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The Role of Green Bonds in Enhancing Renewable Energy Capacity: Evidence and Challenges

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Abstract

This study aims to assess the relationship between green bonds and renewable energy capacity. The selected sample includes all corporate and sovereign green bond issuing countries, namely 50, over the period from 2000 to 2021. A fixed effect regression is conducted to account for within-country variations in green energy before and after the issuance of these bonds. The findings indicate a positive relationship between green bonds and renewable energy capacity. Additionally, countries are featured by higher investments in sustainable projects after the issuance of these instruments, addressing associated threats of greenwashing.

Keywords: Green Bonds, Climate Change, Greenwashing, Renewable Energy Capacity, Fixed Effect

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1. Introduction

In the 1800s, the introduction of fossil fuels significantly contributed to an unprecedented economic growth. Other than promoting progress, this event was responsible for a gradual and long-term transformation in temperatures and weather patterns known as climate change. With a 1.36 degrees Celsius rise in global average temperature compared to pre-industrial times (NASA, 2023), climate change has caused an increase in extreme weather events, rising sea levels, and habitat loss. According to the Intergovernmental Panel on Climate Change (IPCC) – a body set by the UN with the purpose of promoting unbiased scientific information regarding this crisis – these changes are jeopardizing food security, water supply and human health, giving rise to potential economic depression and migratory waves.

Although there has been consensus between climate scientists about the anthropogenic nature of this phenomenon since its emergence (Cook et al. 2013), environmentalism only became a mainstream political topic with the adoption of binding treaties like the Kyoto Protocol in 1997 and the Paris Agreement in 2015. This shift was further amplified by large-scale movements such as Fridays for Future (FFF), whose strikes saw the active participation of 6 million people worldwide (World Economic Forum, 2019). Since then, national and international organizations have been adopting various solutions to mitigate the disastrous effects of climate change, including investments in the renewable energy sector and carbon pricing policies to replace high-emission technologies. Corporations also have a major responsibility to advance climate action by decarbonizing their production processes and allowing customers to make greener choices. However, the steps taken so far are insufficient. This is due to a lack of initiatives across countries to align with both national and international regulations aimed at reducing global emissions (World Economic Forum, 2024).

The reasons driving this inadequate response are various, including political frictions and global inequalities. The significant costs required to transition from brown economies to green ones also constitute a major challenge to fight climate change. Therefore, it is essential to combine efficient policies and investment programs designed to finance innovative solutions and reduce such costs (International Monetary Fund, 2019). In this regard, several economic actors are financing projects based on environmental and social considerations, with green bonds (GBs) representing the most widespread option to support these initiatives (Climate Bonds Initiative, 2024).

However, the emergence of these instruments sparked debates about their effectiveness in fighting climate change. Indeed, the lack of binding regulations around GBs specifying the nature of financed initiatives raised concerns about potential greenwashing threats (Section 2.1 & Section 2.3). The most relevant academic literature on GBs examines their financial performance compared to conventional bonds and their influence on ESG scores after the issuance (C. Flammer, 2021; Zhang & Kong, 2022; Olabi & Abdelkareem, 2022). This thesis, however, will assess the relationship between GBs and environmental parameters at a country level, considering both corporate and sovereign GBs (Section 2.1). More specifically, it will focus on renewable energy capacity in issuing countries, given the nature of financed projects and the impact of these sources on the environment (Section 2.2). Consequently, the following research question will be addressed:

To what extent do green bonds increase renewable energy capacity in issuing countries?

This thesis will be structured as follows. Section 2 will review the existing academic literature on the topic. After analyzing the main features of the GBs market, the theoretical framework will explore the risks of greenwashing associated with these instruments and examine the main determinants of the green transition to provide a more focused overview of this issue. Sections 3 and 4 will describe the data collection process and research methodology by providing an explanation on the statistical method selected and its relevance. Section 5 will present and discuss the results and limitations of the study, while Section 6 will draw concluding remarks about the topic.

2. Theoretical Framework

The expansion of the GBs market led to a significant increase in the academic literature on sustainable finance, with influential papers focusing on GBs' financial characteristics. There are contrasting views regarding the pricing and impact on environmental parameters of these instruments. Therefore, the following chapters review the most relevant papers on GBs to investigate the reasons behind their extensive diffusion and their impact on climate change as there is mixed evidence about their effectiveness due to greenwashing concerns. Before assessing why GBs are exposed to such risk, this research identifies the main area of GBs investment: the renewable energy sector, whose environmental benefits are crucial for the green transition.

2.1 The Green Bonds Market

In 2007, the European Investment Bank (EIB) issued the world's first GB. Since then, the GB market has exponentially grown, reaching a total cumulative volume of approximately $3 trillion in 2024 (Climate Bonds Initiative, 2024). With the expansion of this new market, the International Capital Market Association (ICMA) introduced the Green Bond Principles (GBP). These voluntary guidelines, published in 2014 and updated over time, describe GBs as fixed-income instruments exclusively aimed at financing green projects. According to the *Use of Proceeds* section of the GBP, these projects' eligibility is based on a comprehensive analysis of their potential environmental benefits.

The existing literature on this topic further investigates the main features of GBs and their differences from conventional fixed-income instruments. More specifically, there is a debate on their price, with most influential research outlining that overall GBs have no premium compared to conventional bonds. Furthermore, a big portion of GBs is held by socially responsible funds or investors, who exhibit strong preferences for sustainable tools. This trend provides evidence for the signaling theory, claiming that issuers send a credible signal about their environmental commitment and attract green investors by issuing GBs (Flammer, 2021; Baker, Bergstresser, Serafeim & Wurgler, 2022). This positive effect is also reflected by the abnormal positive returns that issuing firms experience on the issuance day and their improved stock liquidity afterwards, which significantly benefit shareholders (Flammer, 2021; Tang & Zhang, 2020).

