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Can Sovereign Green Bonds Accelerate the Transition to Net-Zero Greenhouse Gas Emissions?

Giusy Chesini[1]

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Abstract This paper focuses on sovereign green bonds issued in Europe. By issuing green bonds, European governments commit themselves to realizing environmentally friendly projects and encourage other entities, including private-sector ones, to do the same, thus increasing further domestic investments in addressing climate change. However, considering that governments could pursue their sustainable goals by also issuing conventional bonds, this begs the question of why governments should prefer green bonds. A dataset of European sovereign green bonds was retrieved from the Bloomberg Fixed Income database to answer this question. The data cover all European sovereign green bonds issued until the end of 2023. Quantitative analysis confirms the existence of a small green premium for the issuers, representing an incentive to increase the issuances of sovereign green bonds. Furthermore, the government's carbon emissions reduction, the power sector decarbonization, and good climate policies, measured by the Government Climate Risk Score, contribute to further reducing a country's climate risk and consequently the costs of the issuance, thus triggering a virtuous circle which could, in turn, accelerate the transition to net-zero emissions. Despite these benefits, hurdles still exist, and have curbed the development of the market. Examples include divergence between the use of funds raised through green bonds, which should be earmarked exclusively for climate and environmental projects, and the fungibility requirements for proceeds from sovereign debt and fiscal revenues.

Keywords Green bond · Sovereign · Regulation · Greenium · Climate change · Climate policy

✉ Giusy Chesini
giusy.chesini@univr.it

[1] Department of Management, University of Verona, 24 – 37129 Via Cantarane, Verona, Italy

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Introduction

Green bonds are an innovative financial tool for addressing environmental and climate challenges. They refer to debt securities whose proceeds are exclusively used to partly or entirely finance or refinance new or existing eligible environment-friendly investment projects (International City/County Management Association, 2021).

To understand the need for sovereigns to invest directly in environmentally friendly projects, it is worthwhile to preliminarily emphasize the dramatic impact of climate change on the entire economy and the consequent commitment of each nation to prevent the adverse effects resulting from global warming, such as droughts, wildfires, and floods. The commitments primarily derive from the nationally determined contributions (NDCs) submitted by the European Union (EU) and its member states, together with other nations, following the Paris Agreement under the United Nations (UN) Convention on Climate Change (United Nations, 2015a). In December 2020, an update of the agreement set a binding target of a net domestic reduction of at least 55% in greenhouse gas (GHG) emissions by 2030 compared to the 1990 level (Tolliver et al., 2019; World Bank, 2022). The NDCs require substantial funding and are part of an even more substantial financial need to meet the Sustainable Development Goals (SDGs) in the 2030 Agenda for Sustainable Development of the UN Development Programme (United Nations, 2015b).

Therefore, countries have assumed commitments to reducing GHG emissions to levels consistent with the Paris Agreement, and green bonds could be a valuable financial vehicle to stimulate a net-zero emissions economy by financing climate-smart infrastructures, such as renewable energy generation and climate-smart technology research and development (World Bank, 2022). Moreover, by issuing such bonds, countries effectively demonstrate their national commitment to sustainability as a strong signal to the market, indicating the direction of investments to stakeholders and fostering the private sector to follow suit (Heine et al., 2019).

Having ascertained that countries need to raise funds to address the challenge of climate change, it is unclear why they should choose green bonds instead of conventional bonds. In the private sector, green bonds represent one of the most substantial innovations in sustainable finance in the past 15 years. In contrast, green bond issuances at the sovereign level are relatively recent, triggered mainly by commitments required by the international agreements mentioned previously. Not surprisingly, the first sovereign green bond issuance can be attributed to the Polish government in late 2016, shortly after the agreements were approved.

Among the main arguments favoring government-issued green bonds is that they facilitate the distribution of burdens for climate change mitigation between generations. Indeed, climate change is, by definition, an intergenerational problem, given that greenhouse gases are long-lived, and their impacts are felt well after the emissions are generated (Sartzetakis, 2021). Furthermore, considering that the economic costs of investing in climate change mitigation and adaptation measures could represent a central political obstacle for governments, the issue of green bonds should

face less public opposition than broad-based taxes that require an immediate sacrifice (Kantorowicz et al., 2024).

In addition, the issuance of sovereign green bonds could also respond to the need of sovereigns to finance their investments with longer maturities (given the potentially longer horizon of green projects) and maybe at a lower borrowing cost relative to conventional bonds, reflecting what is commonly known as the "greenium". The latter is highly questionable because, in principle, it is difficult to figure out why green bonds should be priced differently than any other bond issued by the same issuer. Green projects do not generally present a lower risk than other governmental projects. Furthermore, it is not easy to argue that these bonds fund projects that otherwise would not have been financed with conventional sovereign bonds (Grzegorczyk & Wolff, 2022).

Even if there are some favorable conditions for the issuance of sovereign green bonds, currently, they are not as relevant in the bond markets (Giglio et al., 2021), probably because of the lack of a strict international set of guidelines outlining what constitutes a green bond. This lack of guidance leads to the risk of fund mismanagement, commonly known as greenwashing (Ando et al., 2022). The latter is possible because the issuers, under current regulations, would not receive any substantial penalty if their green promises are not kept (Grzegorczyk & Wolff, 2022). To diminish the perception of possible greenwashing, the issuance of green bonds is usually accompanied by a second-party opinion to ensure compliance with established green bond principles and standards. The cost of the opinion should be considered as part of the overall issuance expenses, and can vary from one issuance to another.

