Assessing the Impact of Sovereign Green Bonds on Energy Transition: A Staggered Difference-in-Difference Analysis

Darragh O'Neill
(42221)

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Abstract

An increasing number of governments are adopting the issuance of sovereign green bonds (SGBs) as part of their strategies for transitioning to renewable energy and achieving their net zero greenhouse gas emissions targets. However, due to the nascency of the SGB market, little empirical evidence of their effectiveness as drivers of energy transition exists. This thesis investigates the impact of SGB issuance on a country's energy mix and on corporate green bond (CGB) issuance volumes in the country of SGB issuance. First, I discuss the mechanisms through which SGB issuance could have a positive impact on environmental outcomes at a country level. I then provide an insight into the characteristics of SGBs and their issuers before analysing the effects of SGB issuance on renewable electricity share of total installed electricity capacity, and on CGB issuance volumes, using a staggered difference-in-difference event study approach. My results suggest that SGBs alone do not accelerate the transition to renewable energy or lead to higher issuance volumes of CGBs. However, SGBs may still provide value when employed as part of a wider decarbonization strategy, as promoters of other green initiatives being carried out by the issuing government.

Keywords: Sovereign Green Bonds; Green Bonds; Energy Transition; Sustainable Finance; Staggered Difference-in-Differences

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1. Introduction

More frequent and extreme weather events induced by climate change attributable to human activities are already causing widespread adverse impact, loss, and damage to nature and people (IPCC, 2022a). In order to limit the negative impacts of human activity-induced climate change, 196 parties ratified the Paris Agreement in 2015 at COP21, with the goal of limiting the global average temperature increase to well below 2°C above pre-industrial levels (UNFCCC, 2023a). Achieving this goal hinges on the reduction of additional greenhouse gas (GHG) emissions to net zero, a target that that around 140 countries had set or were considering, as of November 2022 (Climate Action Tracker, 2023). Energy (electricity, heat, and transport) is the largest contributor to global GHG emissions, accounting for 73 per cent of total emissions (Ritchie et al., 2020). Under the International Energy Agency's Net Zero Emissions Scenario, which provides a roadmap for achieving net zero additional GHG emissions by 2050, stabilising the increase in global average temperature over pre-industrial levels to 1.5°C, and enabling universal access to modern energy by 2030, annual investments in renewable energy (RE) will need to reach a level of USD 4.2 trillion by 2030, approximately 4 per cent of global GDP, of which USD 3 trillion is expected to come from the private sector (IEA, 2022). This required amount is almost 8.5 times the USD 495 billion invested in RE in 2022 (BNEF, 2023).

Governments must play a critical role in catalysing private sector investment in climate change mitigation and adaption (Georgieva & Adrian, 2022). A number of mechanisms have been proposed for incentivising investment in green projects, and deterring investment in carbon-intensive endeavours, including subsidies, public-private partnerships (PPPs), robust carbon pricing, green bonds (Georgieva & Adrian, 2022; IEA, 2023b; Jun et al., 2016).

Through PPPs, governments can encourage investment in renewable energy capacity development by reducing the risk burden for private investors (Georgieva & Adrian, 2022). This de-risking of the project for private sector investors can be achieved through the provision of a variety of credit enhancements and/or guarantees by governments to private investors, or through the injection of public sector capital to the project in the form of an equity stake, with private investors taking on the debt portion of the investment.

The International Energy Agency (IEA) describe existing fossil fuel subsidies as a roadblock to the transition pathway to renewable energy (IEA, 2023b). Through the reduction of these subsidies, combined with the introduction of subsidies for RE capacity development or of a robust carbon price that properly reflects the environmental costs of fossil fuels, governments can significantly influence the payoff profiles of investments in both clean and carbon-intensive energy supply, encouraging private capital to flow out of carbon-intensive energy supply, and into the development of RE infrastructure.

Finally, green bond (GB) issuance has been proposed as a way of promoting investment in green projects by enhancing the issuer's reputation, by clarifying their environmental strategy, by reducing the search costs of responsible investors seeking to invest in green projects, and by increasing the issuer's access to longer-term financing (Jun et al., 2016). The issuance of green bonds by central government, or sovereign, issuers, often referred to as sovereign green bonds (SGBs), has been suggested as a mechanism through which governments can facilitate the scaling up of green bond markets, and thus catalysing private sector investment in green projects. However, due to the nascency of the SGB market, little empirical evidence of the hypothesised positive impacts of SGB issuance exists.

The study of the effects of SGB issuance is important, as it informs the decision-making processes of sovereign issuers considering entry to the SGB market. While SGBs have the potential to catalyse private sector investment in green industries, their issuance also comes with the additional costs of managing and reporting on the allocation of proceeds, of reporting the estimated impact of their investments, and of obtaining verification from second party opinion or third-party assurance providers that the projects being invested on can be considered as 'green' (Jun et al., 2016). As a result, should the hypothesised positive effects of SGB issuance fail to materialise, SGBs may become counterproductive to a government's decarbonisation efforts, as the added verification and reporting costs could reduce the level of capital available for deployment to green projects than would have been available if the issuer had chosen to issue a similar conventional bond.

This thesis addresses a gap in the literature by deploying a staggered difference-in-difference event study approach to empirically investigate the effect of SGB issuance on the country's renewable electricity share of total electricity capacity, and its effect on the issuance volume of GBs by private sector issuers in that country.

My initial results appear to provide evidence that SGB issuance has a positive effect both on growth in renewable electricity share of total electricity capacity and on issuance volumes of corporate green bonds (CGBs). However, upon further investigation, I see that these results are heavily influenced by the effects observed in Poland, which I find unlikely to be related to their SGB issuance. After repeating the study with Poland excluded from the treatment group, I find no evidence that SGB issuance increases either the renewable electricity share of total electricity capacity or the issuance volume of GBs by private sector investors in the country of SGB issuance.

The remainder of the paper is structured as follows. Section 2 provides an overview of the existing literature studying the issuance of SGBs, the impacts of GB issuance, and the determinants of corporate green bond market development. Section 3 provides a description of GBs and the additional requirements placed on their issuers, an overview of the development of the GB market to date, and a comparison of sovereign and corporate bond markets. Section 4 describes the hypothetical framework by which SGB issuance would be expected to produce a positive effect on the renewable electricity share of total electricity capacity, and on the issuance volume of GBs by private sector investors in the country. Section 5 describes the data used in my analysis, along with some stylized facts describing the characteristics of SGBs, CGBs, and their issuers. Section 6 presents and discusses the empirical methodology and results of the analysis of the effect of SGB issuance on renewable electricity share of total electricity capacity. Section 7 provides the same for the analysis of the effect of SGB issuance on CGB issuance volumes. Section 8 presents concluding remarks and suggestions for future research.

2. Literature Review

Due to the nascency of the SGB market, few papers have focused on green bond issuances by sovereign issuers, and even fewer have analysed SGBs empirically. Early studies proposed that SGBs could offer a mechanism for reducing the intergenerational unfairness of paying for the transition to a low-carbon economy by raising capital to finance adaptation efforts, with a green tax introduced for future generations to repay the bonds once adaptation efforts have been completed (Sachs, 2015; Flaherty et al., 2016).

Further studies employ DICE (Dynamic Integrated model of Climate and the Economy) and EIRIN flow-of-funds models to provide evidence that this proposal could reduce, but not eliminate, intergenerational unfairness (Orlov et al., 2017; Monasterolo & Raberto, 2018). DICE models project economic consumption in the future based on changes in current consumption (Nordhaus, 2017). Orlov et al. (2017) deploys the DICE model to show that, while consumption rates of the current generation suffer at the expense of those of future generations due to the need to deploy a vast amount of capital towards climate change mitigation and adaptation efforts, with benefits only fully realised in the long-term, the issuance of SGBs, complemented by the introduction of a green tax for future generations, can help to reduce the intergenerational unfairness of paying for climate change mitigation and adaptation. Monasterolo & Raberto's (2018) EIRIN flow-of-funds model is a behavioural model which simulates the effect of introduction of green fiscal policies and the issuance of SGBs on firms' investments in green and carbon-intensive sectors, on unemployment, and on the credit and bonds market. Through the deployment of the EIRIN model, they find that SGB issuance can help to spread the cost of paying for climate change across generations. Further employments of EIRIN models suggest that SGB issuance produces favourable conditions for the accumulation of renewable production capacity and generate positive spillovers to GDP growth (Monasterolo and Raberto, 2019; Monasterolo et al., 2022).

Doronzo et al. (2021) investigates the financial performance of SGBs on both primary, by analysing yields at issuance compared to similar conventional bonds, and secondary markets, by analysing the evolution of SGB yields, finding that SGBs perform essentially in line with conventional issuances on both markets. However, Ando et al. (2023) find a small, yet growing, primary market price premium (4 basis points) on SGBs in Advanced Economies, with a more significant price premium (11 basis points) in Emerging Markets. Evidence of positive reactions of domestic stock and credit default swap (CDS) markets to SGB issuance also exists (Dell'Atti et al., 2022). While not explicitly focused on SGBs, Azhgaliyeva et al. (2022) find that a higher share of sovereign issuances labelled as 'green' increases the probability of corporate green bond issuance in a country.

In studying the impacts of CGBs, Flammer (2021) finds evidence that green bond issuances lead to improved environmental performance at firm level. The improvement is realised in the form of reduced carbon dioxide emissions and higher environmental ratings, but only for bonds certified by an independent third party. Fatica & Panzica (2021) find that non-financial green bond issuers display a decrease in carbon emissions intensity than similar companies who do not participate in the green bond market, with a more pronounce decrease observed when green bonds with refinancing purposes are excluded.

While these studies find evidence of green bonds leading to improved environmental performance at the firm level, a dearth of analysis exploring their country-level environmental impact exists. This paper contributes to the existing literature by examining the impact of SGB issuance on country-level environmental performance. To the best of my knowledge, it is the first paper to attempt to do so.

Jun et al. (2016) proposes that the issuance of SGB could support the development of local green bond markets by educating potential issuers and investors on the issuance process in their markets, setting a best practice example, and sending a strong signal of government support for green investment. Studies of conventional bond markets have shown that macroeconomic and institutional factors are significant drivers of corporate bond markets (Eichengreen and Luengnaruemitchai, 2004). Macroeconomic and institutional factors have also been observed to influence the growth of sovereign bond markets (Claessens et al., 2007). Dittmar & Yuan (2008) demonstrate that sovereign bond issuances lower corporate yield and bid-ask spreads in emerging markets, suggesting that sovereign bonds promote corporate bond market growth by acting as high-quality benchmarks for corporate issuances.

Using structural equation modelling (SEM), Tolliver et al. (2020) find that macroeconomic and institutional factors, as well as the robustness of a country's Nationally Determined Contributions (NDCs) affect green bond issuance volumes. NDCs are national pledges to reduce greenhouse gas emissions and adapt to the impacts of climate change, that play a central role in the achievement of the goals of the Paris Agreement (UNFCCC, 2023b). Maltais & Nykvist (2020) provide survey evidence that financial incentives for issuers to favour green bond issuance over conventional issuances are weak. This is in line with findings of Doronzo et al. (2021). This paper examines whether sovereign green bonds issuances promote the corporate green bond issuances, as has been observed in conventional bond markets by Dittmar and Yuan (2008). Cheng et al. (2022) report having found that corporate green bond issuances increase following the issuance of a SGB by regressing the number of corporate green bond issues on a sovereign green bond issuance dummy variable, a quarterly time trend, and country fixed effects, in a note to a graph. However, they are yet to publish a paper detailing the methodology and full results of the study.

This paper adds to the literature by being the first to empirically examine the effects of SGB issuance on CGB issuance volumes.

3. Institutional Background

3.1 Green Bonds

Green Bonds are the most dominant instrument in the Green, Social, and Sustainable Plus (GSS+) universe making up 58 per cent of total GSS+ volumes in 2022 (Michetti et al., 2023). Green Bonds are debt instruments issued to finance or refinance green projects with environmental benefits (Jun et al., 2016). Even though the bond proceeds are earmarked for green projects, it is important to note that the obligation of repayment lies with the issuer, meaning that project-specific risk remains with the issuer rather than being passed on to investors (Doronzo et al., 2021). A key barrier for the scaling of green bond markets is that definitions of what make a bond "green" vary (Ehlers & Packer, 2017). In order to address the lack of a universally accepted definition of "green", issuers of green bonds usually publish a Green Bond Framework (GBF), which is often structured around the four pillars of the ICMA's Green Bond Principles (GBPs) (IFC, 2020).

The four pillars of the GBPs are: Use of Proceeds (UoP); Process for Project Evaluation and Selection; Management of Proceeds; and Reporting (ICMA, 2022a). Under the Use of Proceeds pillar, issuers detail the requirements that projects must be satisfied in order to be considered as "green", and therefore eligible to receive funding from the proceeds of the GB issuance. Energy, buildings, and transport are common categories of projects that receive funding from GB issuances, making up 81 per cent of the UoP of GBs in 2021 (Harrison et al., 2022).

The GBPs advise that GB proceeds should be ringfenced in sub-accounts, sub-portfolios, or subjected to appropriate tracking procedures (ICMA, 2022a). Under the 'Reporting' pillar, the GBPs recommend that issuers publish allocation and impact reports on an annual basis to disclose how proceeds have been deployed and what impact has been generated from the projects receiving funding. The ICMA offer further guidance on how to produce impact reports, including key indicators of impact to report on for common UoP categories (ICMA, 2022b).

While the ICMA's GBPs are voluntary guidelines, the principles are widely followed, as exhibited by the fact that 86 per cent of green bonds comply with their recommendation of acquiring external reviews for enhanced transparency (Harrison et al., 2022). Other avenues for establishing the credibility of a green bond's environmental credentials include aligning

UoP to the CBI's sector-specific Climate Bonds Standard, or with China's Green Bond Finance Committee's Green Bond Endorsed Project Catalogue.