The above-mentioned characteristics, alongside with an increased environmental awareness, are contributing to the expansion of the GBs market. According to Monk and Perkins (2020), these instruments have become so popular thanks to their price and legitimacy. Indeed, only after the publication of the GBP, which increased investors' confidence in these new tools, the sustainable finance sector benefitted from a dramatic growth with GBs' issuance tripling. Additionally, as previous empirical research demonstrates, investors do not pay a "greenium" on GBs – a premium price paid for their environmental sustainability. Hence, for the same price, investors can purchase options specifically aimed at fighting climate change.

Overall, thanks to GBs' relatively higher value and legitimacy, the sustainable finance market is expected to further develop, with an increasing amount of countries and corporations issuing these instruments for the first time or significantly increasing single deals' proceeds (Climate Bond Initiative, 2024). Hence, given that GBs are the main sustainable financing solution in an exponentially growing market, it is important to assess if the related investments promote the green transition by investigating their correlation with environmental parameters.

2.2 Hypothesis 1 - The Use of Proceeds: Renewable Energy for Climate Action

To accurately evaluate the relationship between GBs and the green transition, this research identifies the main fields of investment based on GBs' use of proceeds. The observations are retrieved from the Green Bond Guide of the LSEG Eikon database (Section 3.1). As illustrated in Table 1, most of the deals financed by these fixed-income instruments aim at promoting the development of renewable energy infrastructures, with approximately 57% of GBs issued used for this purpose. The clean transport industry is also heavily funded by GBs relative to other sectors. Indeed, although the number of related projects is low, the size of the corresponding deals sums up to $1,350.64 billion, which is the highest figure amongst all observed sectors. However, this could be partly motivated by the higher capital intensity of the clean transport industry. Namely, the latter requires significant investments compared to the renewable energy sector, which often involves the expansion or upgrading of existing facilities (IEA, 2021). Furthermore, other than increasing efficiency, the introduction of green energy sources is crucial for the green transition since it is the best option to transition from polluting sources, such as fossil fuel.

Table 1

List of Use of Proceeds	Total Amount	% of Amount Issued	% of Total Deals
Renewable Energy Projects	$ 794.43 billion	17.93%	56.95%
Climate Change Adaptation	$ 655.64 billion	14.80%	5.28%

Clean Transport	$ 1,350.64 billion	30.49%	2.56%
Green Construction	$ 166.68 billion	3.76%	7.62%
Eligible Green Projects	$ 209.51 billion	4.73%	7.54%
Aquatic Biodiversity Conservation	$ 167.13 billion	3.77%	0.57%

Note: The observations are retrieved from the Green Bond Guide of the LSEG Eikon dataset. The currency is US dollars. The above list only includes the most financed sectors.

Indeed, thanks to the latest technological advancement, green energy is more efficient than before, with storage systems providing stable power for various purposes. These factors contributed to the diffusion of green energy infrastructure, especially amongst technologically advanced firms, featured by an enhanced total factor productivity (TFP). Research demonstrates that this improvement is due to the implementation of renewables, which could be reduced by high policy uncertainty. In this respect, national governments are encouraged to adopt diversified funding strategies for the green energy sector, including sustainable financing solutions such as GBs (Zhang & Kong, 2022; Olabi & Abdelkareem, 2022). The benefits deriving from renewables concern environmental indicators too. In line with long-term sustainability goals, these energy sources promote the reduction of greenhouse gas emissions and a lower reliance on fossil fuels. Precisely, implementing green energy sources is the easiest way to get rid of brown ones, as the former can be efficiently used for electricity generation with minimal environmental impact (Olabi & Abdelkareem, 2022).

After this analysis, the scope of the following research is narrowed down only to the green power sector, given its importance for the green transition. By benefitting from the highest number of GB-financed projects, related indicators are more likely to be positively and significantly influenced by the issuance of GBs, making it more relevant to solely focus on this aspect. Furthermore, unlike previous studies focusing on combined environmental indicators at a firm-level, I investigate country-level variables referring to renewable energy capacity only. Hence, the following hypothesis is tested:

Hypothesis 1: green bonds have a positive and significant impact on renewable energy capacity in issuing countries

2.3 Hypothesis 2 - Navigating the Risks of Greenwashing in the Green Bond Market

Although GBs aim at promoting the green transition, there are concerns about the impact of their corresponding proceeds on environmental indicators. Indeed, due to GBs rapid diffusion, there is a lack of binding regulations on their use of proceeds, which potentially exposes investors to greenwashing. According to Delmas and Burbano (2021), corporations or national governments engage in greenwashing when they communicate a positive environmental impact, while performing poorly in this field. Amongst other things, this behavior is encouraged by the absence of a solid legal frameworks, as with GBs, that are issued in accordance with non-binding recommendations.

Specifically, the most widely adopted voluntary guidelines are the GBP, which provide issuers with guidance on GBs' use of proceeds and reporting procedures. While signaling the legitimacy of GBs, the voluntary connotation of these guidelines poses a significant greenwashing threat, with corporations or national governments exaggerating their projects' environmental benefits to attract more investors. Indeed, although the GBP require GBs to finance green projects, there is no mandatory verification. Hence, a significant portion of issuers resorts to external reviewers to address the associated credibility issue and indicate a higher commitment to green transition. However, the reliability of these reviews is heavily dependent on their accuracy and criteria, which can greatly vary across different parties. This is highlighted by a Baker McKenzie's report (2019), which ascribes the practice of greenwashing in the GBs market to a lack of protections and transparency, leaving investors with a limited range of action in case proceeds are not used as agreed.

The outcomes of empirical studies conducted in this field are mixed. Regardless of their weak regulatory framework, GBs improve ESG transparency and performance as they provide financial support to drive innovation and sustainable finance. This serves as evidence against the claim that GBs are greenwashing instruments. Indeed, other than enhancing their environmental parameters, firms are less likely to engage in greenwashing after issuing GBs with an ESG disclosure score closer to third-party ratings (Flammer, 2021; Tang & Zhang, 2020). In line with this phenomenon, issuing corporations increase their green patents applications as well. However, amongst them, there is a high portion of non-invention licenses, which are less beneficial for long-term sustainability goals since they do not promote major innovations (Shi, Ma, Jiang, Wei & Yue, 2023).