Despite some hurdles, European sovereign green issuances have risen substantially, particularly in the last three years. Thus, it is interesting to examine their characteristics and potential to support countries' efforts to finance the low-carbon transition. Consequently, this study investigates the possibility of sovereign green bonds contributing effectively to managing climate risks, accelerating the transition to the aims of the Paris Agreement.

The first research question concerns the fact that sovereign issuers have entered the playing field later than other kinds of issuers, and some Eastern European countries seem more committed to these issuances than others. Thus, the first research question is: Which countries have issued green sovereign bonds thus far?

Next, it is logical to investigate the motivations that induce different countries to finance green projects by issuing specific green bonds instead of conventional bonds. Thus, the second research question is: What motivations can induce a sovereign to issue green bonds?

One of the motivations could be the greenium, i.e., the market premium on the price of the green bond. The latter would suggest that investors are willing to receive a lower market premium for their green investments. Therefore, this research contributes to the literature by investigating the pricing implications of the green label on the primary market for a sample of green sovereign bonds. These considerations suggest another research question requiring quantitative analysis. Does the yield of sovereign green bonds differ from the yield of conventional bonds?

With quantitative analysis, it is also possible to investigate whether the climate risk-reduction measures expressly set up by a government could affect the yield

of green bonds. In particular, the government's progress on carbon reduction and its commitments to net-zero target pledges should be appreciated by the financial markets and make the green issuances less costly for the sovereigns. Thus, a fourth research question will address this consideration. Could the government's climate risk score, calculated and updated by Bloomberg every six months, provide evidence of the government's climate change improvements and affect the yield of green bonds relative to conventional bonds?

A final research question arises because sovereigns are the latest type of issuers to enter the green market, where they could have played a role in greening the economy much earlier. Consequently, the fifth research question explores obstacles to the growth of the market. In particular, what obstacles exist in developing a European sovereign green bond market?

Literature Review

Sovereign green bond issuances have emerged as a relatively recent phenomenon. The limited number of bonds issued has deterred extensive scholarly examination, making quantitative analyses extremely difficult. Existing research primarily focuses on issuers from other sectors (e.g., Apergis et al., 2023), where a higher volume of bonds provides a more robust foundation for study.

In the literature, two topics have been investigated the most. Both focused on the differences in bond yields. The first concerns whether there is a greenium (i.e., a premium for the issuer) for green bonds compared to similar conventional bonds. The second compares bonds that are simply self-labeled green with those that carry an external review or a second-party opinion. Furthermore, it is possible to distinguish between the broader literature that includes all categories of green bonds and the more recent and specific stream of research dedicated exclusively to sovereign green bonds, which includes the present study.

Examining the broader literature on the greenium, definitive conclusions regarding its existence remain elusive. The findings within the literature vary, influenced by the geographical samples, periods under analysis, and the specific characteristics of issuers and financial markets, whether in the primary or secondary market (Sheng et al., 2021).

Several studies exploring the presence of a greenium found that green bond yields were equivalent to those of similar conventional bonds. Consequently, the absence of a green bond premium (greenium) was evident (Flammer, 2021; Hyun et al., 2019; Kapraun et al., 2021; Lau et al., 2022).

On the contrary, other papers indicated that investors are willing to pay a premium, signifying a higher price (while accepting a lower yield) than equivalent conventional bonds, driven by their commitment to specific environmental objectives. This results in issuers receiving a premium (referred to as the greenium) on the issuance cost. Consequently, environmentally conscious investors are willing to sacrifice some yield to support bonds offering environmental or climate benefits (Baker et al., 2018; Fatica et al., 2021; Gianfrate & Peri, 2019).

Finally, investors may demand a higher yield when investing in green bonds due to the innovative and riskier nature of the underlying green projects. In such cases, green bonds yield higher returns for investors compared to conventional bonds. Therefore, a form of negative premium exists for issuers, as environmentally conscious investors perceive increased risk and demand higher returns (Bachelet et al., 2019; Karpf & Mandel, 2017).

As for studies exploring the impact of external audits or second-party opinions on green bond performance, one of the first was conducted by Bachelet et al. (2019). They showed that through external green audits, private issuers could increase their reputation as sustainable companies, decrease suspicion of greenwashing among investors and, as a result, decrease average returns for investors. A similar result was obtained by Dorfleitner et al. (2022), who found that investors rewarded green bonds approved by external auditors with a premium in terms of lower returns and higher bond prices. Consequently, external reviews appear to be one of the main factors in improving the integrity and credibility of the green bond market.

With a specific focus on sovereign green bonds, the literature is remarkably limited. In particular, there are no studies on second-party opinions, as almost all sovereign green bonds issued in Europe have received an external review of their framework and allocation and impact reports. Most studies focused on comparing green and conventional bonds issued by the same government. These studies often examined public financial management, with a prevalence of qualitative research methodologies. However, it is essential to note that quantitative analyses are not entirely neglected. For example, Doronzo et al. (2021) used a regression model to analyze a global sample of 14 countries. Their results indicated no substantial evidence of pronounced greenium. Synthetically, they showed that greenium typically tends toward negativity in the primary market but shows slight positivity (0.5 bps) in the secondary market. Likewise, looking exclusively at European countries, Grzegorczyk and Wolff (2022) identified ten precise matches between green sovereign bonds and conventional bonds. Their results revealed a consistently lower yield for green sovereign bonds, which they attribute to a behavioral response of investors willing to include green bonds in their portfolios, even at the cost of accepting a lower yield.