3.2 Green Bond Market Development

While the emergence of green bonds is relatively recent, early GBs were essentially a new type of thematic bonds. Thematic bonds are not a new product, having previously been used to finance infrastructure (Semmler et al., 2011) and wars (Kimble, 2006). The European Investment Bank's USD 1 billion Climate Awareness Bond, issued in 2007, is largely considered to be the first example of a green bond (Banga, 2019). Early issuers of green bonds were predominantly Multilateral Development Banks (MDBs), with municipal and corporate issuers entering the frame in 2013, and the green bond market growth accelerating with the introduction of the GBPs in 2014 (Monk & Perkins, 2020). In 2022, GB issuance volumes exceeded USD 487 billion, issued by 741 different issuers, from 51 different countries (Michetti et al., 2023). The first SGB Government of the Republic of Poland on 13 December 2016 (Moore, 2016). The issuance of SGBs is becoming more common, yet the three largest issuers of conventional sovereign debt (USA, Japan, and China) are still to issue their debut SGBs (Michetti et al., 2023), suggesting that the market still has significant room for growth. Another avenue of growth for the green bond market is the emergence of new thematics. In 2018, the Republic of Seychelles issued the world's first Blue Bond, with proceeds to be deployed to support sustainable maritime and fisheries projects (Hay, 2018), and the World Bank's 'Rhino Bond', issued in March 2022, has opened the door for the expansion of green bond applications to tackle biodiversity issues (Sguazzin, 2022).

3.3 Sovereign and Corporate Bond Market Comparison

To understand the mechanisms through which SGB issuance may drive environmental performance improvement, we must first examine the factors that differentiate sovereign debt from other debt asset classes.

While corporates tend to issue debt in order to achieve a preferred capital structure, which balances benefits resulting from an interest tax shield with the increased risk of financial distress (Myers, 2001), sovereign debt issuances are mostly used to finance deficits, either when tax revenues drop below the level needed to pay for existing government spending commitments during times of recession, or when government want to invest in the future of their country through projects that carry high up-front costs (Abbas & Pienkowski, 2022).

When assessing sovereign credit risk, investors must not only assess the issuer's ability to repay the debt, as is the case with corporate issuers, but also the issuer's willingness to repay the debt (Eaton & Fernandez, 1995). This is due to the relative inability of a court to force repayment by a sovereign entity. Instead, investors must rely on the sovereign issuer's desire to avoid the reputational damage that would arise from default, potentially leading to higher borrowing costs in the future.

Yields of sovereign bonds tend to be lower than those of corporate bonds issued in the same country (Bevilaqua et al., 2020). This is believed to result from sovereign credit risk being a component of corporate credit risk, meaning that risk compensations corporate borrowings would need to be at least as high as for their sovereigns. Another reason for the lower yields on sovereign bonds relative to corporate bonds is the enhanced liquidity of the sovereign bond market (Fang et al., 2023). This high degree of liquidity, with lower perceived risk is a key reason that central banks and private banks are common holders of sovereign debt, while non-bank investors are primarily pension and insurance funds.

In green bond markets, sovereign issuers have undertaken the role of setting best practices and promoting the ICMA Green Bond Principles, with all SGB issuers to date having adopted the GBPs, having acquired external reviews of their frameworks, and having committed to the issuance of allocation reports (Cheng et al., 2022). While Energy is one of the most common use of proceeds in green bonds (Harrison et al., 2022), it is a far less common UoP in sovereign issuances, receiving less than a fifth of all SGB proceeds (Cheng et al., 2022).

In some nations, the legal requirement of fungibility of government revenues restricts the scope of sovereign green bonds (Cheng et al., 2022). In Germany, for instance, the earmarking of funds is disallowed, except for pension funds and health insurance (OECD, 2014). As Kramer (2020) points out, this limits the ability of green bond proceeds to be matched against the previous year's budget expenditures, significantly reducing the likelihood of additionality of green investment.

4. Theoretical Framework

4.1 SGB Impact through Additional Government Investment

Green bonds are often considered as a tool for financing climate change mitigation efforts (Orlov, 2018; Flammer, 2021; Fatica & Panzica, 2021). However, there is a dearth of analysis finding improvement in environmental performance at the country level. Although the proceeds raised from green bond issuances are earmarked for environmentally friendly projects, question marks remain over whether green bonds generate additional investment in green projects, or if they simply relabel the investments that would otherwise have been made from a conventional bond (Bongaerts & Schoenmaker, 2019). It is argued that projects lead finance, not the other way around, so the likelihood that investments flowing from green bond capital is additional is low, especially when proceeds are allowed to be deployed for the purpose of refinancing existing projects (Kramer, 2020).

One mechanism through which green bonds could generate additional investment in green projects is through offering a lower-cost source of financing, increasing the number of commercially viable projects. However, no evidence of a 'greenium' has been found for SGBs (Doronzo et al., 2021). Even where a 'greenium' in issuances from non-sovereign issuers has been found to exist, Maltais & Nykvist (2020) provide survey evidence that few bond market participants are of the opinion that it is sufficiently significant to increase the number of commercially viable green projects.

When investigating the post-issuance of environmental performance of CGB issuers, Flammer (2021) found evidence of an improvement in environmental outcomes, despite a lack of evidence suggesting that CGBs offered a cheaper source of capital to issuers. It is possible that a similar effect could be observed in the performance of sovereigns if issuers believe that the positive reputational benefits associated with a green bond issuance justify investment in green projects that would have been judged to be of a lower value otherwise.

4.2 SGB Impact through Additional Private Investment Generation

The mechanisms by which SGB issuances could yield improvements in country-level environmental performance by mobilising private capital towards green projects appear more plausible, since the incentives of corporate green bond issuers are not limited to acquiring cheaper financing sources, but also to achieve improved financial performance through positive stock market reactions (Flammer, 2021). This suggests that investors view the issuance of green bonds as a positive signal. The findings of Dell'Atti et al. (2022), that a country's stock market index increases in value and that their CDS market reacts positively following the issuance of an SGB is consistent with Flammer's findings, suggesting that investors view the SGB issuance of a strong signal of the country's action towards climate change mitigation and adaptation.

In jurisdictions where green bond markets are not well-developed, SGB issuances can serve as a case study of how green bond issuance functions in those markets (Jun et al., 2016). By educating corporates through this mechanism, sovereigns can enhance their domestic corporates' accessibility to the green bond market.

Furthermore, Jun et al. (2016) proposes that SGB issuance can send a strong signal of government support for green investment. This may make investment in green projects appear less risky, since corporates may perceive the probability of securing offtake agreements more likely or may have greater confidence that the public sector will make the necessary infrastructural investments for the project to be a success, for example investments in a green grid to facilitate a corporate's solar farm being added to the grid. Since SGBs have also been proposed as a solution for financing the phasing out of fossil fuel subsidies, investors may also see SGB issuance as a signal of the intention to reduce subsidies to carbon-intensive industries or to increase incentives to invest in green projects (Monasterolo & Raberto, 2019).

A third possible mechanism through which SGBs could act as a catalyst for corporate green bond market development, is by providing a high-quality benchmark to increase market liquidity, as has been observed in conventional markets (Dittmar & Yuan, 2008). Dittmar & Yuan (2008) find that the yield spreads on corporate bonds tend to tighten when a liquid, high-quality sovereign benchmark exists. This is likely due to a reduction in the liquidity risk premium required by investors to hold these securities.

Since green energy is the most common use of proceeds in corporate green bonds (Harrison et al., 2022), I choose to measure the change in a country's renewable electricity generation capacity as an indicator of environmental performance improvement, both in terms of increases in absolute renewable energy capacity, and in its share of a country's total electricity capacity.

When investigating the impact of SGB issuance on renewable energy capacity, I choose to study the impact on RE share of total electricity capacity in order to avoid confusing increases in absolute installed capacity driven by energy demand growth with SGB impact.

I therefore formulate the below hypotheses for investigating the impact of SGB issuance:

H_1: *A country's level of installed renewable electricity capacity as a share of total electricity capacity (RECS) increases following the central government's debut green bond issuance.*

H_2: *A country's issuance volumes of corporate green bonds increases following the central government's debut green bond issuance.*

5. Data and Descriptive Statistics

5.1 Data Sources & Manipulation

I construct a unique, unbalanced panel dataset, by collating renewable electricity capacity data, green bond data, and country characteristics at the country level for 223 countries and territories (hereafter referred to as countries).

The renewable electricity capacity data used comes from the International Renewable Energy Agency (IRENA) Renewable Capacity Statistics 2023 report (IRENA, 2023). The report records details of total renewable electricity capacity, both on- and off-grid, installed in each country at the end of year from 2013 to 2022, providing breakdowns by technology, and the RE share of total installed electricity capacity. Technologies classified as renewable in the report include hydropower, marine, wind, solar, solid and liquid biofuels, biogas, and geothermal. Nuclear energy is excluded. From this report, I extract total renewable electricity capacity and renewable energy share of total installed electricity capacity for inclusion in my panel dataset.

Green Bond data is sourced from Refinitiv Eikon. All CBI Taxonomy-compliant bonds issued between 1 January 2013 and 31 March 2023 by either sovereign or corporate issuers are extracted. The sample is restricted to securities showing an ISIN code. The final sample contains 92 sovereign green bonds from 29 unique issuers, and 6193 corporate green bonds issued by 2003 unique companies. For each bond, Issuer, ISIN, Parent Domicile, Issue Date, Maturity, Issuance Currency, Amount Issued in both Issuance Currency and US Dollar, and Use of Proceeds are extracted. In addition, Country of Issue, Issuer Domicile, and Issuer Sector are recorded for each Corporate Green Bond.

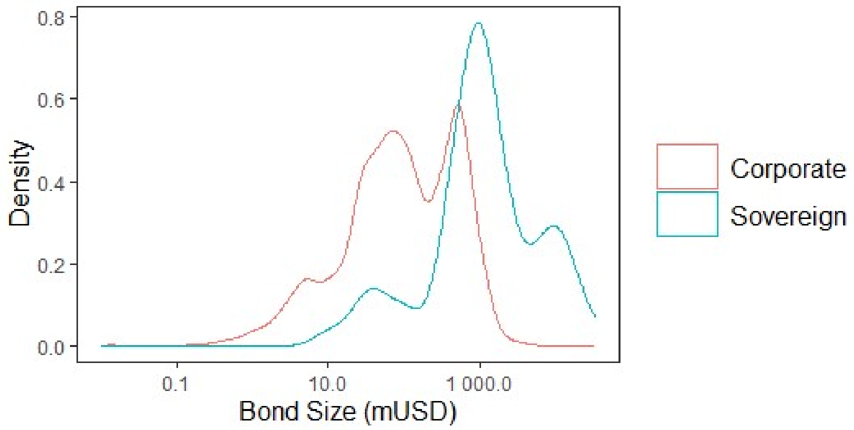
I take each country's GDP from the World Bank's World Development Indicators for years 2013 to 2021. Since GDP data is not available for 2022, I assume the GDP for each country to be the mean of the country's GDP recorded for the period between 2013 to 2021.

5.2 Descriptive Statistics on Sovereign and Corporate Green Bonds

To provide a greater understanding of the characteristics of SGBs and CGBs, I detail descriptive statistics on my sample. Figure 1 offers a comparison of the distribution of green bond issuance size between those issued by sovereign and corporate issuers. Sovereign issuances tend to be larger in size than those issued by corporates. The mean SGB size is just under USD 3.4 billion, while the mean CGB size is marginally above USD 250 million. The largest SGB and CGB issuances were issued by the Government of France (EUR 30.9 billion) and Natixis SA (EUR 6 billion), respectively. The smallest were issued by the Government of Fiji (FJD 20 million / USD 8.8 million) and Tesla Energy Operations Inc (USD 10,000), respectively.

Over 40 per cent of all SGBs are euro-denominated (see Figure 2), with USD-denominated bonds making up a further 25 per cent of SGB issuances. G10-denominated bonds account for 69 per cent of all CGB issuances. Non-G10 currencies with significant volumes of CGB issuances include Chinese Yuan, Malaysian Ringgit, Korean Won, and Brazilian Real,

Figure 1. Green bond issuance size by issuer type.

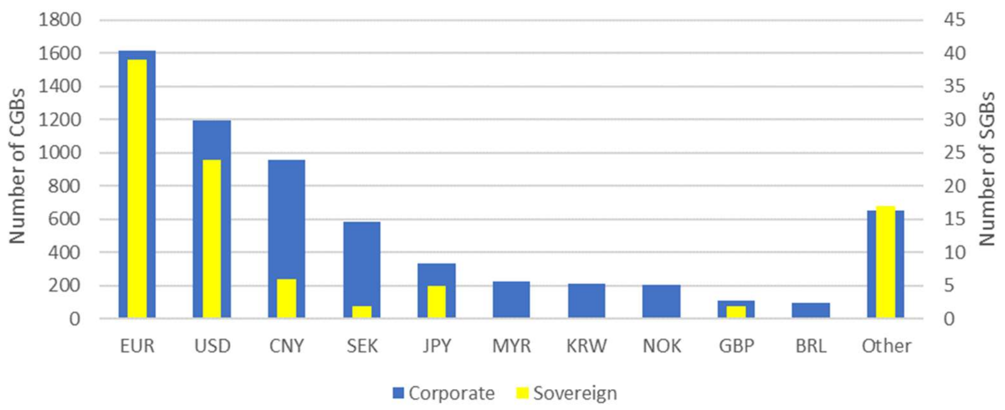


Note: This graph displays the distribution of sovereign green bonds and corporate green bonds in the sample by issued amount in million US dollars.

composing a combined 24 per cent of CGBs.