Moreover, according to Flammer (2021), issuing corporations attract several eco-conscious investors, by sending a signal about their environmental commitment (Section 2.1). Signaling has mixed effects on the risk of greenwashing. Indeed, thanks to GBs, firms or national governments can mislead potential investors by diverting attention from other polluting activities they engage in. At the same time, they can display a greener behavior and a higher concern about the environment compared to non-issuing actors since emitting GBs is costly.

Therefore, it is appropriate to investigate if countries display better environmental indicators after the issuance of GBs, with this practice potentially constituting a threat of greenwashing based on the above findings. Since this research is focused on green energy sources (Section 2.2), I analyze the correlation between being a GB-issuing country and variations in renewable energy capacity, which is expected to be significant and positive given the evidence concerning ESG performance provided by the existing literature. Furthermore, unlike previous studies focusing on greenwashing implications at a firm-level, I investigate this phenomenon for all countries issuing sovereign and corporate GBs. Hence, the following hypothesis is tested:

Hypothesis 2: being a green bond-issuing country positively and significantly affect renewable energy capacity

3. Data

3.1 The Green Bonds Market and Renewable Energy Capacity Projects

To investigate the correlation between green bonds (GBs) and renewable energy capacity in issuing countries, I collected data on the 50 issuing countries from 2000 to 2021 and obtained an unbalanced panel data, with observations missing for 2001. The data was mainly retrieved from LSEG Eikon, an open technology offering several datasets about financial markets and other indicators at an industry and macro-level. Namely, by using the Green Bond Guide, I gathered primary data on GBs, their country and date of issuance, amount issued (in US dollars), and use of proceeds. Furthermore, I included in my dataset a dummy variable indicating whether a country has issued GBs to assess the impact of being an issuing country on renewable energy capacity. I did not select data on social, sustainability, and sustainability-linked bonds as their proceeds are used to finance a mix of green and social projects, with the latter potentially jeopardizing the accuracy of my research which focuses solely on environmental aspects.

To obtain a clear overview, I used the observations obtained from the database to show the expansion of the GBs market over time. In Table 2, I reported the number of countries where corporate or sovereign GBs were issued and their amount in US dollars. During the 11-year period, the number of countries and the amount issued exponentially increased. Noticeably, from 2015 to 2016 the number of GBs issued doubled, raising from approximately $45.8 billion to $91.2 billion. Similarly, the number of countries where either corporate or sovereign green bonds were issued underwent a significant growth, further emphasizing the relevance of these new instruments in the financing of the green transition. It is important to note that Table 2 only provides a partial picture of the GB market, as it does not include the latest figures relative to the 2022-2024 period. These have been excluded from my analysis due to insufficient data available on significant influencing factors, such as GDP per Capita and political stability, during that timeframe.

Table 2

Total GBs issuance by year and number of issuing countries (in US$)

Year	**# of countries**	**Total Amount Issued (in US$)**
2010	7	$2,58 billion
2011	4	$767,7 million
2012	8	$2,11 billion
2013	13	$12,18 billion
2014	20	$29,66 billion
2015	24	$45,81 billion
2016	31	$91,22 billion

2017	37	$169,48 billion
2018	38	$181,43 billion
2019	47	$337,84 billion
2020	48	$429,80 billion
2021	51	$875,52 billion

Note: The observations are retrieved from the Green Bond Guide of the LSEG Eikon dataset. The currency is US dollars.

Furthermore, by investigating the LSEG Eikon's Renewable Energy Dashboard, I managed to retrieve data on renewable energy capacity growth over time across GBs issuing and non-issuing countries. These figures, which only include renewable energy sources, are measured in megawatts (MW) and comprise earliest available data and predictions until 2050. They are particularly relevant when assessing the impact of green bonds on environmental transition. Indeed, as reported by the Green Bond Guide, GBs were mainly issued used to finance renewable energy projects (Section 2.2).

3.2 Macro-level Variables

The following macro-level observations were obtained from the World Bank DataBank, which is an analysis tool containing multiple time series data on various topics. During the collection process, I did not select non-country specific observations referring to macro-regions such as the Arab World or the Euro area to avoid double-counting and multicollinearity in my models.

More specifically, I obtained data on total GDP (in US dollars) and GDP growth (annual %), based on the World Bank, the IMF, and the OECD national accounts data. Other than accounting for the differences across countries in terms of wealth and financing possibilities, these indicators are likely to be positively correlated to the amount of GBs issued and the renewable energy capacity. This is outlined by the Climate Bonds Initiative (2023), which lists amongst the top green bonds' issuers China, the US, and other major European economies. Furthermore, the report emphasizes the strict relationship between green financing solutions and renewable energy projects, highlighting the indirect effect of GDP on this variable. To improve the statistical power of the model, this paper suggests the use of logarithmic transformation of total GDP. By employing this method, the impact of outliers on the results is significantly reduced with the variability of the data being lower and closer to the mean. This transformation is not required for GDP growth. Indeed, since this is a ratio, it is less likely to be featured by outliers.

The DataBank provided me with observations on political stability and regulatory quality as well. The former is an aggregate indicator measuring the perception of political stability and violence, including terrorism. The latter, instead, measures the ability of governments to adopt policies promoting the development of the private sector. They are both featured by values ranging from approximately -2.5 for poor-performing countries to 2.5 for highly performing ones. With high political stability and an efficient system of policies, countries are more likely to issue green bonds and increase their renewable energy capacity. Indeed, the development of the financial market and the green transition are not of paramount interest in case of war or related forms of violence.

Furthermore, I obtained data on medium- and high-technology exports (% of total manufactured exports). This serves as a proxy for technological progress. Indeed, countries with high shares of these exports are more likely to have higher technological expertise. This figure is based on the percentage of high- and medium-technology exports, like aircraft, IT, pharmaceutical, and automotive products, against the total manufactured exports, which include resource-base and low-tech exports as well. For my analysis, this factor is relevant as it is likely to increase GBs issuance and renewable energy capacity. Indeed, a higher technological level potentially implies the development of innovative and efficient solutions in the finance and energy sector, including the development of new products and renewable energy infrastructure.