Dominguez-Jimenez and Lehmann's research (2021) focused on EU countries, particularly emphasizing sovereign debt. They advocated for increased transparency and comprehensive information regarding the climate-related aspects of these countries' public budgets. According to their perspective, enhanced transparency would promote stability and improve the functionality of green bond markets. Notably, environmentally conscious investors prefer more detailed information about the specific expenditures within EU countries' budgets that qualify as green.

Ando et al. (2022) explored the advantages of issuing sovereign green bonds and provided an estimate of the sovereign greenium. The methodology applied by the authors differs for Germany because it adopted a practice not initially followed by other countries, called the issuance of twin bonds. The latter consists of the issuance of two bonds (one green and one conventional) with identical coupons and maturity dates. In their analysis, Germany's greenium fluctuated between 2 and 5 basis points. For the other countries, the authors differentiated between emerging and advanced economies, considering only Euro and United States dollar (USD)-denominated bonds. The

greenium was reported as 3.7 and 30.4 basis points for Euro and USD-denominated bonds, respectively. This discrepancy was attributed to the fact that USD-denominated green bonds were issued by a more substantial number of emerging countries.

In 2023, the same authors refined their research by publishing an International Monetary Fund working paper (Ando et al., 2023), again distinguishing between twin bonds, which were issued not only by Germany but also by Denmark, and the other sovereign green bonds. The greenium resulting from the analysis of twin bonds was positive but small (around three bps). Through a panel regression analysis, they studied the yields of the other sovereign green bonds, comparing them to a dataset of conventional bonds and confirming the previous results.

Cheng et al. (2022) centered their research on the challenges sovereigns face in issuing green bonds. Utilizing the Bank for International Settlement (BIS) sustainable database, they elucidated the tensions arising from the prescribed use of proceeds for sovereign green bonds and the fungibility of public debt. Additionally, they highlighted the prominent role played by sovereign issuers in advancing best practices within the green bond market. Specifically, they observed that the inaugural issuance of a sovereign green bond stimulated an increase in green corporate issuances, particularly those accompanied by second-party opinions.

Finally, the relationship dynamics between sovereign green bonds and country value and risk, though partially unexplored, formed the focus of the investigation of Dell'Atti et al. (2022). Their empirical analysis delved into stock and credit default swap market responses to green bond issuances by ten EU countries between 2016 and 2021. Their findings revealed that investors perceived the issuance of a sovereign green bond as a value-enhancing and risk-reducing action, signaling the country's commitment to a low-carbon economy and accruing social and reputational benefits. Thus, sovereign green bond issuance is a mechanism to mitigate a country's climate risk.

In this context, the present research contributes to the literature on sovereign green bonds in four key dimensions. First, it brings attention to the inhomogeneity in data and strategies among European sovereigns, attributed to the presence of both advanced and emerging economies, each adopting distinct approaches to the green bond markets. Second, it confirms the existence of a small greenium for sovereign green bonds by analyzing a dataset composed of green and conventional bonds for 10 European countries, selected among the green bond issuers for their strong presence in the bond markets. Third, it finds that the issuance of green bonds and the set-up of other green measures and policies are recognized by the markets as a mitigation mechanism for country climate risk that can induce investors to accept a lower yield. Last, from a regulatory standpoint, the research emphasizes the absence of a robust recognition system for determining a bond's green status.

Recent Growth in Sovereign Green Bond Issuances

In Europe, 16 countries issued 54 green debt securities of different maturities and outstanding amounts as of 31 December 2023. The maturity range is between three and 30 years, except for a recent series of green Austrian T-bills with a shorter maturity.

As Table 1 shows, the largest number of sovereign green debt securities, 36 out of 54, are EUR-denominated. The other currencies used are the Hungarian Forint (HUF), the Swedish Krona (SEK), the Japanese Yen (JPN), the Chinese Renminbi (CNY), the Great British Pound (GBP), the Swiss Franc (CHF) and the Danish Krone (DKK).

At the close of 2016, leveraging the momentum generated by the 2015 Paris Agreement, Poland emerged as the inaugural issuer of sovereign green bonds, followed by France in 2017 (Tsonkova, 2019). Since then, numerous other sovereigns have entered the green bond market. While developed countries dominate most issuances, emerging nations (Poland, Hungary, Lithuania, and Serbia) contribute substantially to the overall issuances (Ando et al., 2022).

From 2020 onward, the European sovereign green market experienced rapid expansion, with Germany issuing seven green bonds and Hungary issuing 11, surpassing other countries in bond numbers.

Germany and Hungary present different economic characteristics (Chesini, 2023). In fact, developed and emerging economies tend to approach financial markets differently owing to multiple factors, such as inherent risks, different levels of liquidity, and depth of financial markets. On average, emerging markets have issued sustainable debt at much higher coupons and shorter tenors than advanced economies because of the weaker credit ratings (Goel et al., 2022). Consequently, even if both Germany and Hungary issued more green bonds than other European sovereigns, they did so by pursuing different strategies.