As shown in Table 1 in, two thirds (63 of 95) of all SGBs have a maturity of ten years or less. 59 corporate issuers have issued a combined 90 perpetual green bonds, while three Danish companies, European Energy A/S, Orsted A/S, and Nkt A/S, have issued 8 1000-year bonds between them. By comparison, the longest-dated SGB is a 50-year bond issued by the Government of Singapore in 2022. On the short end of the yield curve, the Government of Austria has issued three SGBs with maturities less than one year, the shortest being the world's first Green Commercial Paper, with a maturity of 32 days (OeBFA, 2023). China Three Gorges Corp issued a 91-day bond in 2022, the shortest of all CGBs.

Figure 2. Green bond principal currency by issuer type.



Note: This graph displays the breakdown of green bond issuances in the sample by principal currency.

Table 1. Maturity of green bonds by issuer type.

Maturity	# CGBs	# SGBs
Less than 1 year	1	3
1 – 5 years	3341	29
6 – 10 years	2079	31
11 – 20 years	497	15
21 – 30 years	114	14
31 - 50 years	39	3
51 – 75 years	23	0
100 years	1	0
1000 years	8	0
Perpetual	90	0

Note: This table reports the number of green bond issuances in the sample falling into each maturity bracket, broken down by issuer type.

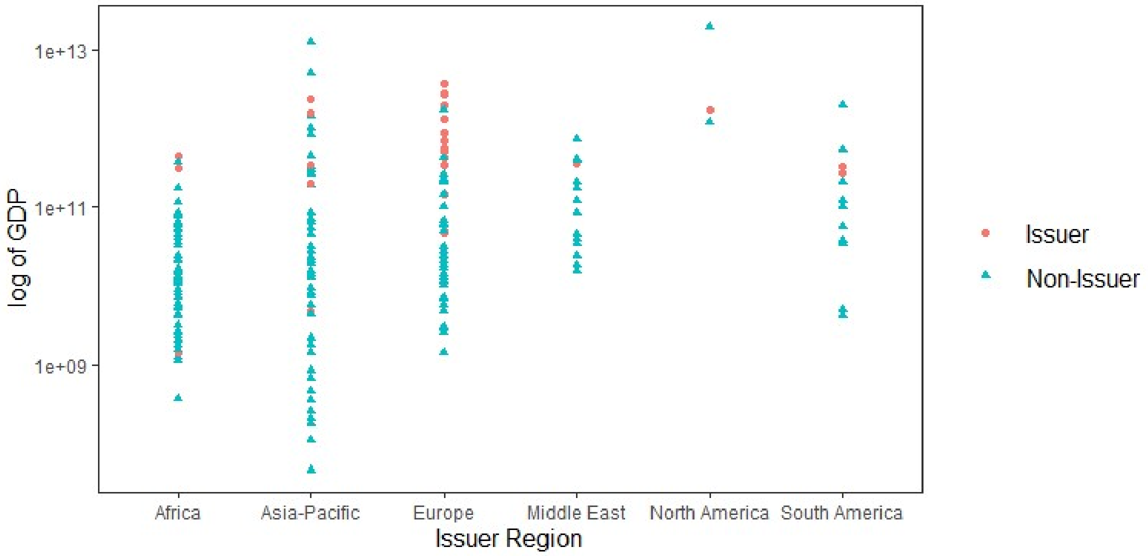
Hong Kong is by far the most prolific issuer of SGBs, with 27 issuances (see Table A1), however European issuances constitute over half of total SGB issuances (see Table 2), and 86 per cent of the total amount issued. SGB issuances are more frequent from countries with larger GDPs in each region (see Figure 3), with Seychelles and Fiji standing out as notable exceptions.

Table 2. Sovereign Green Bond statistics by region

Region	# SGBs Issued	Total SGB Amount Issued (mUSD)	First Issuer (Year)
Europe	48	276,765	Poland (2016)
Asia-Pacific	35	29,993	Fiji (2017)
South America	5	7,837	Chile (2019)
Africa	5	1,571	Nigeria (2017)
North America	1	3,667	Canada (2022)
Middle East	1	2,000	Israel (2023)

Note: This table reports the number of sovereign green bond issuances, their combined issuance amounts in million US dollars, and the year of the first sovereign green bond issuance for each region.

Figure 3. GDP profile of SGB Issuers.



Note: This graph displays the log of average GDP by country between 2012 and 2021, with a distinction made between SGB issuers and non-issuers.

6. Analysis of Effect of SGB Issuance on RE Share of Total Installed Electricity Capacity

6.1 Method

To investigate the effect of sovereign green bond issuance on the RE share of a country's total installed electricity capacity (RECS), I employ a staggered difference-in-difference event study design proposed by Callaway & Sant'Anna (2021). My study is most closely matched to that of Schulz & Rode (2021), who study the effect of public charging infrastructure on electric vehicle adoption in Norway.

Following the framework laid out by Callaway & Sant'Anna (2021), I first define my treatment group as the set of countries who issued a sovereign green bond on or before 31 December 2022. Each observation in the treatment group is then assigned to a treatment cohort G ,dependent of the year of issuance of their first sovereign green bond. Countries who issued their first sovereign green bond during the period beginning 1 January 2016 and ending 31 December 2016 are assigned to the '2016' treatment cohort (i.e., $G = 2016$).

As per Callaway & Sant'Anna (2021), I set $G = 0$ for all countries who had not issued a sovereign green bond on or before 31 December 2022, and define this set as the control group. I define G_g as a binary variable that is equal to one in instances where a country, i, issues their first sovereign green bond in period g (i.e., $G_{i,g} = \mathbf{1}\{G_i = g\}$ and define C as a binary variable that is equal to one in instances where $G = 0$ (i.e., $C_i = \mathbf{1}\{G_i = 0\}$.

I base my analysis on a subset of the panel dataset described in section 5, excluding 30 countries for which RECS data was not available. I illustrate the division of countries by treatment cohort, and control group in Figure 4 and summarise the same in Table A2.

The first set of estimations I obtain are of the effects for all treatment groups across all observed years (Callaway & Sant'Anna, 2021; Schulz & Rode, 2021). I denote $RECS_{i,t}$ as the RECS in country i at the end of year t. I then estimate the average effect on the treated countries for cohort g at time t,

$$ATT(g,t) = \mathbb{E}\left[RECS_{i,t} \middle| G_i = g\right] - \mathbb{E}[RECS_{i,t}|C = 1] \quad (1)$$

by calculating several regressions each using a subsample of those observations in the treatment- and control-group at year t

$$RECS_{i,t} = \beta_0 + \beta_1 \mathbf{1}_{G_i=t} + \beta_2 \mathbf{1}_t + \beta_3 \mathbf{1}_{G_i=t} \mathbf{1}_{\mathrm{t}} + \varepsilon_{\mathrm{i,t}}. \quad (2)$$

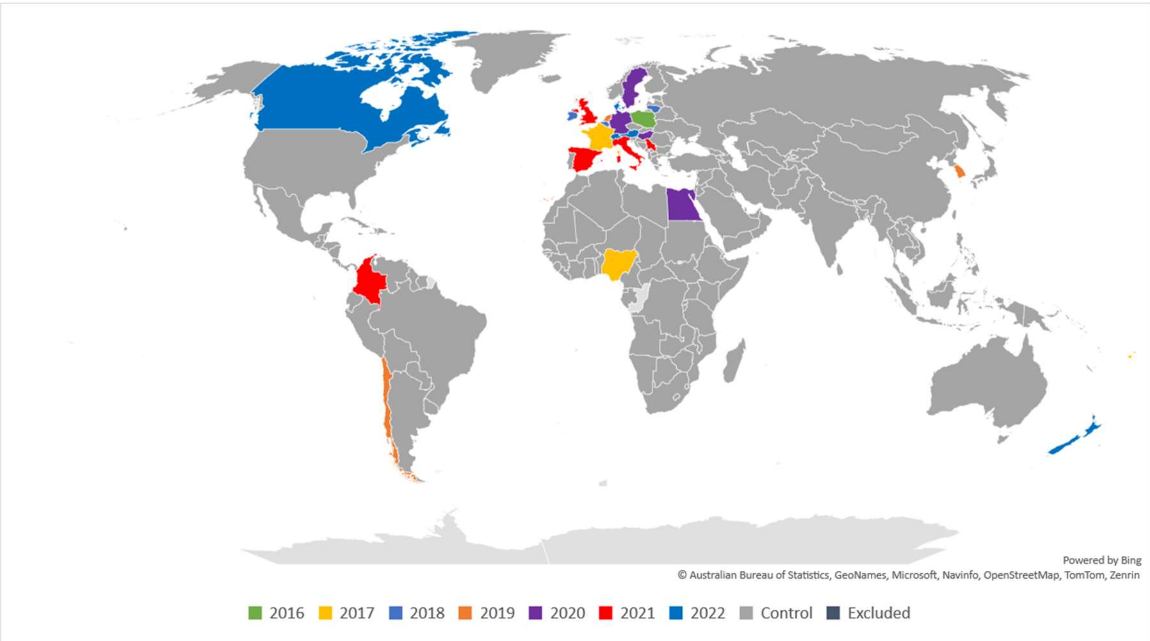
β_0 is the mean of the control group C to treatment cohort g in year t, β_1 is the fixed effect of the treated countries, β_2 is the fixed effect for year t, and β_3 is the estimate average effect on the treated ($\beta_3 \equiv ATT(g,t)$). I then aggregate these results to produce a single series of estimation results relative to the treatment period to calculate the average effect on the treated ATT for event times e, relative to the respective year of treatment ($e = t - g$).

Callaway & Sant'Anna (2021) suggest the use of group-dependent weights $w(g,t)$ when aggregating results in this way as follows:

$$ATT_{es}(e) = \sum_{g \in G} w(g,t) * ATT(g,t). \quad (3)$$

This simplification requires the assumption that the ATT is homogenous across all treatment groups (Callaway & Sant'Anna, 2021). I test this assumption by regressing all individual ATT estimates on time relative to the event year, e, and on the treatment group they are in, g. As displayed in Table A3, ATT estimates vary by event year at the 1 per cent level of significance, but not by treatment group at any conventional level of significance, indicating that they are homogenous and thus meet the requirement for the aggregation suggested by Callaway & Sant'Anna (2021) above.

Figure 4. Cohort Profiles for analysis of SGB issuance effect on RECS



Note: This figure illustrates the division of countries into treatment cohorts, control group, and countries excluded due to incomplete data.

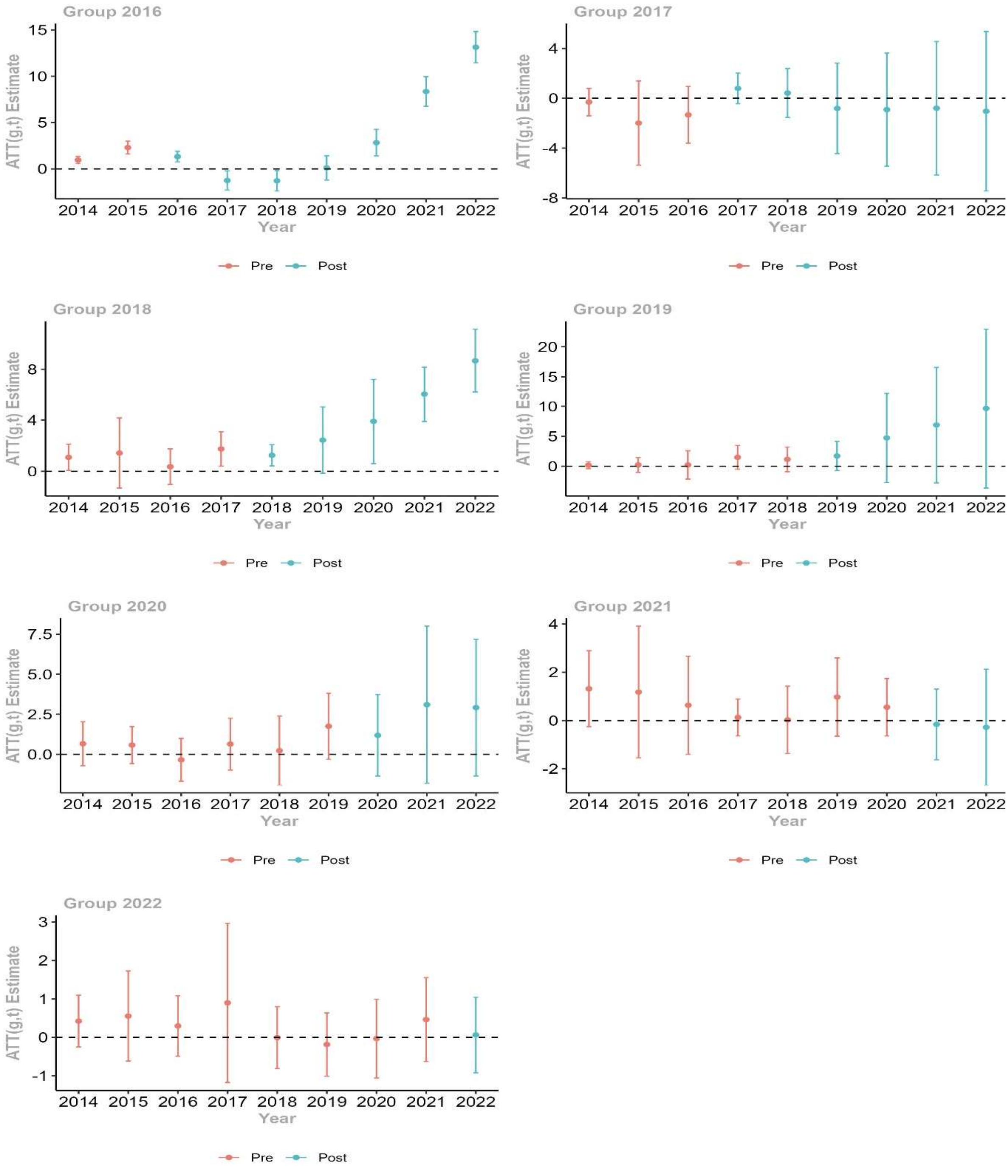
6.2 Results

The group-time average treatment effects are displayed in Figure 5. Figure 6 illustrates average treatment effects aggregated by treatment cohort, event time (i.e., $e = t - g$), and year to capture group-specific effects, event study results, and calendar time effects, respectively. Table 3 displays a summary of these aggregated results.

