Mandatory certifications add a 2.6% premium over voluntary ones, supporting Fizaine *et al*. (2018).

6. Discussion

This study comprehensively analyses the GBCs’ price effects on housing prices with a focus on GBC systems instead of the energy-focused systems in the following aspects: the genuine effect of the certification beyond the potential publication bias and the study-design factors contributing to the variations of green premiums. The significant findings of the explanations in understanding the variations in green premiums are useful for scholars and policymakers.

For researchers, several key findings are crucial for reducing bias in studies. Firstly, considering time effects is essential, as public awareness and the impact of GBCs increase over time (Brown and Watkins, 2015; Aroul and Rodriguez, 2017). Regression results for "published year" and "multiple years" support this, indicating the need to distinguish year differences rather than reporting average effects. Secondly, model selections also significantly affect the estimation results for Hedonic empirical studies, especially the unit and building attributes of the property (Cespedes-Lopez *et al.*, 2019). As demonstrated by the results of "unit" and "building", failing to isolate unit and building attributes can lead to overestimated GBC price premiums, highlighting the importance of comprehensive models that control for housing attributes. Thirdly, to understand GH value, it is of great importance to consider potential factors affecting homebuyers' green purchase intention, such as how they perceive environmental issues and government attitudes (Hsiang *et al.*, 2017; Hossin *et al.*, 2024). Lastly, the positive effects of "certification level" on green premiums, suggesting that higher levels are associated with higher premiums, highlights the inconsistency among certification levels and the significance of submarket analyses based on certification levels (Jiang *et al.*, 2021; Tsai, 2022).

For policymakers, the proof of the existence of GBC premiums highlights the significance of establishing green certification systems, bringing additional value to the real estate markets. With the monetary value supplemented by the environment and health benefits (Zhao *et al.*, 2022), the importance of establishing and implementing GBC systems is further enhanced. More importantly, the green premiums also stimulate the public to invest in GH and increase public awareness of climate change. The multi-dimensional significances of the GBC systems also encourage policymakers to contribute to establishing, implementing and improving them as it can be an effective way of fighting climate change. Additionally, it offers policymakers some potentially insightful guidance on policy strategies for fighting global climate change. To begin with, establishing comprehensive policy support could help to enhance the adoption of GBCs, which may contribute to improving sustainability. However, given that our model explains only 37.9% of the variance, other factors beyond policy support likely influence these outcomes. As discussed for regional disparities, regions with well-developed systems and sound policy supports show a significantly higher value of GH (Zhang *et al.*, 2017), though additional research is needed to fully capture the extent of these effects. Besides, governments' attitudes towards climate change could affect public awareness of the environment, and this also highlights the significance of understanding the impacts of policy uncertainty apart from the policy itself when making policy decisions (Portnov *et al.*, 2018). Furthermore, mandatory policy may help improve the efficiency of GBC adoption, as mandatory certification systems, compared with voluntary ones, are priced with higher values (Fizaine *et al.*, 2018). However, the applicability of this strategy should be further discussed based on different GB development stages for specific cases (Ai *et al.*, 2024), as the coefficient is only 2.6%. Therefore, while mandatory policies may be beneficial in some cases, their success should be evaluated carefully in light of the broader market conditions and regional differences.

Despite its contributions, this study has certain limitations. Excluding non-English studies reduces the sample size and may limit the representativeness of the findings, especially for regions that published GH research in other languages. While our findings provide useful insights, they should be interpreted within the context of the sampled studies, and additional research—including studies in other languages and from underrepresented regions—is needed to validate broader trends.