Considering the emerging countries, Poland, as a trailblazer in this sector, issued four green bonds between 2016 and 2019. Looking at the green-eligible sectors where the proceeds from the bonds should be employed (Table 2), it appears that Polish green bonds undertook appropriate agri-climate-environmental activities by supporting sustainable agricultural operations, afforestation, national parks, and reclamation of heaps (State Treasury of the Republic of Poland, 2016). This selection reflects the fact that more than 93% of Poland consists of rural areas inhabited by around 39% of total Polish citizens. In particular, afforestation implies the conversion to forest of land that historically was not forested. The aim of the reclamation of heaps is very particular and unique in the European context, representing expenditures on the restoration of degraded lands affected by mining.

In April 2018, the Government of Lithuania issued its first 10-year green bond amounting to EUR 20 million through the domestic auction. In 2020, the issue was tapped twice, and its final nominal value reached EUR 68 million. The green bond proceeds were expected to cover the financing gap for the Soviet-era multi-apartment building energy upgrades, achieving broad national objectives for energy efficiency in this way. In the full detailed impact reporting at the end of 2022, it emerged that the government had already used all the proceeds to renovate 170 buildings, reporting high energy savings per year (Ministry of Finance of the Republic of Lithuania, 2023).

Following the UN Climate Agreement in Paris (United Nations, 2015a), Hungary has proven to be particularly sensitive to international requirements seeking to address climate change. In 2016, it became the first European country to ratify legislation to support the Paris Agreement and broke with its traditional European

Table 1 European sovereign green bonds issued from 2016 to 2023 (in mil.)

2016			2017			2018			2019			2020			2021			2022			2023		
Poland	750	EUR	France	30.941	EUR	Belgium	10.631	EUR	Poland	1.500	EUR	Hungary	1.500	HUF	Italy	13.500	EUR	Denmark	16.240	DKK	Ireland	3.500	EUR
						Poland	1.000	EUR	Poland	500	EUR	Germany	5.000	EUR	France	14.186	EUR	Hungary	189.383	HUF	Italy	10.000	EUR
						Lithuania	68	EUR				Sweden	20.000	SEK	Hungary	129.606	HUF	Hungary	46.800	JPN	Austria	1.500	EUR
						Ireland	6.848	EUR				Sweden	20.000	SEK	Germany	6.000	EUR	Hungary	4.700	JPN	Austria	3.000	EUR
												Germany	9.500	EUR	Britain	15.492	GBP	Hungary	7.800	JPN	Germany	6.250	EUR
												Hungary	4.500	JPN	Germany	9.000	EUR	Austria	4.000	EUR	Austria	50	EUR
												Hungary	15.500	JPN	Spain	8.207	EUR	France	4.549	EUR	Austria	1.270	EUR
												Netherlands	15.690	EUR	Serbia	1.000	EUR	Germany	5.000	EUR	Germany	5.500	EUR
															Serbia	1.000	EUR	Italy	6.000	EUR	Austria	1.556	EUR
															Britain	10.854	GBP	Belgium	4.500	EUR	Netherlands	4.982	EUR
															Hungary	1.000	CNY	Austria	1.000	EUR	Denmark	10.030	DKK
																		Switzerland	1.066	CHF	Austria	1.825	EUR
																		Hungary	1.000	EUR	Austria	111	EUR
																		Hungary	2.000	CNY			

The table illustrates the increasing number of sovereign green bonds issued in Europe and the amount and currency of capital raised by each government. Data source: Bloomberg Fixed Income database (Bloomberg, 2023)

Table 2 Second-party opinion providers and eligible green expenditure categories

Sovereign	2nd party opinion provider	Eligible green expenditure categories
Poland	Sustainalytics	Renewable Energy; Clean transportation; Sustainable agricultural operations; Afforestation; National parks; Reclamation of heaps
France	Vigeo Eiris (V.E)	Climate change adaptation; Climate change mitigation; Protection of biodiversity; Reduction of air, soil and water pollution
Belgium	Sustainalytics	Clean transportation; Energy efficiency; Renewable Energy;
	Moody's ESG Solutions	Circular economy; Living resources and land use
Lithuania	-	Multiple small sub-loans to finance energy efficiency investments in multi-apartment buildings
Ireland	Sustainalytics	Sustainable water and wastewater management; Clean transportation; Environmentally sustainable management of living, natural resources and land use; Renewable energy; Built environment /energy efficiency; Climate change adaptation
Hungary	CICERO Research	Renewable energy; Energy efficiency;
	Lianhe Green	Land use and living natural resources; Waste and water management; Clean transportation; Adaptation
Germany	Institutional Shareholder Services (ISS-ESG)	Transport; International cooperation; Research, innovation and awareness raising; Energy and industry; Agriculture, forestry, natural landscapes and biodiversity
Italy	Vigeo Eiris (V.E)	Renewable electricity and heat; Energy efficiency; Transport; Pollution prevention and control and circular economy; Protection of the environment and biological diversity; Research
UK	Vigeo Eiris (V.E)	Clean transportation; Renewable energy; Energy efficiency; Pollution prevention and control; Living and natural resources; Climate change adaptation

Table 2 (continued)