Examining Figure 5, we observe increases in RECS post-SGB issuance that are mostly positive and statistically significant at the 5 per cent level for countries who issued the first SGBs in 2016 and 2018, post-SGB increases that are positive and appear to be marginally insignificant for countries who issued their first SGBs in 2019 and 2020, and no major post-SGB issuance effects for countries who issued their first SGBs in 2017, 2021, and 2022. For the 2016 cohort, we also observe negative and statistically significant point estimates at t = 2017 and t = 2018. The positive observations suggest that SGB issuance could have a positive effect of growth of RECS, although this is not clear due to the insignificancy of many of the results.

We also observe pre-treatment estimates for $ATT(g, t)$ that are significantly different from zero at the 5 per cent level for countries who issued their first SGBs in 2016 and 2018. These positive statistically significant pre-treatment observations indicate that countries in the 2016 and 2018 treatment cohorts experienced greater growth in RECS during periods leading up to the issuance of the SGB than that experience by the control group. This may be an indication that they on a different RECS growth trajectory than countries in the control, calling into question the significantly positive post-treatment results observed for these cohorts. This is discussed further in Section 6.3. The large confidence intervals observed in some cohorts in Figure 6 are an indication of heterogeneity of effect of SGB issuance across different countries who issued their first SGBs in the same year. The size of these confidence intervals is most striking for treatment cohorts 2017, 2019, and 2020. This could be caused by heterogeneity of allocation of proceeds across different bonds, or of an omitted variable or variables being the main drivers of RECS growth, not SGB issuance.

Figure 5. RE Share of Electricity Capacity Group-Time Average Treatment Effects



Notes: The effect of SGB issuance on the RE share of total installed electricity capacity of a country, under the unconditional parallel trends assumption. Red lines give point estimates and simultaneous 95% confidence bands for pre-treatment periods. Under the null hypothesis of the parallel trends assumption holding in all periods, these should be equal to 0. Blue lines provide point estimates and simultaneous 95% confidence bands for the treatment effect of issuing an SGB. The top row includes countries that issued their first SGBs in 2016 (left) and 2017 (right), includes countries that issued their first SGBs in 2018 (left) and 2019 (right), the third row includes countries that issued their first SGBs in 2020 (left) and 2021 (right), and the last row includes countries that issues their first SGBs in 2022.

In Figure 6, we see that group-specific average treatment effects are positive and statistically significant at the 5 per cent level for treatment cohorts 2016 and 2021, positive but marginally insignificant for treatment cohorts 2020 and 2022, and positive but insignificant for treatment cohorts 2017, 2018, and 2020.

Aggregated event-time treatment effects in the middle chart in Figure 6 show that treatment effects are positive and statistically significant at the 5 per cent level for e = 6, and positive yet marginally insignificant for most other positive values of e. The increasingly positive average treatment effects observed in the 3 years post-SGB issuance seems to indicate that SGB issuance could be a driver of RECS growth, however since the results are statistically insignificant, this could also merely be a sign that most countries who issue SGBs are more inclined to invest in RECS than those in the control group, potentially violating the parallel trends assumption underpinning this analysis. This is discussed further in Section 6.3.

When examining average treatment effects aggregated by calendar year t, we see that all effects are positive, with the effects observed in 2016, 2021, and 2022 significant at the 5 per cent level, and the effect observed in 2020 marginally insignificant.

In Table 3, we see that most of the estimates shown to be significant at the 5 per cent level in Figure 6 are also significant at the 1 per cent level. Calendar time aggregations for t = 2021 and t = 2022 are the exceptions. These estimates are significant at the 5 per cent level but insignificant at the 1 per cent level.

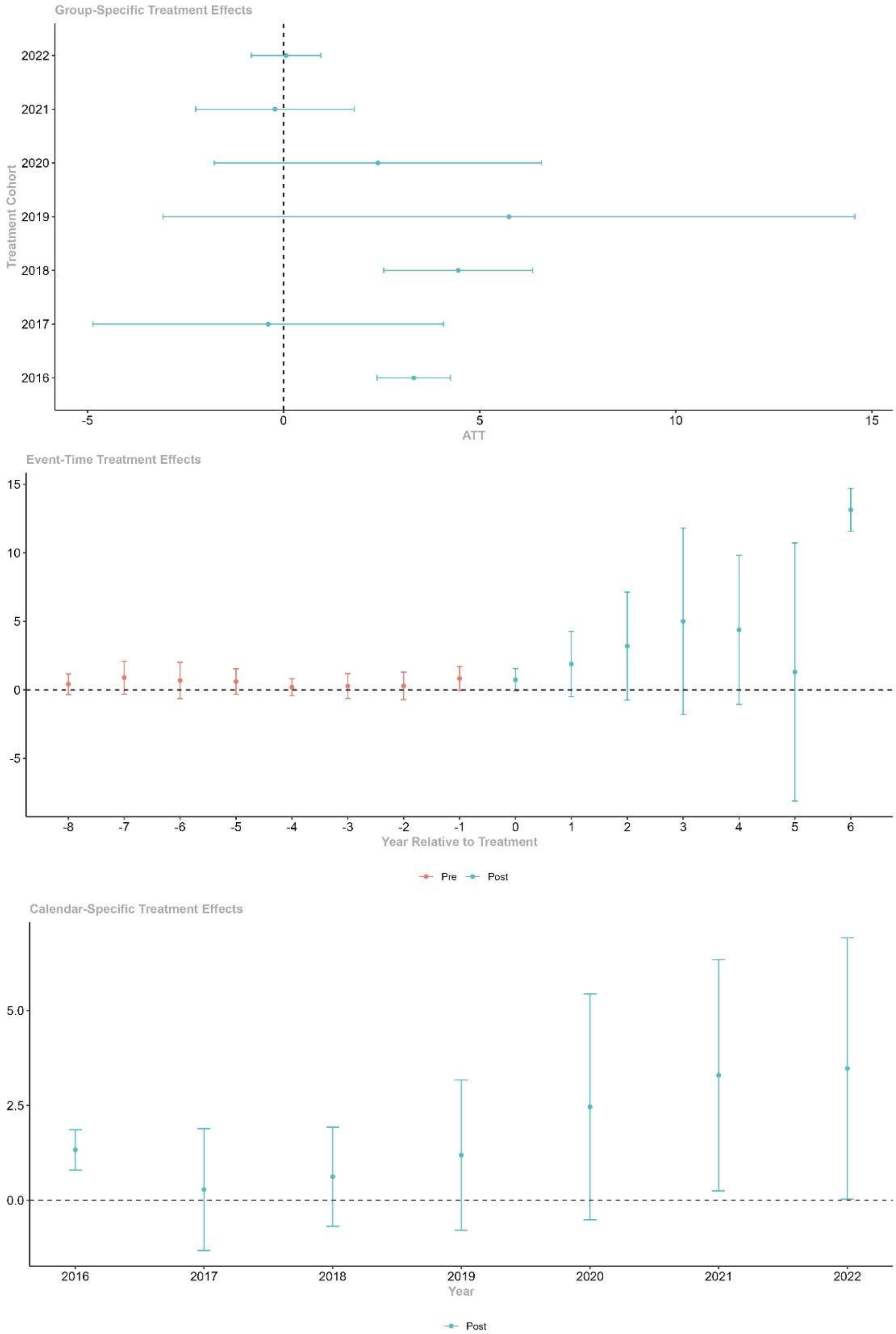
Furthermore, Table 3 provides single parameters for each aggregation method. These single parameters are the estimates obtained for average treatment effect on the treated by using each aggregation method. Regardless of the aggregation method used, the estimate for average treatment effect on the treated produced is positive and significant at the 1 per cent level.

Table 3. Aggregated Treatment Effects of SGB Issuance on RE Share of Total Electricity Capacity

Unconditional Parallel Trends	Partially Aggregated							Single Parameters
Group-Specific Effects	g = 2016	g = 2017	g = 2018	g = 2019	g = 2020	g = 2021	g = 2022	
	3.3174***	-0.392	4.4524***	5.7467	2.4028	-0.2200	0.0604	1.9189***
	(0.4441)	(2.0968)	(0.8526)	(4.0032)	(1.8780)	(0.9512)	(0.4209)	(0.6575)
Event Study	e = 0	e = 1	e = 2	e = 3	e = 4	e = 5	e = 6	
	0.7365	1.8895	3.1945	5.0046	4.3826	1.3068	13.1363***	4.2358***
	(0.3441)	(0.9262)	(1.5741)	(2.8213)	(2.0391)	(3.7680)	(0.6630)	(1.1456)
Calendar Time Effects	t = 2016	t = 2017	t = 2018	t = 2019	t = 2020	t = 2021	t = 2022	
	1.3291***	0.2816	0.6206	1.1893	2.4620	3.2960**	3.4761**	1.8078***
	(0.2185)	(0.6834)	(0.6258)	(0.7771)	(1.2072)	(1.2542)	(1.3994)	(0.6835)

Notes: Aggregations of the effect of SGB issuance on the RE share of total installed electricity capacity of a country, under the unconditional parallel trends assumption. This table shows estimates and standard errors of average treatment effects, aggregated by group (top), event year (middle), and observation year (bottom), as well as single parameters for each aggregation method. p<0.1; p<0.05**; p<0.01***.*

Figure 6. Aggregated SGB Issuance Effects on RE Share of Electricity Capacity Group-Time



Notes: Aggregations of the effect of SGB issuance on the RE share of total installed electricity capacity of a country, under the unconditional parallel trends assumption. Red lines give point estimates and simultaneous 95% confidence bands for pre-treatment periods. Under the null hypothesis of the parallel trends assumption holding in all periods, these should be equal to 0. Blue lines provide point estimates and simultaneous 95% confidence bands for the treatment effect of issuing an SGB. The top chart shows the average treatment effect for each treatment cohort G_g, the middle chart displays average treatment effect observed at each event time, e, ($e = t - g$), and the bottom chart shows average treatment effect in each calendar year t.

6.3 Robustness

Due to the small number of observations in each treatment cohort, Callaway & Sant'Anna (2021) recommend that any inferences should be drawn from the average treatment effects aggregated by event time, e. Therefore, the robustness tests and discussion of results will focus mainly on the results obtained using the event time aggregation method, illustrated in the middle chart in Figure 6, and displayed as the 'Event Study' results in Table 3.

Another consequence of the small number of treatment observations is that I am limited in my ability to include covariates in the model. The number of covariates included cannot exceed the number of observations in the smallest treatment cohort (Callaway & Sant'Anna, 2021). Since the 2016 cohort contains only one country, Poland, I cannot include more than one covariate in my model. I use doubly robust estimators to minimise any bias introduced by model misspecification, as per the advice of Callaway & Sant'Anna (2021).

Two key assumptions underpin the ability to draw inference from the staggered difference-in-difference event study designed by Callaway & Sant'Anna (2021):

> **Assumption 1:** No effects resulting from anticipation of the treatment exist; and
> **Assumption 2**: If the treatment did not occur, the treatment groups would have followed the same trend as the control.

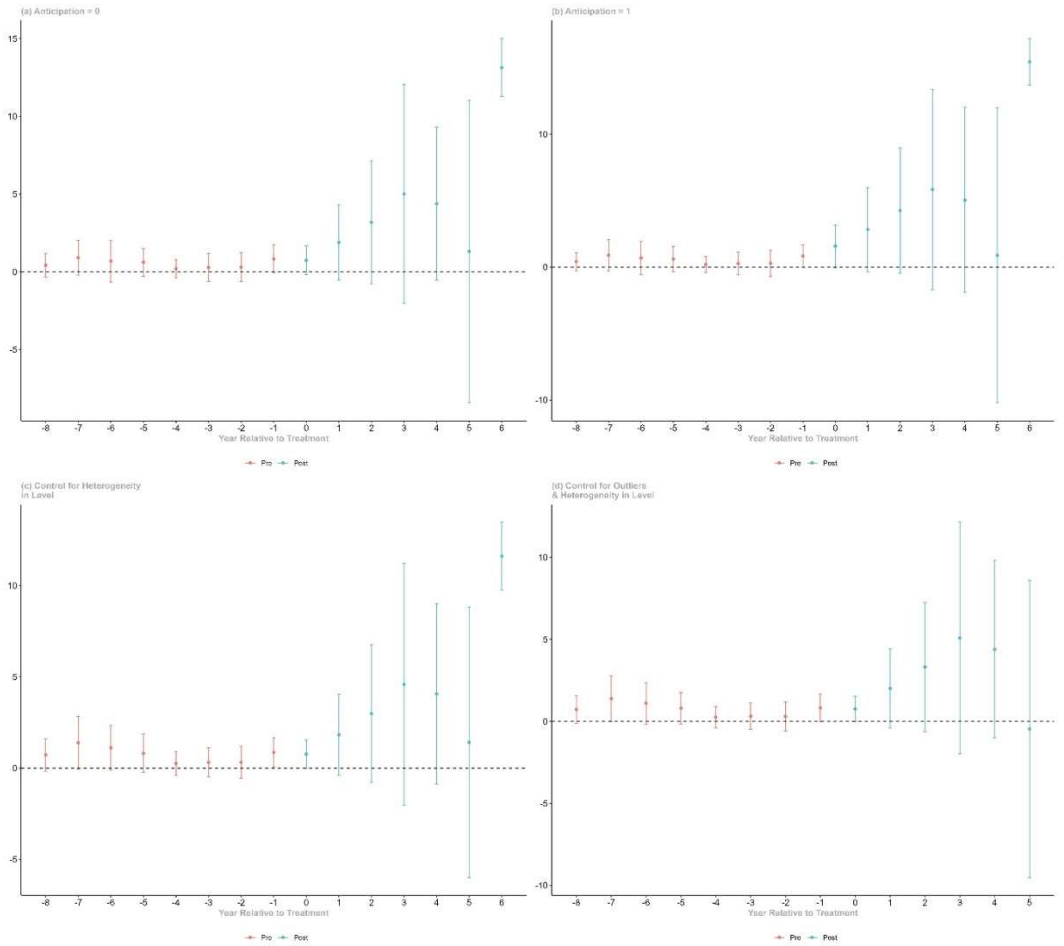
Before testing for anticipatory effects, I first consider the scenarios that could rise to them.