7. Conclusion

This study confirms the existence of GB Certification (GBC) premiums in housing markets and identifies key factors influencing these premiums. Through a rigorous meta-regression analysis, it reveals that GBCs positively affect housing sale prices globally, despite some publication bias, supporting Quigley and Rubinfeld's (1989) demand for comfort theory. Additionally, all three groups of factors, namely, sample and data factors, model and methodological factors, and contextual and scenario factors impact the estimated green premiums. Specifically, the estimated green premiums are affected by study time, control variable selections, study regions, and certifications' features of levels and whether they are mandatory. Increasing public awareness has led to an upward tendency in GBCs' price appreciation over the years. Crucial control variables selection (i.e. unit and building characteristics) significantly impacts the green certification effects, and failing to isolate these effects leads to overestimations. Regional disparities have been documented that GH premiums reported by Asia studies are less remarkable than American and European studies. Certification features play essential roles in determining the price appreciations of the certification, with higher levels of certification and mandatory comprehensive GBCs tend to be valued at higher prices.

The importance of this study lies in its focus on the existence of GBC premiums and reasons for heterogeneous effects related to GBCs on housing markets that are somewhat under-researched. By confirming the existence of GBC premiums, the study provides theoretical support for why GH is valued more highly in the market. It also offers valuable insights for researchers on minimising bias in hedonic model construction, serving as a benchmark for comparing results across studies. These findings have important implications for scholars and policymakers. For policymakers, the study provides a solid foundation for creating effective policies and strategies to promote sustainable housing and enhance the market value of GB certifications. In conclusion, this research addresses the defined objectives by confirming GBC premiums and offering a comprehensive examination of factors that influence these premiums, advancing our understanding of GBCs' value in the housing market. However, this study has limitations, and future studies can contribute to addressing the following limitations to supplement this research domain. Firstly, the focus on English-language publications reduces the sample size and representativeness, and future studies could consider other languages or focus on specific regions to improve generalisability. Secondly, future studies could explore how different certification schemes influence buyer preferences and whether the premiums observed persist over time which is beyond the scope of this study. Lastly, a deeper examination of regional variations and policy interventions could shed light on the broader implications of green certifications for housing affordability and sustainability.

Notes

1. We selected meta-regression analysis as it is particularly suited for synthesising findings from multiple studies while accounting for heterogeneity across effect sizes. Other methods, such as hierarchical modelling or machine learning approaches, were considered but ultimately rejected. Hierarchical models, while robust, were deemed less appropriate due to the relatively small sample size, which could limit model stability (Akter and Khan, 2018). Machine learning techniques, due to their Blackbox nature, though powerful, were not pursued as they do not align with our primary goal of hypothesis testing and the clear identification of causal relationships. Furthermore, it requires a large dataset for training purposes (Soltani and Lee, 2024).

2. To ensure the robustness of our adoption of the SPAR-4-SLR protocol, we also applied the PRISMA framework as a robustness check. No significant variations were identified when comparing the results from SPAR-4-SLR and PRISMA. Given that the study area and screening criteria remained consistent across both protocols, the final set of studies selected for further analysis was identical. For brevity, the full PRISMA results are not included in the manuscript, but the results are available upon request.

3. Test for normality and homoscedasticity have been conducted, and the results suggested that the data obey the normal distribution but a significant heteroskedasticity issue has been detected, indicating the use of WLS instead of OLS. Further, the Durbin–Watson and VIF statistics confirm the independence of observations and no significant issue of multicollinearity. For brevity, the details of these tests are reported by request.

4. The potential non-linear effects might not be a major concern affecting the results considering the characteristics of the meta-regression and variables. Therefore, the normality tests for the used variables were conducted, but the results suggest that no significant non-linearity statistics have been identified.
5. The correlation matrix and the Variance Inflation Factors results were checked, and no severe multicollinearity issue was detected. However, due to the word limitations, the results are not reported. The details of these tests are reported by request.
6. Although Model 3 contains some variables that are not statistically significant, all the findings have their implications. Therefore, those insignificant variables are not removed from the model and the results of all variables are reported, which is also a widely used strategy for meta-regression analysis (Cespedes-Lopez *et al.*, 2019).
7. Robustness checks have also been conducted, and the results suggest that the findings in model 3 are robust. For brevity, the results are reported by request.

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