Table 3 reports descriptive statistics of the variables under investigation, outlining that the number of observations equals to 1,049. Renewable energy capacity has a mean of 25,162.66 MW with a very high variability. Similarly, the number of green bonds issued is featured by significant deviations within the dataset, with an average of $2.07 billion. This is also reflected by the GDP growth rate, which highlights the presence of both periods of significant expansions and contractions. The political stability score, the regulatory quality and the medium and high-technology exports indicate a diverse political environment, as well as different levels of technological advancement across the countries observed.

Table 3

Descriptive statistics table on the dependent and independent variables

	Observations	**Mean**	**Std. Deviation**	**Min**	**Max**
Renewable Energy Capacity (MW)	1,049	25,162.66	57,897.98	0	765,714.90
Amount Issued (divided by 1 billion US$)	1,049	2.07	9.50	0	143
GDP Growth	1,049	2.98	3.89	-17.67	24.47
Political Stability Score	1,049	0.31	0.89	-2.38	1.76
Medium and High-technology Exports	1,049	48.61	20.19	2.93	85.39
Regulatory Quality	1,049	0.84	0.80	-1.29	2.25
Total GDP (divided by 1 billion US$)	1,049	1,210	2,750	4.66	23,300

3.3 The Forward Lag Estimation Analysis

After reviewing the World Bank (IBRD) Green Bonds FY22 Impact Report on the completion of GBs' project, I decided to forward lag renewable energy capacity by 3 and 5 years to capture the true relationship between my variables of interest. The above-mentioned report includes a list of all renewable energy and energy efficiency projects financed with the proceeds of the GBs issued by the International Bank for Reconstruction and Development's (IBRD). This financial institution serves as the lending arm of the World Bank Group, which is the largest development bank in the world. Its global commitment makes the documentation on renewable energy a good standard regarding the time it takes for the completion of related projects. Table

4 further underlines this aspect by reporting part of the programs undertook by the IBRD, which took place in several locations in Europe, Asia, South America, and North America.

Table 4

Part of IBRD GBs' projects with the corresponding country, start year, end year, and duration

Name of the Project	Country	Start Year	End Year	Duration
CN: Beijing Distributed Solar Photovoltaic Scale-Up Project	China	2013	2019	6 years
Urumqi District Heating Project	China	2011	2015	4 years
Mexico (CRL) Integrated Energy Services	Mexico	2008	2015	7 years
Turkey SME Energy Efficiency Project	Turkey	2013	2019	6 years
Second Rural Electrification	Peru	2011	2017	7 years
POWER SYSTEM DEVELOPMENT PROJECT IV	India	2008	2014	6 years

Note: This table contains information from the World Bank (IBRD) Green Bonds FY22 Impact Report and the World Bank website ((https://thedocs.worldbank.org/en/doc/667f95939700497452d00a1544ba2d01-0340022024/original/World-Bank-IBRD-FY23-IMPACT-REPORT.pdf)

Based on the 25 projects listed in the above-mentioned report, I selected the average of the completion time as a forward lag for renewable energy capacity. As already mentioned, this value was equal to 5. Furthermore, I also included a 3-year forward lag to account for the effect of partly completed infrastructure and smaller projects, given that, unlike the majority of GBs issuers, the WorldBank benefits from large financial reserves.

Furthermore, by forward lagging renewable energy capacity, I also address reverse causality to some extent. As outlined by Leszczensky and Wolbring (2019), this method produces particularly significant results in panel model with simultaneous and lagged effects aligning with real-world causal mechanisms. Therefore, given that the above estimation analysis was based on the duration of real projects, I improved both the robustness and the validity of my research by accounting for the temporal nature of investments.

4. Methodology

4.1 The Fixed Effect Method

The fixed effect method allows to examine the correlation of GBs on renewable energy capacity by accounting for unobserved time-invariant bias, which might be caused by cultural and geographical factors.

While eliminating potential bias caused by time-invariant factors, this method investigates the impact of GBs and other independent variables on renewable energy capacity. This analysis is based on within-countries variations and is particularly suitable due to the nature of my dataset, which is characterized by several political, social, and economic differences across observations. Indeed, by employing the fixed effect, it is possible to minimize potential bias resulting from the omission of variables that vary between countries but are constant over time.

Furthermore, renewable energy capacity is very dependent on geographic factors. Thanks to the fixed effect, it is possible to account for potential bias caused by this attribute, which is likely to stay constant over time. Similarly, the bias caused by other time-invariant factors is removed, improving the robustness of the model.

Overall, given the characteristics of the dataset, the fixed effect method provides the most reliable results. This choice is further supported by Dougherty (2011), who analyzes three distinct statistical methods for panel data: the Ordinary Least Square (OLS) regression, the random effect and the fixed effect. Because the data gathered for the following analysis was not random but based on GBs issuing countries, it is possible to conclude that the best method for this research is the fixed effect. Indeed, the Ordinary Least Square (OLS) regression would provide strongly biased results due to the omission of time-invariant unobservable variables. The random effect method, instead, would require no unobserved factors correlated with the variables of the regression. This assumption does not hold, due to the presence of specific governmental policies and cultural factors that could potentially affect the issuance of GBs and the development of renewable energy capacity, resulting in an over- or under-estimation of the coefficients in the analysis.

For the fixed effect method to produce reliable results, it is necessary to infer some assumptions. According to Glass, Peckham and Sanders (1972), these include the normal distribution, the equal variance, and the independence of the error terms assumptions, with the latter implying that the error term is not correlated to the independent variables. Furthermore, there must be no perfect multicollinearity across the independent variables, as this affects the statistical significance of the coefficients due to the high correlations between the predictors.