As argued by Kramer (2020), governments could develop renewable electricity capacity prior to the issuance of their debut SGB and use the SGB to refinance the projects once developed. While this may be the case, the investment needed to increase RECS to a significant degree is likely to be far greater than the proceeds generated from an SGB issuance.

A second scenario that could result in anticipatory effects Is that private sector investment in renewable electricity generation capacity increases on announcement of an upcoming SGB issuance, or on the publication of a sovereign issuer's green bond framework, which would indicate the intention to issue a green bond. In either case, the time needed to complete the development of the project so that increased capacity would be recognised is likely to be greater than the period between framework publication or bond announcement and issuance.

Figure 7(b) displays the results of the baseline event study altered to exclude the year before treatment from the computed control groups to study anticipatory effects. The results are equivalent to our baseline results, displayed in Figure 7(a), indicating the absence of anticipatory effects.

Figure 7. Robustness to Anticipatory effects.



Notes: Aggregations of the effect of SGB issuance on the RE share of total installed electricity capacity of a country by event time, under the unconditional parallel trends assumption. Red lines give point estimates and simultaneous 95% confidence bands for pre-treatment periods. Under the null hypothesis of the parallel trends assumption holding in all periods, these should be equal to 0. Blue lines provide point estimates and simultaneous 95% confidence bands for the treatment effect of issuing an SGB. Figure 7(a) (top left) shows the average treatment effect observed at each event time, e, ($e = t - g$), with no anticipatory effects. Figure 7(b) (top right) shows the same but allows for 1 year of anticipation. Figure 7(c) (bottom left) shows the average treatment effect after the introduction of 2013 RE share of total electricity capacity as a control variable. Figure 7(d) shows the average treatment effect with Poland excluded from the data.

The second key assumption for this analysis is often referred to as the parallel trends assumption (Callaway & Sant'Anna, 2021). Since my baseline model, specified in equation (1) does not control for covariates, I test for violations of the unconditional version of the parallel trends assumption. The assumption states that countries, who receive treatment (i.e., $G_i <> 0$) would have followed a parallel trend to countries who did not receive treatment (i.e., $G_i = 0$), had treatment not occurred. In my analysis, this translates to the assumption that if a country who issued an SGB on or before 31 December 2022 not done so, the evolution of RECS of that country would have developed following the same pattern as that of countries who have not issued an SGB.

Since it is not possible to observe this directly, this assumption is commonly tested by testing for heterogeneity of pre-trends between the treatment sample and the control group (Callaway & Sant'Anna, 2021). In my case, this means testing for a difference in the rate of change of RECS between treatment and control groups, prior to the issuance of an SGB by countries in the treatment group.

Violations of pre-treatment parallel trends are usually observed as significantly non-zero estimates of $ATT(g,t)$ in pre-treatment datapoints (Rambachan & Roth, 2023). However, this alone is not always sufficient to verify that the parallel trends assumption holds (Jaeger et al. 2020). The assumption is more plausible if treatment and control groups are homogeneous both in terms of pre-treatment trends and pre-treatment level of the dependent variable (Kahn-Lang & Lang, 2020).

There are no instances of significantly non-zero pre-treatment estimates of aggregated $ATT(g,t)$, as shown in Figure 7(a). I follow the suggestion of Kahn-Lang & Lang (2020), adding RECS in 2013 as a control variable to my model. I present the results in Figure 7(c).

It is worth noting that the only statistically significant result obtained from the event time-aggregated study, including the robustness tests in Figure 7(b) and 7(c), is at $e = 6$. This result is obtained from a single treatment observation, as Poland are the only country in my study to have been exposed to the treatment for 6 years, having been the first issuer of an SGB in 2016 (Moore, 2016). This is especially relevant because, as noted in section 6.2, pre-treatment $ATT(g,t)$ estimates are significantly different from zero for the 2016 treatment cohort, of which Poland is the sole member. These estimates indicate a potential violation of the parallel trends assumption, which could render the statistically significant observation returned at $e = 6$ invalid.

I test for the sensitivity of the statistically significant single parameter estimate returned by the event time aggregation method to the observation at $e = 6$ by rerunning the model, this time excluding Poland from the panel dataset, while maintaining the level control introduced in Figure 7(c). The result, displayed in Figure 7(d) and detailed in Table 4, is that the single parameter estimate returned by the event time aggregation method is statistically insignificant at all conventional levels of significance when Poland is excluded from the dataset. As shown in Table 4, both the group- and calendar time aggregation methods still return single parameter estimates for average treatment effect on the treated that are significant at the 5 per cent level. However, as mentioned previously, Callaway & Sant'Anna (2021) warn against drawing any inference from these statistics due to the small size of my treatment sample.

Table 4. Single parameter results by aggregation method without Poland.

	Dependent Variable:
	ATT
$Group - Specific$	1.8743**
	(0.7148)
$Event - Time$	2.5165
	(1.3617)
$Calendar - Time$	1.8865**
	(0.8381)
Notes: *p<0.1; **p<0.05; ***p<0.01	

6.4 Discussion

In this section, I discuss the decision of whether to consider the results obtaining by excluding Poland as more reflective than the baseline results or less reflective, before discussing the results of my analysis in the context of the effectiveness of SGB issuance as a tool for catalysing RECS growth, using Poland as an example. I investigate the drivers behind the increase in RECS share in Poland, and discuss the role that their SGB issuances could have played in contributing to this increase.

I verify that a large increase in installed photovoltaic solar electricity capacity is the main driver of Poland's increase in RECS (IRENA, 2023). Furthermore, I find that the increase in photovoltaic capacity coincides with the introduction of subsidies for the installation of photovoltaic panels or energy storage by the Polish government in 2019 (Ministerstwo Klimatu i Środowiska, 2019; Ptak, 2023). The most recent allocation report produced by the Poland's Ministry of Finance shows no evidence that their SGB issuances are contributing to the financing of these subsidies (Ministerstwo Finansów, 2022). Instead proceeds flowing into renewable energy projects are used to finance unrelated excise tax exemptions which are mainly applied to wind energy.

While the lack of evidence of SGB proceeds flowing to the financing of the photovoltaic installation subsidies could lead one to decide that the statistically significant results observed caused by the sharp increase of RECS in Poland should be discounted when assessing the results of my analysis, it could also be argued that the decision to allocate SGB proceeds to one eligible project over another is somewhat arbitrary. One could argue that by financing the excise duty exemption with SGB proceeds, other government capital was freed up to finance the subsidies for photovoltaic panel installation.

That argument, however, seems to imply that the capital raised by the SGB issuance is additional to the capital that the state could have otherwise raised. This argument appears flimsy at best, especially given the fact that there is no evidence of SGBs offering a lower cost of capital to issuers (Doronzo et al., 2022). An alternative, more compelling argument, would be that the issuance of an SGB raises awareness about the types of benefits that can be availed of, like the photovoltaic subsidies, leading to an increase in adoption of the subsidies, and therefore, having a positive impact on the speed of the country's transition to renewable energy. A quick Google search of "Poland green bond solar" returns many results referencing the subsidies.

While this example provides evidence that SGBs could offer a tool for promoting green initiatives, it also makes it difficult to justify drawing any causal inference from my analysis, as the photovoltaic subsidies are a clear example of a variable, omitted from my model, likely to have a strong causal relationship with the increase in RECS in Poland.

7. Analysis of SGB Issuance on CGB Issuances

7.1 Method

To investigate the effect of sovereign green bond issuance on the corporate green bond issuance volume in a country, I again employ the staggered difference-in-difference event study design proposed by Callaway & Sant'Anna (2021) used in Section 6.

Consistent with Section 6 and with Callaway & Sant'Anna (2021), my treatment group is defined as the set of countries who issued a sovereign green bond on or before 31 December 2022 and each observation in the treatment group is assigned to a treatment cohort G, where G is equal to the year of issuance of their first sovereign green bond.

Countries who had not issued a sovereign green bond as of 31 December 2022, are assigned to cohort $G = 0$, and this set is defined as the control group. I define G_g as a binary variable that is equal to one in instances where a country, i, issues their first sovereign green bond in period g (i.e., $G_{i,g} = 1\{G_i = g\}$) and define C as a binary variable that is equal to one in instances where G=0 (i.e., $C_i = 1\{G_i = 0\}$).

Since 157 of the 223 countries in my sample (70%) had not had any instances of a CGB issuance as of 31 December 2022, I remove 51 countries, deemed too small to issue a green bond, from the dataset in order to reduce any distortion from countries who lack a stock exchange capable of listing CGBs. Andorra is the smallest country in my dataset to have at least one issuance of a CGB. During the observed timeframe, Andorra's mean GDP was just over 3 billion US dollars (in current value), with a lowest value of 2,789 mUSD (current) in 2015. I deem countries who had not yet experienced a CGB or SGB issuance by 31 December 2022 and had not recorded a GDP greater than 2 billion USD (current) for any year between 2013 and 2022 as too small to issue a CGB and remove them from the dataset. The majority of these countries are overseas territories or countries that lack their own stock exchange. Therefore, they are largely irrelevant to the study and their inclusion could distort the results in a manner that would not reflect the true effect of SGB issuance. 49 countries are eliminated from the study in this way. I remove a further 2 countries for which no GDP data exists on the World Bank World Development Indicators database. All removed countries are listed in Table A4.

The first set of estimations I obtain are of the effects for all treatment groups across all observed years (Callaway & Sant'Anna, 2021; Schulz & Rode, 2021). I denote $CGBVOL_{i,t}$

as the log of CGB volume (in mUSD) issued in country i during year t. I then estimate the average effect on the treated countries for cohort g at time t,

$$ATT(g,t) = \mathbb{E}\left[CGBVOL_{i,t} \,\middle|\, G_i = g\right] - \mathbb{E}[CGBVOL_{i,t}|C = 1] \tag{4}$$

by calculating several regressions each using a subsample of those observations in the treatment- and control-group at year t

$$CGBVOL_{i,t} = \beta_0 + \beta_1 \mathbf{1}_{G_i=t} + \beta_2 \mathbf{1}_t + \beta_3 \mathbf{1}_{G_i=t} \mathbf{1}_\mathrm{t} + \varepsilon_{\mathrm{i,t}}. \tag{5}$$

β_0 is the mean of the control group C to treatment cohort g in year t, β_1 is the fixed effect of the treated countries, β_2 is the fixed effect for year t, and β_3 is the estimate average effect on the treated ($\beta_3 \equiv ATT(g,t)$). I then aggregate these results to produce a single series of estimation results relative to the treatment period to calculate the average effect on the treated ATT for event times e, relative to the respective year of treatment ($e = t - g$).

As suggested by Callaway & Sant'Anna (2021), I use the group-dependent weights $w(g,t)$ when aggregating results in this way as follows:

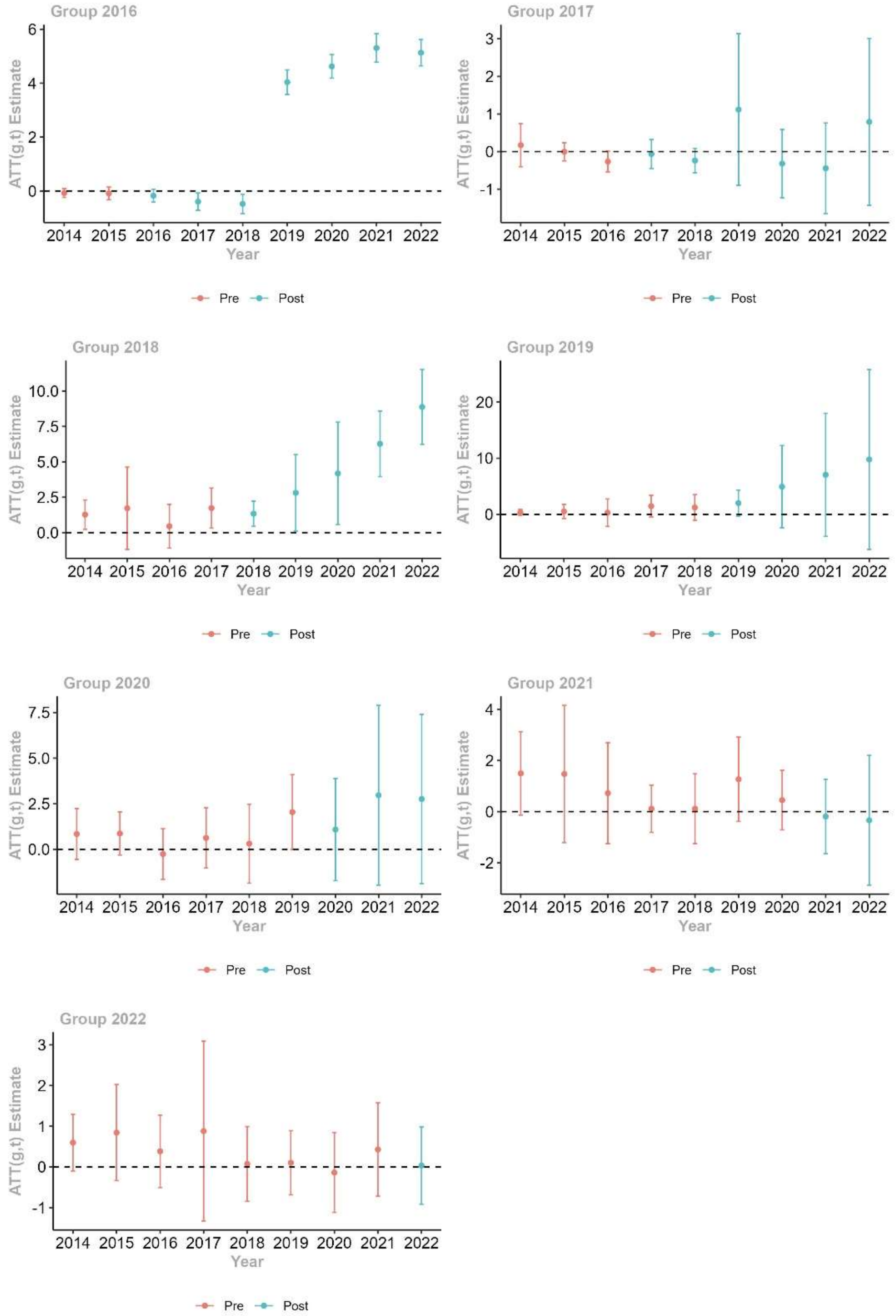
$$ATT_{es}(e) = \sum_{g \in G} w(g,t) * ATT(g,t). \tag{6}$$