Sovereign	2nd party opinion provider	Eligible green expenditure categories
Spain	Vigeo Eiris (V.E)	Renewable energy; Clean transportation; Sustainable water and wastewater management; Energy efficiency; Protection and restoration of biodiversity and ecosystems and environmentally sustainable management of natural resources; Pollution prevention and control and circular economy; Adaptation to climate change
Serbia	Institutional Shareholder Services (ISS-ESG)	Renewable energy; Energy efficiency; Transportation; Sustainable water and wastewater management; Pollution prevention and control and circular economy; Protection of the environment and biodiversity and sustainable agriculture
Denmark	CICERO Research	Renewable energy; Clean transportation
Austria	Institutional Shareholder Services (ISS-ESG)	Clean transportation; Renewable energy; Pollution prevention and control; Environmentally sustainable management of living natural resources and land use; Terrestrial and aquatic biodiversity; Climate change adaptation; Sustainable water and wastewater management
Switzerland	Institutional Shareholder Services (ISS-ESG)	Clean transportation; Agriculture, forestry, natural landscapes and biodiversity; Green buildings and energy efficiency; Renewable energy; International cooperation; Research, innovation and awareness raising
Sweden	CICERO Research	Renewable energy and energy efficiency; Pollution prevention and control; Environmentally sustainable management of living natural resources and land use; Terrestrial and aquatic biodiversity conservation; Clean transportation; Sustainable water and wastewater management
Netherlands	Sustainalytics Climate Bonds Initiative	Renewable energy; Energy efficiency; Clean transportation; Climate change adaptation & sustainable water management

The table shows the provider of the second-party opinion for each sovereign and the description of eligible green expenditures as outlined in each Green Bond Framework

Visegrad Group allies: Poland, the Czech Republic, and Slovakia. In fact, in the past, these countries tended to stick together in resisting measures that would price out the dirtiest fossil fuels. However, Hungary was less coal-reliant than some of its central and eastern European neighbors and, indeed, more inclined to take a position in the new international green market.

In particular, in 2018, the rising costs of EU carbon prices, after years of lagging, motivated Hungary toward a climate strategy to reduce carbon emissions by replacing fossil fuels, improving energy efficiency, developing a green economy, and adding forests. Consequently, in June 2020, Hungary began to issue green bonds after setting a climate neutrality goal for 2050 in a law signaling support for the net zero emission strategy (Government Debt Management Agency of Hungary, 2020). The bulk of funds raised with the first issuance was earmarked to run, maintain, and upgrade the Hungarian railway system.

In December 2021, Hungary received permission from the Bank of China to issue the first green sovereign panda bond denominated in Chinese yuan. Moreover, at the beginning of 2022, Hungary became the first foreign sovereign issuer to enter the yen green bond market. At the end of 2022, Hungary had issued one green bond in EUR, three in HUF, two in CNY, and five in YEN. The strategy pursued by the Hungarian Government is oriented toward expanding its international scope in financial markets while implementing broad and overreaching climate, energy, and environmental policies to transition the country to a low-carbon and environmentally friendly economy (Government Debt Management Agency of Hungary, 2020).

Serbia, the last emerging country considered, issued its first green bond in 2021. Analyzing the Green Bond Framework, the green sectors eligible for expenditure are not dissimilar to those declared by most developed countries. In fact, Serbia did not prioritize a specific green sector like other emerging economies. Serbia issued €1 billion in its first green bond sale, and this seven-year bond achieved the lowest annual coupon rate in its history. The green bond issue was subscribed to more than three times. Examining the second-party opinion provided by Institutional Shareholder Services (ISS) Corporate, 100% of the proceeds were earmarked for green assets as of December 2023, and the issuer followed a transparent process for allocating the proceeds (ISS-Corporate, 2024).

Considering the advanced economies and the amount of funds raised by each one, France is the most relevant issuer regarding funds raised through green bonds, followed by Germany. France issued its first sovereign bond in January 2017, following Poland, which preceded it by only one month. France had started playing the role of leader in this market with a substantial issuance serving as testimony and proof of the authoritative role played in 2015 when France was the host and convenor of the historic Paris Agreement. The first French sovereign bond raised Paris's sustainable finance profile among European countries and worldwide (Climate Bonds Initiative, 2018).

Germany, the second largest issuer, has been nearly a latecomer in tapping into the potential of green sovereign bonds, contrasting with its reputation as an energy transition pioneer. Specifically, it has been issuing twin bonds since September 2020. The twin-bonds approach involves issuing a conventional and a green bond with the same maturity date and coupon. The main difference is that proceeds from

the green bond are earmarked for green projects (Federal Ministry of Finance, 2020). However, there are other differences. The green bond's issuance volume is generally smaller, and the issuance date is later than the related conventional bond. The German government launched twin bonds to attract investors into the sustainable finance market without disadvantaging them with respect to other investors. The twin bond concept allows investors to swap conventional German government bonds with green bonds and vice versa, if deemed necessary, for example, for liquidity purposes (Climate Bonds Initiative, 2021).

Furthermore, through the issuance of twin bonds, Germany's strategy aims to establish the yields of green federal securities as the reference for the Euro green finance market. Seven twin bonds were on the market as of the end of 2023. Doronzo et al. (2021) noted that in German twin bonds the greenium is consistently positive and does not seem to react much to large uncertainty shocks, such as the Russian invasion of Ukraine in February 2022.

In 2022, another country, the Kingdom of Denmark, started issuing sovereign green bonds as twin bonds in line with the twin bond concept introduced by Germany in 2020. Towards the end of 2023, Denmark issued another green bond with the same characteristics.