4.2 Estimating Equation – Hypothesis 1

The following equation is used to investigate the contribution of green bonds to renewable energy capacity in issuing countries:

$$RenewableEnergyCapacity_{it} = \beta_0 + \beta_1 AmountIssuedUSD_{i,t-x} + \beta_2 GDPGrowth_{i,t-x} + \beta_3 TotalGDP_{i,t-x} + \beta_4 PoliticalStabilityScore_{i,t-x} + \beta_5 Mediumandhightechexports_{i,t-x} + \beta_6 RegulatoryQuality_{i,t-x} + \gamma_t + \sigma_t + e_{it} \quad \textbf{(1)}$$

where *i* represents the country, *t* represents the year, *x* represents the number of year(s) by which the variable is lagged, β is the effect of each independent variable on renewable energy capacity, γ_t is the time fixed effect, σ_t is the country fixed effect, and e_{it} is the error term.

While Equation 1 includes lagged independent variables to align with conventional notation, as indicated by *t-x*, this research will forward lag renewable energy capacity (Section 3.3 & Section 5.1). By employing this procedure, which is mathematically equivalent to lagging the independent variables, the obtained results will present how the factors under analysis contribute to future green energy development and account for the period of completion of the projects financed with these fixed-income instruments.

In line with the use of GBs' proceeds and the literature concerning the impact of related projects, it is expected that the parameter β_1 will have a positive sign but low magnitude. Indeed, GBs' issuance can only explain a very small fraction of the increase in renewable energy capacity in issuing countries.

4.3 Estimating Equation – Hypothesis 2

This research investigates the engagement of countries in the green transition after the issuance of green bonds, given that the latter potentially serve as greenwashing instruments (Section 2.3). Hence, in the following regression GBs' issuance is a dummy variable, taking value 1 when a country starts issuing GBs and 0 otherwise.

$$RenewableEnergyCapacity_{it} = \beta_0 + \beta_1 GreenBondIssuedDummy_{i,t-x} + \beta_2 GDPGrowth_{i,t-x} + \beta_3 TotalGDP_{i,t-x} + \beta_4 PoliticalStabilityScore_{i,t-x} + \beta_5 Mediumandhightechexports_{i,t-x} + \beta_6 RegulatoryQuality_{i,t-x} + \gamma_t + \sigma_t + e_{it} \quad \textbf{(2)}$$

The subscripts and coefficients have the same meaning as explained in Section 4.2. Similarly to Equation 1, this empirical specification includes lagged independent variables only to align to conventional notation. However, the model in Section 5.2 will use forward lagging for renewable energy capacity, as both methods provide equivalent results.

4.4 Robustness Checks

To check both models' robustness, this paper will scale the total amount of GBs issued and the renewable energy capacity by the total GDP (in US$) of the corresponding countries. By employing this scaling procedure, the model will account for the size of the economies under analysis, removing potential upwards bias. This bias occurs because high-GDP countries naturally have higher GB issuance and renewable energy capacity, as they have more economic resources and higher energy requirements. Normalization ensures that the coefficients are not higher due to the presence of major economies in the sample. This will require the exclusion of total GDP as a control variable, to avoid potential multicollinearity issues.

Furthermore, to validate the reliability of the main model and better capture the relationship between the control and main variables, I will conduct another robustness check using 1- and 2-year lags for GDP growth, total GDP and medium- and high-technology exports. These factors are more likely to influence the renewable energy capacity and the amount of GBs issued when considered from previous years. For instance, last year's GDP or technology advancements affect this year's green energy and sustainable investments to a larger degree compared to most recent figures. Unlike the main model, this robustness check only focuses on the impact of past economic conditions on current renewable energy capacity, without employing forward-lagged values of renewable energy capacity.

5. Results

5.1 Results – Hypothesis 1

Table 5 reports the results of a fixed effect panel regression based on Equation 1, with the integration of 3-years or 5-years forward lags for the dependent variable (Section 4.2). The results show that there is a positive and significant correlation between the amount of GBs issued and renewable energy capacity in issuing countries at a 5% significance level with no lags, at 10% significance level with 3-years and at 1% significance level 5-years forward lags. Namely, for every $1 million dollar spent on such fixed income instruments, renewable energy capacity in issuing countries increases by 1.79 MW with no lags, 5.79 MW with 3-years forward lags, and 11.8 MW with 5-years forward lags. As expected, the magnitude of this correlation is very low since GBs finance only a small fraction of all projects aimed at increasing renewable energy capacity. However, these findings help mitigate greenwashing claims related to GBs since there is a slight positive correlation given the results of this within-country comparison before and after their issuance.

On the other hand, the coefficients of the control variables under analysis are not consistently significant across the three models, except for GDP growth, total GDP, and regulatory quality. The first variable takes negative values in all models, with significant effect in the first at a 10% significance level. Therefore, contrary to my preliminary analysis (Section 2.2), GDP growth decreases the level of renewable energy capacity in GBs issuing countries. This phenomenon could be explained by the fact that an expansion of economic activities might lead to an immediate increase in energy demand. Hence, given these circumstances, countries are more likely to opt for conventional sources which are easier and cheaper compared to green ones. Similarly, regulatory quality is featured by a negative and significant coefficient in all three models for a 10% significance level. With a high magnitude, the variable suggests that better regulations might lead to stricter compliance requirements, which could potentially slow down the development of renewable energy projects. Total GDP, instead, is positively and significantly correlated to renewable energy capacity in the first and second model at a 10% significance level. Therefore, if GDP increases by 1%, the amount of renewable energy capacity goes up by approximately 20,000 units in the two scenarios, highlighting the importance of a strong economy for investments in green energy projects.

To check the robustness of this model and account for the potential bias caused by the high amount of GBs and renewable energy capacity in major economies, I scaled the variables of interest by total GDP. As reported in Table 6, the coefficients for GBs issued in the three models are no longer statistically significant after normalization is carried out. Considering this new finding, it is necessary to reinterpret the relevance of the initial results, which might have been biased by the economic size of the countries analyzed.