The results for the test of homogenous $ATTs$ across all treatment groups required under this simplification are displayed in Table A5 (Callaway & Sant'Anna, 2021). These results are obtained by regressing all individual ATT estimates on time relative to the event year, e, and on the treatment cohort they are in, g. As shown in Table A5, ATT estimates vary by event year at the 10 per cent level of significance, but not by treatment group at any conventional level of significance, indicating that they are homogenous and thus meet the requirement for the aggregation suggested by Callaway & Sant'Anna (2021) above.

7.2 Results

The group-time average treatment effects are displayed in Figure 8. Figure 9 illustrates average treatment effects aggregated by treatment cohort, event time (i.e., $e = t - g$), and year to capture group-specific effects, event study results, and calendar time effects, respectively. Table 5 displays a summary of these aggregated results.

Figure 8. CGB Issuance Volumes Group-Time Average Treatment Effects



Notes: The effect of SGB issuance on CGB issuance volumes in a country, under the unconditional parallel trends assumption. Red lines give point estimates and simultaneous 95% confidence bands for pre-treatment periods. Under the null hypothesis of the parallel trends assumption holding in all periods, these should be equal to 0. Blue lines provide point estimates and simultaneous 95% confidence bands for the treatment effect of issuing an SGB. The top row includes countries that issued their first SGBs in 2016 (left) and 2017 (right), includes countries that issued their first SGBs in 2018 (left) and 2019 (right), the third row includes countries that issued their first SGBs in 2020 (left) and 2021 (right), and the last row includes countries that issues their first SGBs in 2022.

In Figure 8, we see that group-specific average treatment effects are positive and statistically significant at the 5 per cent level for the 2016 treatment cohort, negative but marginally insignificant for the 2022 treatment cohort, and insignificant for the remainder of the cohorts. Poland is the only member of the 2016 cohort. The spike in treatment effect observed in 2019, with no treatment effect observed in the two years following issuance of the SGB suggests that an omitted variable is more likely to have caused the increase in CGB issuance volumes than the SGB issuance.

Aggregated event-time treatment effects in the middle chart in Figure 9 show that both pre- and post-treatment effects tend to be positive but statistically insignificant, the exceptions being at $e = -5$ and $e = 6$, both of which are positive and significant at the 5 per cent level, and at $e = -6$, which is the only negative result for aggregated event-time treatment effect, yet is marginally insignificant.

Most average treatment effects aggregated by calendar year t are positive but insignificant. Effects at $t = 2016$ and at $t = 2017$ are negative but insignificant, 2016 marginally. 2021 returns the only statistically significant (at the 10 per cent level) result for calendar year-aggregated average treatment effect and is positive.

Both the statistically significant results observed for event-time aggregated treatment effect at $e = 6$ and the group-specific aggregated treatment effect observed for treatment cohort 2016 are again solely based on the increase in CGB issuance volumes in Poland, which we suggest above is not likely to be caused by the SGB issuance in 2016.

In Table 5, we see that group-specific and event-time estimates shown to be significant at the 5 per cent level in Figure 9 are also significant at the 1 per cent level. Additionally, the group-specific effect for the 2022 cohort is significant at the 10 per cent level.

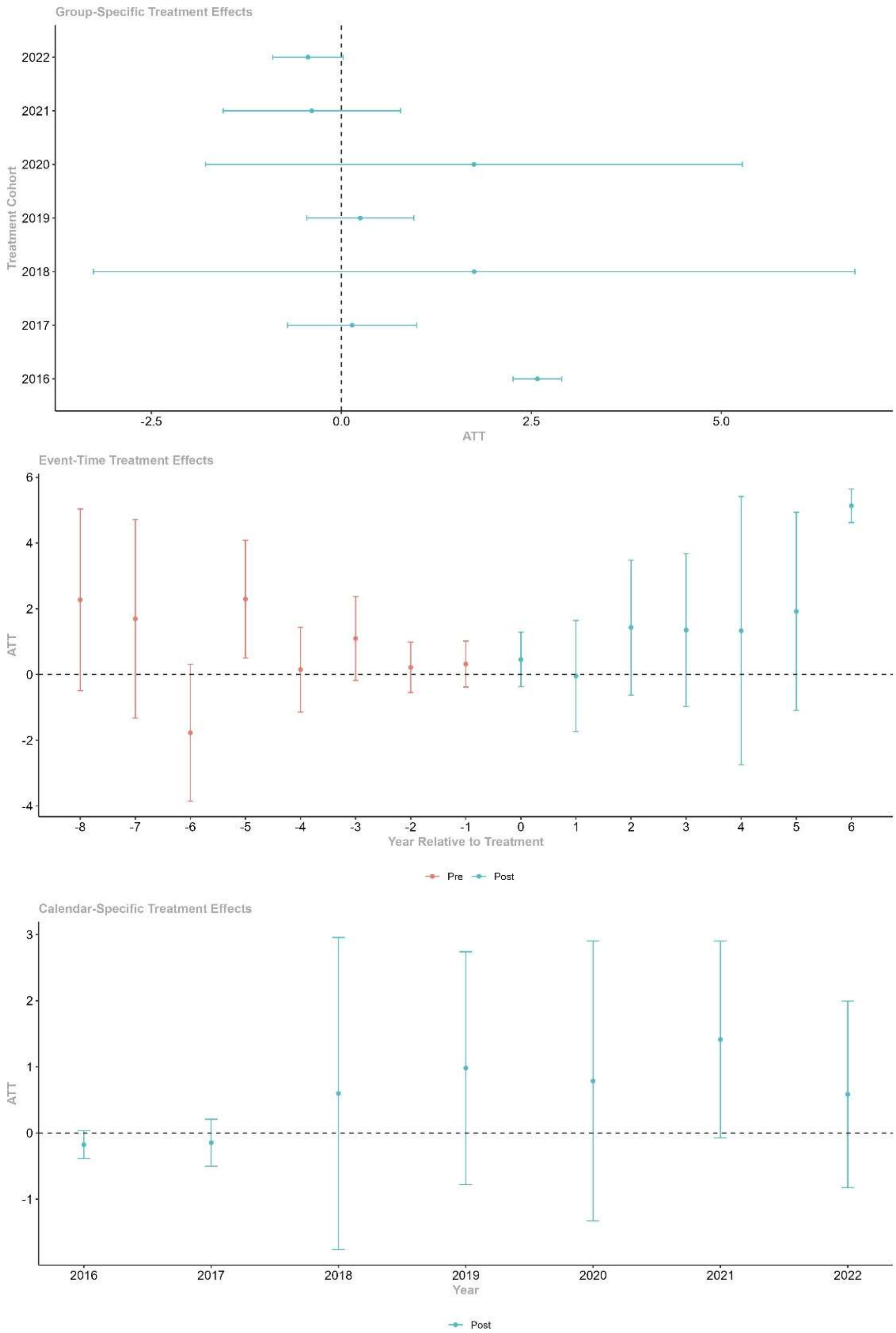
Furthermore, Table 5 provides single parameters for each aggregation method. These single parameters are the estimates obtained for average treatment effect on the treated by using each aggregation method. We see that the single parameters for each aggregation method are all positive but only the parameter obtained via event-time aggregation is statistically significant. This result is significant and the 1 per cent level.

Table 5. Aggregated Treatment Effects of SGB Issuance on CGB Issuance Volumes

Unconditional Parallel Trends	Partially Aggregated							Single Parameters
Group-Specific Effects	g = 2016	g = 2017	g = 2018	g = 2019	g = 2020	g = 2021	g = 2022	
	2.5793***	0.1407	1.7465	0.2487	1.7443	-0.3890	-0.4399	0.4954
	(0.1440)	(0.3813)	(2.2490)	(0.3165)	(1.5853)	(0.5237)	(0.2075)	(0.3857)
Event Study	e = 0	e = 1	e = 2	e = 3	e = 4	e = 5	e = 6	
	0.4563	- 0.0469	1.4283	1.3528	1.3329	1.9208	5.1328***	1.6539***
	(0.3461)	(0.7063)	(0.8578)	(0.9685)	(1.7039)	(1.2582)	(0.2128)	(0.6127)
Calendar Time Effects	t = 2016	t = 2017	t = 2018	t = 2019	t = 2020	t = 2021	t = 2022	
	-0.1760	-0.1467	0.5980	0.9810	0.7868	1.4145*	0.5858	0.5776
	(0.0932)	(0.1574)	(1.0480)	(0.7817)	(0.9407)	(0.6614)	(0.6266)	(0.4195)

Notes: Aggregations of the effect of SGB issuance on CGB issuance volumes in a country, under the unconditional parallel trends assumption. This table shows estimates and standard errors of average treatment effects, aggregated by group (top), event year (middle), and observation year (bottom), as well as single parameters for each aggregation method.
$p<0.1$; $p<0.05$**; $p<0.01$***.*

Figure 9. Aggregated SGB Issuance Effects on CGB Issuance Volumes



Notes: Aggregations of the effect of SGB issuance on CGB issuance volumes in a country, under the unconditional parallel trends assumption. Red lines give point estimates and simultaneous 95% confidence bands for pre-treatment periods. Under the null hypothesis of the parallel trends assumption holding in all periods, these should be equal to 0. Blue lines provide point estimates and simultaneous 95% confidence bands for the treatment effect of issuing an SGB. The top chart shows the average treatment effect for each treatment cohort G_g, the middle chart displays average treatment effect observed at each event time, e, ($e = t - g$), and the bottom chart shows average treatment effect in each calendar year t.

7.3 Robustness

As in section 6, the analysis of SGB issuance effects on CGB issuance volumes is restricted due to the small treatment sample size, especially since the 2016 treatment cohort contains only Poland. As such, I again follow the recommendation by Callaway & Sant'Anna (2021) not to draw inferences from the group-specific- or calendar-time-aggregated treatment effects, only from the event time-aggregated effects. Therefore, the robustness tests and discussion of results will focus mainly on the results obtained using the event time aggregation method, illustrated in the middle chart in Figure 9, and displayed as the 'Event Study' results in Table 5.