Finally, a recent novelty deserves mention, that of the issuance of green sovereign money market instruments, commonly called T-bills, by a pioneer country in this market segment, the Republic of Austria. It issued its first sovereign bond (4 billion EUR of debt due 2049) in May 2022. After a few months, in October, Austria completed the country's green funding requirement for that year, becoming the first European country to issue green T-bills. The first T-bill was a 4-month maturity instrument, redeemed in February 2023. It was followed by other issuances on a rolling three-month period from February to May, May to August, August to November, November to February, and onwards.

In summary, issuances of sovereign green bonds have involved many European countries with advanced and emerging economies (Chesini, 2023). The benefits of tackling the challenge of climate change that both types of countries derive from green bond issuances are considerable. Besides signaling their international green commitments, emerging countries can obtain even more substantial benefits by involving new international investors, improving ratings, and consequently lowering funding costs (World Bank, 2022).

Empirical Analysis

The quantitative analysis empirically investigates the factors influencing green bond yields. A dataset of sovereign green bonds was compiled from Bloomberg's Fixed Income database (Bloomberg, 2023). The dataset covers all green sovereign bonds properly identified by Bloomberg and comprises 54 European sovereign green bonds issued by 16 sovereigns from December 2016 to December 2023 (Table 1). To compare the yields of green and conventional bonds, another dataset of conventional bonds issued by the same sovereigns in the same years was compiled (Ando et al., 2023).

The analysis focused on the primary market because green bonds tend to be bought mainly by institutional investors and held to maturity. For statistical reasons, after a qualitative analysis, the issuers with fewer conventional and green bonds were eliminated. In addition, the green T-bills issued by the Austrian government were eliminated as well. Consequently, the analysis focused on only ten sovereigns and 306 bonds, as shown in Table 3. In this restricted dataset, each sovereign issued at least two green bonds and a more relevant number of conventional bonds. Consequently, the final unbalanced dataset is composed of 36 green bonds and 270 conventional bonds.

To find possible differences in yields between green and conventional sovereign bonds, and to investigate the drivers of these differences, a model similar to those presented by Fatica et al. (2021) and Kapraun et al. (2021) was adopted. The baseline panel regression specification is as follows,

$$Yield_{i,t,b} = \beta_0 + \beta_1 Green_{i,t,b} + \beta_2 X_{b,i,t} + \beta_3 Z_{i,t} \quad (1)$$

where *Yieldi,t,b* refers to the yield to maturity at the time of issuance of bond *b* issued by issuer *i* in time *t*. *Greeni,t,b* is our primary variable of interest, which equals one if a bond is green and zero otherwise. *Xb,i,t* is a vector that includes a set of bond characteristics that may affect the yield. Finally, *Zi,t* is a vector of macroeconomic variables concerning countries/sovereigns that may affect the bonds' yield.

In particular, the dependent variable in the model is the yield to maturity (*Yield*), while the independent variables are those indicated in Table 4. The independent variable, called the Government Climate Risk (GCR) score (*Govt_climate_risk_score*), to the best of our knowledge, has not previously been used in the literature and is the result of three equally weighted score pillars. First is a measure of carbon transition, i.e., a measure of the government's progress on carbon reduction, carbon per capita and gross domestic product (GDP), and the gap

Table 3 Restricted dataset. Distribution of sovereign bonds by country (2016–2023)

Country	Conventional	Green	Total
Austria	25	2	27
Belgium	23	2	25
Britain	28	2	30
Denmark	8	2	10
France	28	3	31
Germany	36	7	43
Hungary	13	11	24
Ireland	11	2	13
Italy	84	3	87
Netherlands	14	2	16
Total	270	36	306

The table presents the dataset used in the panel regressions to compare the yield of conventional and green bonds issued by the same sovereign countries. The bonds were retrieved from the Bloomberg Fixed Income database (Bloomberg, 2023)

from a country's NDC (Paris Agreement). This measure provides insight on the region's historical, current and forward-looking emissions target.

Second is a measure of power sector transition, i.e., a score measuring a government's progress and future effort towards power sector decarbonization. It includes country-level capacity and generation data, as well as the outlook for wind and solar capacity additions and clean energy investment dollars. Third is a measure of climate policies, i.e., the government's commitment to Net-Zero targets' pledges, green debt issuance, and renewable energy policy frameworks.

Moving on to the model, the regressions for both fixed and random effects panel data were run. The Hausmann test was employed to decide which regression best fits the data. The test rejected the alternate hypothesis of fixed effects in the model. Therefore, only the random-effects model results are reported in Table 5.

To measure the greenium, a dummy variable (*dummy_green*) was introduced. The *dummy_green* variable is statistically significant (at the 0.01 level) and negative (b = -0.6819113). The negative sign of the coefficient suggests that when the dummy variable becomes 1 from 0 (i.e., the bond is green), the yield the sovereign pays is lower than that of conventional bonds. Thus, a greenium does exist. One possible explanation for this result is that the simple characterization of a bond as green is recognized by investors as a reason to accept a lower yield. The presence of a small greenium in sovereign green bonds is also found in Doronzo et al. (2021), Grzegorczyk and Wolff (2022), and Ando et al. (2022).

Considering the independent variables, *Rating* is statistically significant (0.0656**) and positive. In the analysis, the value 1 was attributed to AAA.