Additionally, to better capture the relationship between the control and main variables, I used 1- and 2-year lags for GDP growth, the log of GDP and medium- and high-technology exports. In this analysis, the amount of GBs issued has a positive coefficient when using 1-year and 2-year lags for GDP growth, the logarithm of GDP and medium- and high-technology exports. Additionally, 1-year lagged GDP growth is positively and significantly correlated at a 10% significance level with renewable energy capacity, signaling that economic growth might be a positive indicator for green investments and sustainable finance. Overall, it is possible to claim that these results are in line with this research's main analysis (Appendix B, Table B.1).

Table 5

Regression Results of GBs' Amount Issued on Renewable Energy Capacity

	(1)	(2)	(3)
Dependent variable:	Renewable Energy Capacity (MW)	Renewable Energy Capacity_F3 (MW)	Renewable Energy Capacity_F5 (MW)
Amount Issued	1.79**	5.79*	11.8 ***
(scaled by $1 million)	(0.785)	(3.07)	(2.42)
GDP Growth	-662.13*	-508.97	-281.75
	(389.11)	(349.90)	(181.14)
Log GDP	21,244.53*	23,928.76*	25,793.68
	(12,818.8)	(13,480.09)	(15,941.47)

Political Stability Score	4,411.10 (5,316.03)	5,996.9 (4,961.93)	2,461.37 (4,805.10)
Medium and High-technology Exports	131.89 (241.91)	148.25 (273.79)	139.19 (315.20)
Regulatory Quality	-13,377.72* (7,742.42)	-21,968.42* (11,820.11)	-23,491.5* (12,139.44)
Fixed effects	Country-year fixed effect		
Observations	1,049	899	799

Sample: GB issuing countries (from 2000 to 2021, with missing observations in 2001). **Time-varying controls:** GDP growth, log of total GDP, the political stability score, the % of medium- and high-technology exports, the regulatory quality score. Results of the fixed effect regression of renewable energy capacity with no lags, 3-years and 5-years forward lags on the amount of GBs issued and other control variables. Robust standard errors are reported in parenthesis. ***, **, * indicate significance at 99%, 95% and 90% level respectively

Table 6

Robustness Check: Regression Results of Normalized GBs' Amount Issued on Normalized Renewable Energy Capacity

	(1)	(2)	(3)
Dependent variable:	Normalized Renewable Energy Capacity (MW)	Normalized Renewable Energy Capacity_F3(MW)	Normalized Renewable Energy Capacity_F5 (MW)
Normalized Amount Issued (scaled by $1 billion)	2.02 (2.81)	2.37 (0.335)	0.304 (0.282)

GDP Growth	$5.31e^{-11}$	-5.35e^{-10}**	-4.73e^{-10}***
	(1.55e^{-10})	(2.37e^{-10})	(1.67e^{-10})
Political Stability Score	-4.07e^{-9}	-2.47e^{-9}	-4.30e^{-9}**
	(4.25e^{-9})	(2.23e^{-9})	(2.14e^{-9})
Medium and High-technology Exports	$-1.35e^{-11}$	$-5.45e^{-12}$	$-5.59e^{-9}$
	(2.07e^{-10})	(8.55e^{-11})	(4.79e^{-9})
Regulatory Quality	-2.35e^{-8}***	-1.24e^{-8}*	-5.59e^{-9}
	(5.81e^{-9})	(6.84e^{-9})	(4.79e^{-9})
Fixed effects	Country-year fixed effect		
Observations	1,049	899	799

Sample: GB issuing countries (from 2000 to 2021, with missing observations in 2001). **Time-varying controls:** GDP growth, the political stability score, the % of medium- and high-technology exports, the regulatory quality score. Results of the fixed effect regression of normalized renewable energy capacity with no lags, 3-years and 5-years forward lags on the normalized amount of GBs issued and other control variables. Robust standard errors are reported in parenthesis. ***, **, * indicate significance at 99%, 95% and 90% level respectively

5.2 Results – Hypothesis 2

To investigate if issuing countries commit to environmental projects beyond GBs, indicating a broader engagement to sustainability, I transformed the amount of GBs issued into a dummy based on Equation 2 (Section 4.3). This method clearly provides the difference in terms of renewable energy capacity before and after the emission of such instruments and reports the potential presence of a threshold effect, indicating that, regardless of the issued amount, these countries engage in sustainable practice. As illustrated in Table 7, this correlation is positive and significant at a 1% significance level across the three models. Namely, when countries start issuing GBs, there is an increase in renewable energy capacity of approximately 7,172 MW, 15,554 MW, 18,366 MW, with no lags, 3-years forward lags, and 5-years forward lags respectively. The control variables under investigation, instead, are not consistently significant in the three scenarios. A similar coefficient is reported when using 1-year and 2-year lags for GDP growth, the logarithm of GDP and medium- and high-technology exports, with these results being in line with this research's main analysis (Appendix B, Table B2).

After normalizing renewable energy capacity by total GDP and eliminating this variable to avoid multicollinearity, I obtained results that are approximately in line with the previous regressions. Indeed, Table 8 shows that issuing GBs increases the dependent variable by 5,420 MW and 6,510 MW with three and five years forward lags at a 1% significance level. These results are obtained by scaling the coefficients by 1 trillion US$, which is the average GDP of the observed countries. The control variables do not always significantly affect the dependent variable, expect for GDP growth, political stability and regulatory quality. More specifically, these variables are negatively correlated with renewable energy capacity. This is potentially due to higher energy requirements and more complex regulatory frameworks, which might jeopardize the development of the green energy sector.

Overall, Table 7 and 8 highlight a positive and significant relationship between GBs issuance and renewable energy capacity. Based on these results, it is possible to claim that, regardless of the weak legal landscape featuring these instruments, they do not encourage greenwashing to some extent. By employing a dummy for their issuance years, it is possible to assess the effect of being a GB issuing country on renewable energy capacity and draw potential conclusions on the commitment of these nations to the green transition. Indeed, as claimed by Flammer (2021, see Section 2.1), with the issuance of GBs, national governments and corporations signal their pledge to stop climate change and attract additional investments to the green sector. Furthermore, these economic actors prioritize are more likely to invest in sustainable projects regardless of their source of financing, leading to higher levels of renewable energy capacity not necessarily linked to GBs.