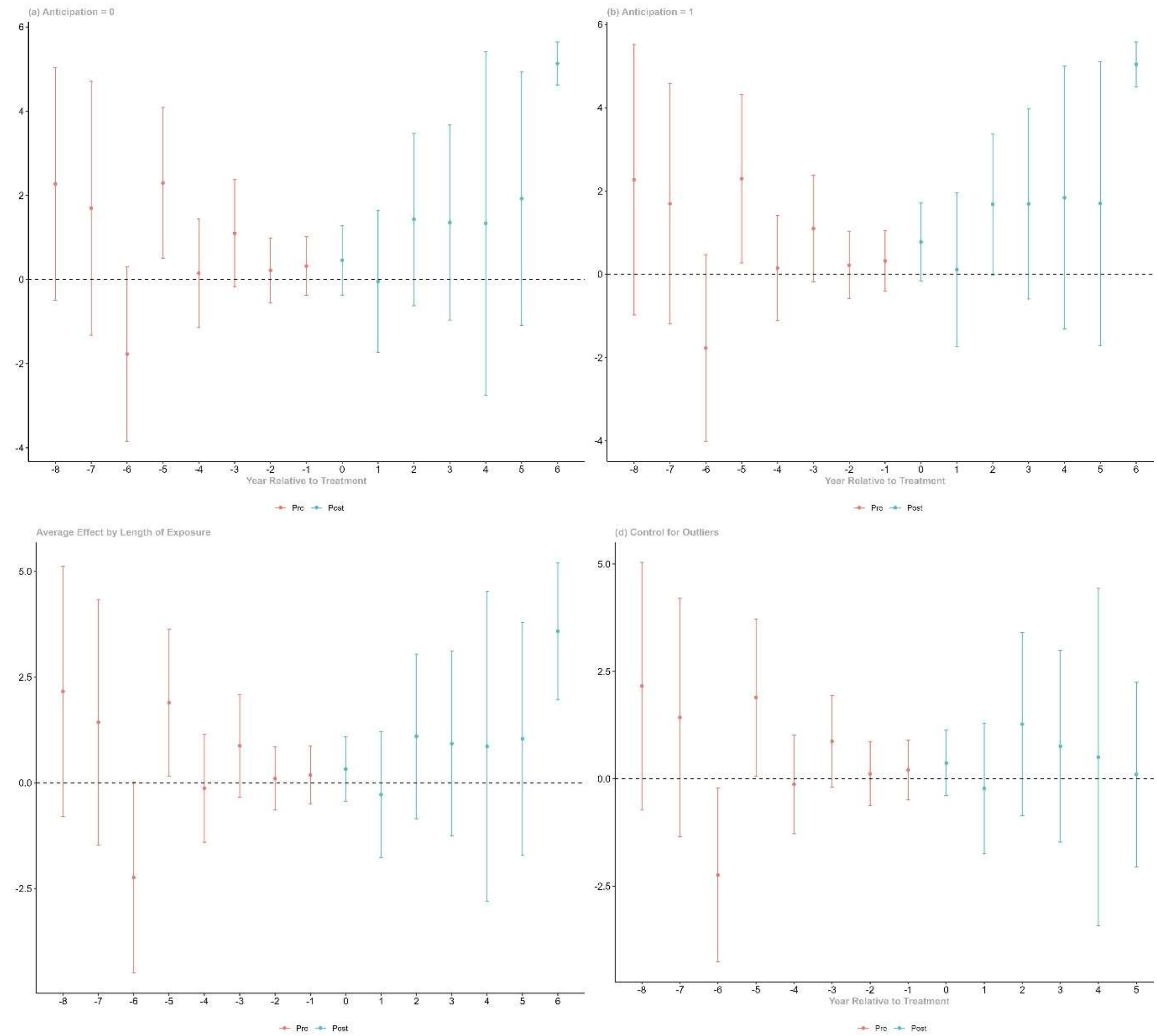
As with section 6, I begin the robustness assessment by investigating whether the two integral assumptions to the analytic method by Callaway & Sant'Anna (2021) hold.

As seen in Figure 10(a) and 10(b), the plot allowing for one year of anticipatory effects (10b), is almost identical to the plot with no anticipatory effects showing (10a). This indicates that the no anticipatory effects assumption holds for this analysis.

In Figure 9, I observe that there is a pre-treatment estimate of event-time-aggregated $ATT(g,t)$ at $e = -5$ that is significantly different from zero, indicating a potential violation of the unconditional parallel trends assumption (Callaway & Sant'Anna, 2021). After adding the log of GDP as a covariate to my model, to control for heterogeneity across size of countries, the event-time-aggregated average treatment effect at $e = -5$ becomes statistically insignificant at the 5 per cent level. However, the result at $e = -6$ becomes significant at the 5 per cent level, indicating that the conditional may not hold either (Callaway & Sant'Anna, 2021). This plot is shown in Figure 10(c). Given the lack of proximity to the treatment period, its appearance as an outlier relative to the other pre-treatment estimates, and the fact that it is only marginally significant at the 5 per cent level, I believe that this estimator would have weak explanatory power over post-treatment trends, and thus am willing to consider that the conditional parallel trends assumption may not be violated, as Rambachan & Roth (2023) deem a possibility.

Similar to my result in the analysis of SGB issuance effect on RECS in section 6, the only statistically significant event-time-aggregated average treatment effect estimate occurs at $e = 6$, for which Poland is the only contributor. It appears to be an outlier, both due to its dramatically different mean position and its smaller simultaneous confidence intervals, relative to all other post-treatment estimates.

Figure 10. Robustness to Anticipatory effects on CGB issuance volumes



Notes: Aggregations of the effect of SGB issuance on CGB issuance volumes by event time, under the unconditional parallel trends assumption. Red lines give point estimates and simultaneous 95% confidence bands for pre-treatment periods. Under the null hypothesis of the parallel trends assumption holding in all periods, these should be equal to 0. Blue lines provide point estimates and simultaneous 95% confidence bands for the treatment effect of issuing an SGB. Figure 10(a) (top left) shows the average treatment effect observed at each event time, e, ($e = t - g$), with no anticipatory effects. Figure 10(b) (top right) shows the same but allows for 1 year of anticipation. Figure 10(c) shows the average treatment effect after introducing log of GDP as a control variable. Figure 10(d) shows the same, with Poland excluded from the data.

I test for the sensitivity of the statistically significant single parameter estimate returned by the event time aggregation method to the observation at $e = 6$ by rerunning the model, this time excluding Poland from the panel dataset, while maintaining the control for country size introduced in Figure 10(c). The result, displayed in Figure 10(d) and detailed in Table 6, is that the single parameter estimate returned by the event time aggregation method is no longer statistically significant at all conventional levels of significance when Poland is excluded from the dataset.

Table 6. Single parameter results of effect on CGB issuance volumes by aggregation method without Poland.

	Dependent Variable:
	ATT
$Group - Specific$	0.2154
	(0.3764)
$Event - Time$	0.4648
	(0.6816)
$Calendar - Time$	0.3748
	(0.4846)
Notes: *p<0.1; **p<0.05; ***p<0.01	

7.4 Discussion

This analysis returns little evidence that a country's debut SGB issuance has any effect on the volume of CGBs issued in the country. Where statistically significant results are returned, their appear to be a number of potential red flags with robustness warning against making any causal statements.

First, our treatment groups contain only a small number of observations, weaking the ability to correctly specify the model by limiting the inclusion of covariates to a single variable.

Second, the few results that do return statistically significant estimates are extremely reliant on a small number of observations, which seem to be unrepresentative of the rest of the data.

Finally, the possibility of a violation of the parallel trends assumption exists. Although its likely power to predict post-treatment estimates may be weak, it adds to the lack of confidence in this model's predictive power.

There do not seem to be any compelling arguments resulting from this analysis indicating that SGB issuance has any effect on CGB issuance volumes.

8. Conclusion

This thesis is one of the earliest studies to focus on sovereign green bonds, one of only a handful to approach the topic empirically, and the first to employ a difference-in-difference approach to investigating outcomes related to their issuance.

I show that SGBs tend to be larger, in terms of issued amount, than green bonds issued by corporates, that the vast majority of SGBs are denominated in the world's 10 most dominant currencies (G10), and that they are almost exclusively issued by large countries in Europe and Asia, the issuances by Fiji and Seychelles being clear exceptions.

I investigate the effectiveness of SGBs as a tool for mobilising private capital towards green projects, and thus improving a country's environmental performance outcomes. My results suggest that SGB issuances have no impact on the amount of private capital deployed in environmentally friendly ventures through the channel of corporate green bond issuance, and thus have little to no explanatory power over increases in renewable energy share of the country's total installed electricity capacity, although I provide an argument proposing how SGBs can be used as part of a wider policy, and may be effective in promoting the adoption of government initiatives to improve environmental outcomes.

The result I obtain that SGB issuance does not increase the amount of capital raised by corporates via green bond issuance in the same country appears to contradict the findings of Azhgaliyeva et al. (2022) and Cheng et al. (2022), who find that the probability of a CGB issuance in any given month increases following the issuance of an SGB, and that SGB issuances are associated with a higher number of CGB issuances, respectively.

To my knowledge, this is the first paper to study the environmental impacts of SGB issuance. One of the key limitations of my analysis is the small number of treatment observations, due to the small number of countries that have issued SGBs. However, SGB issuance is becoming more common, and as more countries issue them, and post-issuance environmental performance track records become more established, future research could perform similar analysis to that conducted in this paper and achieve more informative results. Furthermore, I have only investigated the effect on environmental performance on a single metric. Future research could extend this research to alternative measures of environmental performance. Of particular interest would be outcomes measuring impact on water and green buildings, as these are the two most common uses of sovereign green bond proceeds (Harrison et al., 2022).

9. References

Abbas, S. M. A., & Pienkowski, A. (2022). What is sovereign debt? International Monetary Fund: Finance & Development. https://www.imf.org/en/Publications/fandd/issues/2022/12/basics-what-is-sovereign-debt#:~:text=This%20is%20known%20as%20%E2%80%9Ctax,financed%20by%20issuing%20sovereign%20debt.

Ando, S., Fu, C., Roch, F., & Wiriadinata, U. (2023). How Large is the Sovereign Greenium? IMF Working Paper No. 2023/080. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4423375.

Azhgaliyeva, D., Kapsalyamova, Z., & Mishra, R. (2022). Oil price shocks and green bonds: An empirical evidence. Energy Economics, 112, 106108. https://doi.org/10.1016/j.eneco.2022.106108.

Banga, J. (2019). The green bond market: a potential source of climate finance for developing countries. Journal of Sustainable Finance & Investment, 9(1), 17-32. https://doi.org/10.1080/20430795.2018.1498617.

Bevilaqua, J., Hale, G. B., & Tallman, E. (2020). Corporate yields and sovereign yields. Journal of International Economics, 14, 103304. https://doi.org/10.1016/j.jinteco.2020.103304.

BNEF, (2023). A Record $495 Billion Invested in Renewable Energy in 2022. https://about.bnef.com/blog/a-record-495-billion-invested-in-renewable-energy-in-2022/#:~:text=Investment%20in%20renewable%20energy%20last,dollars%20for%20the%20first%20time.

Bongaerts, D., & Schoenmaker, D. (2019). The Next Step in Green Bond Financing. http://dx.doi.org/10.2139/ssrn.3389762.

Callaway, B., & Sant'Anna, P. (2021). Difference-in-Differences with multiple time periods. Journal of Econometrics, 225, 200-230. https://doi.org/10.1016/j.jeconom.2020.12.001.

Cheng, G., Ehlers, T., & Packer, F. (2022). Sovereigns and sustainable bonds: challenges and new options. BIS Quarterly Review, September 2022, 47-56. https://www.bis.org/publ/qtrpdf/r_qt2209d.pdf.

Claessens, S., Klingebiel, K., & Schmukler, S. (2007). Government bonds in domestic and foreign currency: the role of institutional and macroeconomic factors. Review of International Economics, 15, 370–413. https://doi.org/10.1111/j.1467-9396.2007.00682.x.

Climate Action Tracker, (2023). CAT net zero target evaluations. https://climateactiontracker.org/global/cat-net-zero-target-evaluations/.

Dell'Atti, S., Di Tommaso, C., & Pacelli, V. (2022). Sovereign green bond and country value and risk: Evidence from European Union countries. Journal of International Financial Management and Accounting, 33(3), 505–521. https://doi.org/10.1111/jifm.12155.

Dittmar, R., & Yuan, K. (2008). Do Sovereign Bonds Benefit Corporate Bonds in Emerging Markets? The Review of Financial Studies, 21(5), 1983-2014. https://www.jstor.org/stable/40056875.

Doronzo, R., Siracusa, V., & Antonelli, S. (2021). Green Bonds: the Sovereign Issuers' Perspective. Mercati, infrastrutture, sistemi di pagamento, Working Paper No. 3. http://dx.doi.org/10.2139/ssrn.3854966.

Eaton, J., & Fernandez, R. (1995). Chapter 39 Sovereign Debt. Handbook of International Economics, 3, 2031-2077.

Ehlers, T., & Packer, F. (2017). Green bond finance and certification. BIS Quarterly Review, September 2017, 89-104. https://www.bis.org/publ/qtrpdf/r_qt1709h.htm.

Eichengreen, B., & Luengnaruemitchai, P. (2004). Why Doesn't Asia Have Bigger Bond Markets? No. W10576. National Bureau of Economic Research, Cambridge, Massachusetts, USA. https://ssrn.com/abstract=559226.

Fang, X., Hardy, B., & Lewis, K. K. (2023). Who holds sovereign debt and why it matters. NBER Working Paper Series, Working Paper 30087. https://www.nber.org/system/files/working_papers/w30087/w30087.pdf.

Fatica, S., & Panzica, R. (2021). Green bonds as a tool against climate change? Business Strategy and the Environment, 30(5), 2688-2701. https://doi.org/10.1002/bse.2771.

Flaherty, M., Gevorkyan, A., Radpour, S., & Semmler, W. (2016). Financing climate policies through climate bonds – A three stage model and empirics. Research in International Business and Finance, 42, 468-479. https://doi.org/10.1016/j.ribaf.2016.06.001.

Flammer, C. (2021). Corporate green bonds. Journal of Financial Economics. 142, 499–516. https://doi.org/10.1016/j.jfineco.2021.01.010.

Georgieva, K., & Adrian, T. (2022). Public Sector Must Play Major Role in Catalyzing Private Climate Finance. https://www.imf.org/en/Blogs/Articles/2022/08/18/public-sector-must-play-major-role-in-catalyzing-private-climate-finance.

Harrison, C., MacGeoch, M., & Michetti, C. (2022). Sustainable Debt Global State of the Market 2021, Climate Bonds Initiative. https://www.climatebonds.net/files/reports/cbi_global_sotm_2021_02h_0.pdf.

Hay, J. (2018). Seychelles' blue bond is no ordinary green bond. Global Capital, London. https://www.proquest.com/docview/2140768927?accountid=39039&parentSessionId=ZNqpVT8B8Gi4%2BEa5eZv7mjyhlkLHTRTzsQeXCnK509w%3D&pq-origsite=primo.

ICMA, (2022a). Green bond principles. International Capital Market Association. https://www.icmagroup.org/assets/documents/Sustainable-finance/2022-updates/Green-Bond-Principles_June-2022-280622.pdf.

ICMA, (2022b). Harmonised framework for impact reporting. https://www.icmagroup.org/assets/documents/Sustainable-finance/2022-updates/Harmonised-Framework-for-Impact-Reporting-Green-Bonds_June-2022v2-020822.pdf.

IEA, (2023a). World Energy Outlook 2022. https://www.iea.org/reports/world-energy-outlook-2022.