Table 4 Independent variables used in the econometric model

Independent variable	Definition
Ln_Amount	natural logarithm of the bond's amount outstanding
Rating	bond rating given by one of the following rating agencies: Moody's, S&P, Fitch, DBRS, Scope). If there are more ratings for the same bond, the average is considered
Issued_px	price of the bond at the issuance date
CPN	coupon for each bond
Years	time to maturity of each bond calculated in years
Crncy	currency of the bond
GDPcapita Govt_climate_risk_score	gross domestic product per capita theme score, which measures the governments' decarbonization transition efforts by analyzing the progress and preparedness of each sovereign country in meeting the global Paris Agreement goals

The table presents the independent variables used in the panel regression analysis. All data were retrieved from the Bloomberg Fixed Income database (Bloomberg, 2023)

Table 5 Results of the GLS regression of bond yields on independent variables (2016–2023)

Dependent variable	
Dummy_green	-0.6812***
	(0.153)
Rating	0.0656**
	(0.312)
Issue_px	-0.0627***
	(0.138)
CPN	0.223***
	(0.043)
Years	0.0098**
	(0.004)
GDPcapita	-0.000000858*
	(0.0000004)
Govt_climate_risk_score	-0.330**
	(0.153)
Ln_Amount	-0.0128
	(0.046)
Dummy_crncy	-0.824***
	(0.128)

N = 257. Groups = 10. R-squared Within = 0.1919, Between = 0.8900, Overall = 0.4616. The table reports the results of the panel regression with random effects of *Yield* on the independent variables. The values of the variables were retrieved from the Bloomberg Fixed Income database (Bloomberg, 2023). The variable definitions are listed in Table 4. The numbers in parentheses represent the standard errors of the regression coefficients. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively

Higher values were attributed to the lower ratings, meaning that the lower the number indicating the rating, the higher the rating and, consequently, the lower the yield.

Issue_px is statistically significant (- 0.0627***) and negative because the higher the price of the bond, the lower the yield. The estimated coefficient for *CPN* is statistically significant and positive (b = 0.223***). As *CPN* increases, *Yield* increases as well. *Years* is also statistically significant and positive (0.00983**). As *Years* increases, *Yield* increases as well, as in other papers (e.g., Apergis et al., 2022).

Then the macroeconomic variables were considered, i.e., the variables not representing the individual bond but the country. *GDPcapita* is statistically significant and negative (-0.000000858*) indicating that when the GDP per capita is lower, the country should be poorer. Consequently, the debt is riskier and the yield is higher.

Govt_climate_risk_score measures a government's decarbonization transition efforts and its preparedness to meet the global Paris Agreement goals. The score ranges from 0 to 10, where 10 is the best. The variable representing the score is statistically significant and negative (- 0.330**). The higher the score, the lower the yield. This result is highly understandable considering the methodology used

by Bloomberg (2023), where the less climate risky sovereigns have higher scores. Thus, the climate risk score shows that the sovereign issuance of green bonds also acts as a mitigation mechanism for country risk and, with a completely different methodology, the present analysis confirms the result of Dell'Atti et al. (2022).

The variable *Ln_Amount* is not significant, but the sign is correct (- 0.0128). The higher the amount of the bond, the higher the liquidity and the lower the yield (Apergis et al., 2021).

Finally, the analysis introduces another dummy variable concerning the bond's currency to verify if the greenium is higher for green bonds issued in Euro. The *dummy_crncy* is statistically significant and negative (- 0.8241***), indicating a lower yield for bonds issued in Euro (Ando et al., 2022). To confirm the results, different panel regressions were run excluding one or more countries from the dataset, and the results did not change.

In summary, the statistical analysis indicates that sovereign green bonds tend to be issued with a small greenium. In addition, the more a country can implement new climate policies, reduce GHG emissions, and deploy decarbonization processes, the lower its climate risk, and, consequently, the higher the greenium in respect to the funding costs in the market. Combining both results, European sovereigns should issue green bonds and transparently implement green projects and policies. In doing so, they can be funded by providing a lower yield to the investors concerning conventional bonds. Moreover, these improvements are recognized in their respective climate risk score. In turn, they can issue new green bonds with lower risk and lower yields. Furthermore, it should not be overlooked that the issuance of sovereign green bonds is an essential signal to the market and incentivizes other issuers in the private sector to follow suit and make more effort to reach the aims of the Paris Agreement.

Main Hurdles to the Issuance of Sovereign Green Bonds

It is possible to identify two relevant obstacles to developing the market of sovereign green bonds until now. The first involves almost all green bond issuers, while the second is related explicitly to the sovereigns.

The first hurdle is a regulatory issue. The European regulation did not provide a strict definition of green bonds. Until now, the financial sector has relied extensively on authoritative guidelines issued by different private entities. In particular, in 2014, the International Capital Market Association (ICMA) began to provide guidelines and green project categories. It proposed the Green Bond Principles (GBPs), which have quickly become the most-used references by operators (ICMA, 2021; Sartzetakis, 2021).

Other similar principles have been issued for self-regulation in the green financial industry. For example, the Climate Bonds Initiative (CBI) built its own Climate Bonds Standards (CBSs), providing a sector-specific definition of green in early 2012 (Climate Bonds Initiative, 2019). This framework is specifically aimed at climate bonds, which can be categorized as a subset of green bonds. While green bonds are usually issued to raise money for environmental projects, climate bonds

more narrowly focus on raising funds for investments in emission reductions or climate change adaptation. The GBPs and the CBSs provide many recommendations but no obligations, essentially because they result from private initiatives. Bond issuers' compliance remains voluntary, leading to the possibility of misused funds, commonly known as greenwashing (Mosionek-Schweda & Szmelter, 2019; Rose, 2021).