Table 7

Regression Results of GB Issued Dummy Variable on Renewable Energy Capacity

	(1)	(2)	(3)

Dependent variable:	Normalized Renewable Energy Capacity (MW)	Normalized Renewable Energy Capacity_F3 (MW)	Normalized Renewable Energy Capacity_F5 (MW)
Green Bond Issued Dummy	7,172.13*** (1,823.63)	15,554.38*** (5,083.85)	18,366.47*** (6,923.28)
GDP Growth	-318.95 (299.03)	-419.79 (395.98)	-262.74 (233.64)
Log GDP	23,189 (17,400.63)	23,860 (17,463.21)	26,378.42 (17,770.48)
Political Stability Score	-1,380.59 (4,611.64)	1,732.17 (5,006.29)	-553.66 (5,384.79)
Medium and High-technology Exports	−5.29 (148.59)	174.73 (339.57)	216.41 (368.43)
Regulatory Quality	-16,729.96 (10,815.80)	-19,468.15 (11,784.14)	-25,562.04 (14,977.39)
Fixed effects		Country-year fixed effect	
Observations	1049	899	799

Sample: GB issuing countries (from 2000 to 2021, with missing observations in 2001). **Time-varying controls:** GDP growth, log of total GDP, the political stability score, the % of medium- and high-technology exports, the regulatory quality score. Results of the fixed effect regression of renewable energy capacity with no lags, 3-years and 5-years forward lags on GB issued dummy and other control variables. Robust standard errors are reported in parenthesis. ***, **, * indicate significance at 99%, 95% and 90% level respectively

Table 8

Robustness Check: Regression Results of GB Issued Dummy Variable on Normalized Renewable Energy Capacity

	(1)	(2)	(3)
Dependent variable:	Normalized Renewable Energy Capacity (MW)	Normalized Renewable Energy Capacity_F3 (MW)	Normalized Renewable Energy Capacity_F5 (MW)
Green Bond Issued Dummy	1,780 (1,560)	5,420*** (1,200)	6,510*** (1,280)
GDP Growth	79.7 (156)	-514** (232)	-460*** (158)
Political Stability Score	-4,160 (4,250)	-2,270 (2,140)	-4,330*** (2,060)
Medium and High-technology Exports	−15.8 (208)	9.01 (91.3)	−165 (140)
Regulatory Quality	-23,700*** (5,660)	−14,300** (6,700)	-6,780 (4,600)
Fixed effect		Country-year fixed effect	
Observations	1049	899	799

Sample: GB issuing countries (from 2000 to 2021, with missing observations in 2001). **Time-varying controls:** GDP growth, the political stability score, the % of medium- and high-technology exports, the regulatory quality score. Results of the fixed effect regression of normalized renewable energy capacity with no lags, 3-years and 5-years forward lags on GB issued dummy and other control variables. The coefficients are scaled by $1 trillion dollar as this is a representative amount given that it is close to the average GDP of the countries observed. Robust standard errors are reported in parenthesis. ***, **, * indicate significance at 99%, 95% and 90% level respectively

5.3 Limitations

After running a panel regression comparing countries before and after the issuance of GBs, this research highlights a positive and significant correlation between these instruments and renewable energy capacity. However, the models employed do not infer causality on the impact of GBs, due to the presence of some limitations jeopardizing the validity of its results. Indeed, the analysis suffers from omitted variable bias (OVB), as there are potential factors influencing both the issuance of GBs and renewable energy capacity, which were not included in the above regressions. Indeed, although the fixed effect model accounts for unobserved heterogeneity, there might be unobserved variables changing over time, which affect the results' reliability. For instance, over the given time span, some countries may have developed a legal framework encouraging the development of green financing instruments and projects, which increases by default both variables and produces a biased estimate of GBs impact.

Furthermore, although the scaling procedure provides more comparable results and accounts for the economic size of issuing countries, it could contribute to biased results. Indeed, by further investigating the dataset, I concluded that major economies do not necessarily issue more GBs than other countries. For instance, the total amount of GBs issued by the Netherlands ($141 billion) is 113.9% higher than Japan ($65.9 billion), although the Japanese economy is approximately 4 times larger than the Dutch one. Therefore, given that results from Table 6 should be interpreted cautiously, this research supports the initial claim that GBs encourage the green transition based on the other regressions. Similarly, the medium and high technology export variable, which is a proxy for a country's technological advancement, may not capture the impact of scientific progress on GBs issuance and renewables instalment.

Additionally, this research suffers from the fact that the phenomenon under analysis is relatively new. Indeed, as displayed in Table 2, the GBs markets boomed only around 2016, with an increasingly number of issuing countries and proceeds' value. Moreover, to account for the time it takes to complete green projects, the renewable energy capacity variable has been forward lagged by 3 and 5 periods, leading to a substantial loss of observations. Therefore, due to the reduced sample size, the results' reliability is limited to a small time range.

Nevertheless, the analysis and its conclusions can serve as a starting point for future research on GBs, with special emphasis on their impact on the green transition. Further investigation regarding the relationship between renewable energy capacity and GBs issuance will also be required, as there might be reverse causality between the two variables. Indeed, it is likely that countries with a higher renewable energy capacity issue more GBs, given their stronger engagement to the environmental cause.

6. Conclusion

This research is based on an extensive review of the existing literature, which compare corporate GBs to conventional bonds, investigate the reasons behind their popularity and their role in addressing climate change. According to their ESG scores and disclosure transparency, these instruments appear to be beneficial for the environment, partly mitigating potential greenwashing concerns. However, the most relevant literature is lacking information on sovereign GBs and their direct impact on the environment. Therefore, this thesis investigates the relationship between GBs – both sovereign and corporate – on renewable energy capacity in issuing countries to obtain a more complete overview of these instruments. The method employed to carry out this analysis is the fixed-effect method, which reports the before and after within-country variation.