IEA, (2023b). Fossil Fuel Subsidies in Clean Energy Transitions: Time for a New Approach? https://www.iea.org/reports/fossil-fuel-subsidies-in-clean-energy-transitions-time-for-a-new-approach.

IFC, (2020). Green bond handbook: A step-by-step guide to issuing a green bond. https://www.ifc.org/wps/wcm/connect/f11546a9-b986-4b0d-b1fc-93d798ce86dc/202203-IFC-Green-Bond-Handbook.pdf?MOD=AJPERES&CVID=n.wxr2b.

IPCC, (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate

Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

IRENA, (2023). Renewable capacity statistics 2023, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023.

Jaeger, D. A., Joyce, T. J., & Kaestner, R. (2020). A Cautionary Tale of Evaluating Identifying Assumptions: Did Reality TV Really Cause a Decline in Teenage Childbearing? Journal of Business and Economic Statistics, 38(2), 317-326. https://doi.org/10.3386/w24856.

Jun, M., Kaminker, C., Kidney, S., & Pfaff, N., 2016. Green bonds: country experiences, barriers and options. Input paper in support of the G20 finance study group. https://www.oecd.org/environment/cc/Green_Bonds_Country_Experiences_Barriers_and_Options.pdf.

Kahn-Lang, A., & Lang, K. (2020). The promise and pitfalls of differences-in-differences: reflections on '16 and Pregnant' and other applications. Journal of Business and Economic Statistics, 38(3), 613-620. https://doi.org/10.1080/07350015.2018.1546591.

Kimble, J.J. (2006). Mobilizing the Home Front: War Bonds and Domestic Propaganda. Texas A&M University Press.

Kramer, M (2020): "Germany's inaugural green bond… not so green after all", CEPS, September, www.ceps.eu/germanys-inaugural-green-bond-not-so-green-after-all/.

Maltais, A., & Nykvist, B. (2020). Understanding the role of green bonds in advancing sustainability. Journal of Sustainable Finance & Investment, 10, 1–20. https://doi.org/10.1080/20430795.2020.1724864.

Michetti, C., Chouhan, N., Harrison, C., & MacGeoch, M. (2023). Sustainable Debt Global State of the Market 2022, Climate Bonds Initiative. https://www.climatebonds.net/files/reports/cbi_sotm_2022_03d.pdf.

Ministerstwo Finansów, (2022). Green Bond Report on the Use of Proceeds Update, December 2022. https://www.gov.pl/attachment/63ffea62-4726-4a34-98c7-3cf2a3109f4d.

Ministerstwo Klimatu i Środowiska, (2019). "My Electricity" programme launched. https://www.gov.pl/web/climate/my-electricity-programme-launched

Monasterolo, I., Dunz, N., Mazzochetti, A., & Gourdel, R. (2022). Derisking the low-carbon transition: investors' reaction to climate policies, decarbonization and distributive effects. Review of Revolutionary Political Economy, 3, 31-71. https://link.springer.com/article/10.1007/s43253-021-00062-3.

Monasterolo, I., & Raberto, M. (2018). The EIRIN Flow-of-funds Behavioural Model of Green Fiscal Policies and Green Sovereign Bonds. Ecological Economics, 144, 228-243. https://doi.org/10.1016/j.ecolecon.2017.07.029.

Monasterolo, I., & Raberto, M. (2019). The impact of phasing out fossil fuel subsidies on the low-carbon transition. Energy Policy, 124, 355-370. https://doi.org/10.1016/j.enpol.2018.08.051.

Monk, A., & Perkins, R. (2020). What explains the emergence and diffusion of green bonds? Energy Policy, 145, 111641. https://doi.org/10.1016/j.enpol.2020.111641.

Moore, E. (2016). Poland issues world's first green bond. https://www.ft.com/content/28c137e9-bde9-3c0e-bc27-bf0d084bbe0e.

Myers, S. C. (2001). Capital Structure. Journal of Economic Perspectives, 15(2), 81-102. https://www.jstor.org/stable/2696593.

Nordhaus, W. (2017). Integrated Assessment Models of Climate Change. The Reporter (3). https://www.nber.org/reporter/2017number3/integrated-assessment-models-climate-change#:~:text=The%20DICE%20model%20views%20the,increase%20consumption%20in%20the%20future.

OeBFA, (2023). Investor Information – Republic of Austria – April 2023. https://www.oebfa.at/dam/jcr:9bef959c-4a8a-4454-b6bd-35124f6fe222/Republic%20of%20Austria%20Investor%20Information_Apr23.pdf

OECD, (2014): "Budget Review: Germany", OECD Journal on Budgeting, no 2014/02. https://www.oecd.org/gov/budgeting/Budget-Review-Germany.pdf.

Orlov, S., Rovenskaya, E., Puaschunder, J. M., & Semmler, W. (2017). Green Bonds, Transition to a Low-Carbon Economy, and Intergenerational Fairness: Evidence from an Extended DICE Model. http://dx.doi.org/10.2139/ssrn.3086483.

Ptak, A. (2023). Poland doubled electricity production from renewable micro-installations in 2022. https://notesfrompoland.com/2023/03/21/poland-doubled-electricity-production-from-renewable-micro-installations-in-2022/.

Rambachan, A., & Roth, J. (2023). A More Credible Approach to Parallel Trends. The Review of Economic Studies. https://doi.org/10.1093/restud/rdad018.

Ritchie, H., Roser, M., & Rosado, P. (2020). CO2 and Greenhouse Gas Emissions. https://ourworldindata.org/co2-and-greenhouse-gas-emissions.

Sachs, J.D. (2015). Climate Change and Intergenerational Well-Being. The Oxford Handbook of the Macroeconomics of Global Warming. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199856978.013.0011.

Schulz, F., & Rode, J. (2022). Public charging infrastructure and electric vehicles in Norway. Energy Policy, 160, 112660. https://doi.org/10.1016/j.enpol.2021.112660.

Semmler, W., Greiner, A., Diallo, B., Rajaram, A., & Rezai, A. (2011). Fiscal policy, public expenditure composition and growth: Theory and empirics. The IEB International Journal of Finance, 48–89. https://doi.org/10.1596/1813-9450-4405.

Sguazzin, A. (2022). Rhino Bond Sold by World Bank in First Issuance of Its Kind. Bloomberg. https://www.bloomberg.com/news/articles/2022-03-24/rhino-bond-is-sold-by-world-bank-in-first-issuance-of-its-kind#xj4y7vzkg.

Tolliver, C., Keeley, A. R., & Managi, S. (2020). Drivers of green bond market growth: The importance of Nationally Determined Contributions to the Paris Agreement and implications for sustainability. Journal of Cleaner Production, 244, 118643. https://doi.org/10.1016/j.jclepro.2019.118643.

UNFCCC, (2023a). The Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement.

UNFCCC, (2023b). Nationally Determined Contributions (NDCs). https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs.

10. Appendices

Table A1. Sovereign Green Bond statistics by country.

Country	**# SGBs Issued**	**Total Amount Issued (mUSD)**	**Year of First Issuance**
Hong Kong	27	22,128	2019
Hungary	11	4,815	2020
Germany	6	51,612	2020
Austria	5	10,333	2022
Poland	4	4,135	2016
Chile	4	7,377	2019
Italy	3	37,425	2021
France	3	61,776	2017
Egypt	2	1,500	2020
Switzerland	2	1,970	2022
Belgium	2	17,657	2018
Nigeria	2	56	2017
Serbia	2	2,208	2021
Sweden	2	3,875	2020
South Korea	2	1,773	2019
United Kingdom	2	39,079	2021
Fiji	2	44	2017
India	2	1,957	2023
Ireland	2	11,424	2018
Netherlands	1	17,322	2019
Lithuania	1	75	2018
Colombia	1	460	2021
Denmark	1	2,406	2022

Spain	1	10,652	2021
Canada	1	3,667	2022
New Zealand	1	2,293	2022
Seychelles	1	15	2018
Singapore	1	1,797	2022
Israel	1	2,000	2023

Note: This table reports the number of sovereign green bond issuances, their combined issuance amounts in million US dollars, and the year of the first sovereign green bond issuance for each issuer.

Table A2. Countries by cohort group for analysis on SGB issuance on RECS.

Cohort	Observations	Countries
2016	1	Poland
2017	3	Fiji; France; Nigeria
2018	4	Belgium; Ireland; Lithuania; Seychelles
2019	4	Chile; Hong Kong; South Korea; Netherlands
2020	4	Egypt; Germany; Hungary; Sweden
2021	5	Colombia; Italy; Serbia; Spain; United Kingdom
2022	6	Austria; Canada; Denmark; New Zealand; Singapore; Switzerland
Control	196	Algeria; Angola; Benin; Botswana; Burkina Faso; Burundi; Cabo Verde; Cameroon; Central African Republic; Chad; Comoros; Congo DCR; Congo; Ivory Coast; Djibouti; Equatorial Guinea; Eritrea; Eswatini; Ethiopia; Gabon; The Gambia; Ghana; Guinea; Guinea-Bissau; Kenya; Lesotho; Liberia; Libya; Madagascar; Malawi; Mali; Mauritania; Mauritius; Mayotte; Morocco; Mozambique; Namibia; Niger; Reunion; Rwanda; Sao Tome and Principe; Senegal; Sierra Leone; Somalia; South Africa; South Sudan; Sudan; Tanzania; Togo; Tunisia; Uganda; Zambia; Zimbabwe; Afghanistan; Bangladesh; Bhutan; Brunei Darussalam; Cambodia; China; Taiwan; India; Indonesia; Japan; Kazakhstan; North Korea; Kyrgyzstan; Laos; Malaysia; Maldives; Mongolia; Myanmar; Nepal; Pakistan; Philippines; Sri Lanka; Tajikistan; Thailand; East Timor; Turkmenistan; Uzbekistan; Vietnam; Anguilla; Antigua and Barbuda; Aruba; Bahamas; Barbados; Belize; Bonaire; British Virgin Islands; Cayman Islands; Costa Rica; Cuba; Curacao; Dominica; Dominican Republic; El Salvador; Grenada; Guadeloupe; Guatemala; Haiti; Honduras; Jamaica; Martinique; Montserrat; Nicaragua; Panama; Puerto Rico; Saint Barthelemy; Saint Kitts and Nevis; Saint Lucia; Saint Martin; Saint Vincent and the Grenadines; Trinidad and Tobago; Turks and Caicos Islands; Virgin Islands (U.S.); Armenia; Azerbaijan; Georgia; Russia; Turkiye; Albania; Andorra; Belarus; Bosnia and Herzegovina; Bulgaria; Croatia; Cyprus; Czech Republic; Estonia; Faroe Islands; Finland; Greece; Iceland; Kosovo; Latvia; Luxembourg; Malta; Moldova; Montenegro; North Macedonia; Norway; Portugal; Romania; Slovakia; Slovenia; Ukraine; Bahrain; Iran; Iraq; Israel; Jordan; Kuwait; Lebanon; Oman; Palestine; Qatar; Saudi Arabia; Syria; United Arab Emirates; Yemen; Greenland; Mexico; Saint Pierre and Miquelon; United States of America; American Samoa; Australia; Cook Islands; French Polynesia; Guam; Kiribati; Marshall Islands; Micronesia; Nauru; New Caledonia; Niue; Palau; Papua New Guinea; Samoa; Solomon Islands; Tokelau; Tonga; Tuvalu; Vanuatu; Argentina; Bolivia; Brazil; Ecuador; Falkland Islands; French Guiana; Guyana; Paraguay; Peru; South Georgia and South Sandwich Islands; Suriname; Uruguay; Venezuela

Notes: Describes the division of countries into treatment cohorts, and control group for the analysis of SGB issuance of RECS.

Table A3. Comparison of all ATT estimates of the estimation before aggregation to the event study for baseline results of the effect of SGB issuance of RECS.

	Dependent Variable:
	ATT
$event\ year$	0.4706***
	(0.121)
$cohort$	0.2025
	(0.1975)
$Constant$	-406.8752
	(398.7263)
Observations	63
Notes: *p<0.1; **p<0.05; ***p<0.01	

Table A4. Countries excluded from analysis of SGB issuance effect on CGB volume.

Reason for Exclusion	**Observations**
Too Small	Cabo Verde; Comoros; Eritrea; Guinea-Bissau; Mayotte; Reunion; Sao Tome and Principe; South Sudan; North Korea; Turkmenistan; Anguilla; Antigua and Barbuda; Bonaire; Cuba; Dominica; Grenada; Guadeloupe; Martinique; Montserrat; Saint Barthelemy; Saint Kitts and Nevis; Saint Martin; Saint Vincent and the Grenadines; Turks and Caicos Islands; Virgin Islands (U.S.); Kuwait; Palestine; Syria; Yemen; Greenland; Saint Pierre and Miquelon; American Samoa; Cook Islands; Kiribati; Marshall Islands; Micronesia; Nauru; Niue; Palau; Samoa; Solomon Islands; Tokelau; Tonga; Tuvalu; Vanuatu; Falkland Islands; French Guiana; South Georgia and South Sandwich Islands; Venezuela
No Data	Taiwan; British Virgin Islands

Notes: ‘Too Small’ countries are categorised as having GDP not more than USD 2 billion for any period between 2013 and 2022, and having not experienced an SGB or CGB issuance prior to 31 December 2022. ‘No Data’ countries are ones for which GDP data was unavailable in the World Bank’s World Development Indicator database.

Table A5. Comparison of all ATT estimates of the estimation before aggregation to the event study for baseline results (shown in Fig. 3 (a)).

	Dependent Variable:
	ATT
event year	1.472e-01*
	(7.868e-02)
cohort	-9.827e-04
	(1.285e-01)
Constant	3.027e+00
	(2.594e+02)
Observations	63
Notes: *p<0.1	