In this context, in December 2019, the European Commission launched the European Green Deal to promote and facilitate the transition to a climate-friendly environment while pursuing the economy's growth. To reach this ambitious goal, a comprehensive mix of legislative and non-legislative measures were scheduled and progressively implemented (Claeys et al., 2019). According to this ambitious strategy, in July 2021, the European Commission presented a proposal for regulation of European green bonds defining the European Green Bond Standard (EU GBS), i.e., a set of voluntary standards applicable to any green bond issuer, aiming to help scale up and support the environmental ambitions of the green bond market. The fundamental intention is to impose stricter sustainability requirements on issuers when they raise funds to protect investors from greenwashing (European Commission, 2021). In November 2023, the EU GBS Regulation was finally published (Official Journal of the European Union, 2023). From 2025, the EU GBS will start applying. It is more rigorous than other existing green bond standards, particularly regarding the allocation of bond proceeds, and will minimize the concern about greenwashing.

The second challenge, unique to sovereign issuers, revolves around the fungibility of fiscal revenues. The inception of the green sovereign bond segment in late 2016 is likely attributed to this significant hurdle. Sovereign issuers grapple with the tensions between allocating funds expressly designated for green projects and meeting the fungibility demands of financial resources (Doronzo et al., 2021).

The fungibility of fiscal revenues is one of the main principles of public financial management, and it poses a challenge for many potential sovereign issuers of green bonds. Such issuers cannot legally commit themselves to using the proceeds of the bond for a specific green purpose. Even if this restriction does not apply to all sovereigns (Dominguez-Jimenez & Lehmann, 2021), practically public budgets are subject to frequent changes and, thus, potentially to uses other than those envisaged for the proceeds of an existing green bond issuance (Cheng et al., 2022). Consequently, the current framework for most sovereign green bonds does not guarantee that new green investments will be made using the bond proceeds. Often, the funds are used to refinance past expenditures. Some sovereigns have tried to address this issue by committing some portion (e.g., at least 50% of the proceeds) for same-year spending or a combination of current and future expenditures (Cheng et al., 2022).

In summary, the issuance of sovereign green bonds requires increased efforts and imposes additional transparency obligations compared to conventional bond issuances. At times, a substantial investment in government operations is necessary for the efficient and successful issuance of green bonds. Additionally, it is crucial to consider the direct tangible costs associated with the preparation of the allocation and impact reports and related second-party opinions. Lastly, reputational costs should be treated as if the government will fail to fulfill its commitments related to green projects (Lindner & Chung, 2023).

Conclusions

This research aims to answer the question of whether sovereign green bonds can accelerate the transition to a greener economy. It also presents an overview of the recent development of the European sovereign green bond market, describing the existing barriers to further market development. Furthermore, it contributes to the literature because the market is still in its infancy, and few studies have focused only on European sovereign green bonds. Even though the European sovereign green bond market remains small, it has increased steadfastly in the last few years mainly because governments, like other market participants, are asked for more credible policies to face the challenge of climate change.

Among the benefits of sovereign green bond issuances, it is worth underscoring their role as a benchmark in domestic sustainable markets. The supply is not keeping up with demand. Usually they have been oversubscribed due to the growing ESG investor clientele demanding more and more ESG assets. Of course, demand dynamics vary according to the prevailing economic and geopolitical backdrop and the size and maturity of different securities. For example, the first French issuance of sovereign green bonds presented a demand eight times higher than the supply.

The presence of emerging economies among issuers necessitates an exploration of their motivations for entering this market. It appears that green bonds tend to be issued with a longer maturity, so the refinancing risk is lower, and the benefits may be more considerable for emerging European countries with less stable demand for extra-long maturities. In addition to signaling their commitment to sustainability goals, emerging economies can diversify their investor base and achieve better pricing. The case of Hungary, with its issuances in the Chinese and Japanese financial markets, illustrates this phenomenon quite well. On the other hand, Serbia, for example, achieved the lowest annual coupon rate in its history with its first issuance of green bonds.

The panel regression analysis indicates that sovereign green bonds, on average, are issued with a small greenium with respect to conventional bonds, as other scholars have already documented. The result is more remarkable for green bonds issued in euros. The analysis also considers a new score, computed and updated by Bloomberg (2023), which measures the efforts of a country towards the goals indicated in the Paris Agreement. The panel analysis demonstrates that the commitments and actions of governments related to carbon reduction, power sector decarbonization and the adoption of climate policies contribute to reducing a country's climate risk and, consequently, the costs of the issuances. This should further incentivize the governments to finance new green projects by issuing green bonds.

Two main obstacles have prevented European countries from paving the way in issuing sovereign green bonds until now. First, due to fungibility requirements, most sovereign debt legal frameworks do not allow the earmarking of proceeds to specific green projects. In fact, unlike sovereign conventional bonds, whose proceeds can be used for general purposes, the proceeds from green bonds need to finance specific green projects, tying the hands of the issuer. Second, until now, there have been no uniform and strict green bond standards within the EU, and this may have curbed the

segment's growth. In this regard, the new EU GBS, which take effect in 2025, will better ensure that European issuers can benefit from green financing and that investors can find the green investments they seek without the risk of greenwashing.

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