Based on this research's results, it is possible to claim that there is a positive relationship between the amount of GBs issued and renewable energy capacity. This is further demonstrated by employing a dummy for GB issuance as a dependent variable, with the coefficients displaying a positive correlation as well. Therefore, since these new instruments have proved to be effective against climate change to some extent, this thesis further mitigates any greenwashing concern. These findings are especially significant for eco-conscious investors who display a strong willingness to purchase GBs in case their proceeds are used to finance green projects instead of other initiatives. Furthermore, the results obtained underline that issuing corporations and national governments might increase their investments in renewable energy capacity regardless of the size of their GBs deals. To some extent, this demonstrates that issuers do not engage in sustainable finance solely to attract more investors, as they appear to be more likely to invest in green projects beyond these instruments as well.

The positive correlation between these instruments and renewable energy capacity constitutes an incentive for policymakers to issue GBs and encourage corporations to do the same. Indeed, sustainable finance significantly increases financing opportunities for environmental projects, facilitating the green transition. Furthermore, by adopting stricter regulations regarding GBs finance projects, it is likely that the market will further increase in size as already happened after the publication of the GBP by the ICMA, due to the legitimacy GBs would gain (Monk & Perkins, 2020).

Given these insights, future research will benefit from a higher availability of data and assess the long-term effects of GBs on the green transition. Furthermore, by performing a comparative study across countries, it could identify key economic and policy aspects influencing the success of GBs in the renewable energy sector as well as in the clean transport and green construction one. The methodology selected for this research could also be improved by employing a different statistical method which could establish causality more robustly and by including other control variables. Indeed, it could be pivotal for future study to assess the implementation of policies aimed at reducing greenwashing in the GB market, such as the EU taxonomy.

In conclusion, GBs constitute a significant instrument in favor of climate action. The results of this study underline their positive correlation with renewable energy capacity, providing relevant information to policymakers about the contribution of sustainable finance to the green transition. With climate change being the biggest challenge of our century, this research constitutes a starting point to further investigate the role of innovative sustainable solutions in addressing this phenomenon.

Appendix A

List of the 50 GB-issuing countries:

1. Argentina
2. Australia
3. Austria
4. Belgium
5. Brazil
6. Canada
7. Chile
8. China
9. Colombia
10. Cote d'Ivoire
11. Denmark
12. Finland
13. France
14. Germany
15. Greece
16. Honduras
17. Hungary
18. Iceland
19. India
20. Indonesia
21. Ireland
22. Italy
23. Japan
24. Latvia
25. Lithuania
26. Luxembourg
27. Malaysia
28. Mauritius
29. Mexico
30. Netherlands
31. New Zealand

32. Nigeria
33. Norway
34. Panama
35. Peru
36. Philippines
37. Poland
38. Portugal
39. Republic of Korea
40. Romania
41. Russian Federation
42. Singapore
43. Slovakia
44. South Africa
45. Spain
46. Sweden
47. Switzerland
48. Thailand
49. United Kingdom
50. United States

Appendix B

Table B.1

Regression Results of GBs' Amount Issued on Renewable Energy Capacity

	(1)
Dependent variable:	Renewable Energy Capacity (MW)
Amount Issued (scaled by $1 million)	1.65** (0.695)
GDP Growth	-514.28 (389.11)
Log GDP	27,869.91 (25,385.71)
Political Stability Score	-824.95 (4,757.42)
Medium and High-technology Exports	-44.03 (110.54)
Regulatory Quality	-16,727.22 (10,504.96)
GDP Growth (1-year lag)	452.42* (251.75)
GDP Growth (2-year lag)	-754.31 (588.04)
Log GDP (1-year lag)	1,852.19 (7,581.67)
Log GDP (2-year lag)	3,850.46 (9,966.83)

Medium and High Technology Exports (1-year lag)	8.79 (84.69)
Medium and High Technology Exports (2-year lag)	162.35 (203.41)
Fixed effects	Country-year fixed effect
Observations	900

Sample: GB issuing countries (from 2000 to 2021, with missing observations in 2001). **Time-varying controls:** GDP growth (with no lags, 1-year lag and 2-year lag), log of total GDP (with no lags, 1-year lag and 2-year lag), the political stability score, the % of medium- and high-technology exports (with no lags, 1-year lag and 2-year lag), the regulatory quality score. Results of the fixed effect regression of renewable energy capacity with no lags on the amount of GBs issued and other control variables. Robust standard errors are reported in parenthesis. ***, **, * indicate significance at 99%, 95% and 90% level respectively

Table B.2

Regression Results of GBs' Amount Issued on Renewable Energy Capacity

	(1)
Dependent variable:	Renewable Energy Capacity (MW)
Green Bond Issued Dummy	8,633.96** (2,819.51)
GDP Growth	-383.37 (382.31)
Log GDP	47,860.43 (38,521.85)

Political Stability Score	-10,397.38 (7,304.24)
Medium and High-technology Exports	-116.36 (151.91)
Regulatory Quality	-21,147.55 (13,946.15)
GDP Growth (1-year lag)	-313.7 (276.57)
GDP Growth (2-year lag)	-393.52 (524.25)
Log GDP (1-year lag)	3,521.69 (5,153.32)
Log GDP (2-year lag)	-10,083.53 (11,754.38)
Medium and High Technology Exports (1-year lag)	120.79 (100.69)
Medium and High Technology Exports (2-year lag)	70.72 (214.43)
Fixed effects	Country-year fixed effect

Observations	900

Sample: GB issuing countries (from 2000 to 2021, with missing observations in 2001). **Time-varying controls:** GDP growth (with no lags, 1-year lag and 2-year lag), log of total GDP (with no lags, 1-year lag and 2-year lag), the political stability score, the % of medium- and high-technology exports (with no lags, 1-year lag and 2-year lag), the regulatory quality score. Results of the fixed effect regression of renewable energy capacity with no lags on GB issued dummy and other control variables. Robust standard errors are reported in parenthesis. ***, **, * indicate significance at 99%, 95% and 90% level respectively

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