Natural Assets and Public Debt: Evidence from Sovereign Green Bonds*

Jitendra Aswani[1] and William W. Xiong[2]

[1] *MIT Sloan*
[2] *Binghamton University - SUNY*

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Abstract

Are risks to natural assets reflected in public green debt? Using sovereign bonds issued between 2016 and 2024, we show that biodiversity loss and natural capital risk are positively associated with yields in both the primary and secondary markets. Economically, a 1% increase in risk to natural assets is associated with a 21-40 basis point increase in yields. To study whether mitigation activities affect pricing, we construct a novel bond-level dataset on green projects using a large language model (LLM) enhanced with retrieval-augmented generation (RAG). Announced "green intentions" are not priced, whereas realized "green efforts" to mitigate nature-related risks reduce yields when implementation aligns with the underlying risks. Regarding ecological impact, 40% of sovereign green bonds finance sustainable forestry, and their issuing countries, on average, gain a 0.2 percentage-point increase in forest area (as a share of habitable land) and a 68.4-million-hectare reduction in forest cover loss relative to pre-issuance levels, while carbon emissions per capita are unaffected. Overall, investors price risks to natural assets and weigh implementation more than the stated commitments.

Keywords: Sovereign green bonds; biodiversity loss; natural capital risk; public debt pricing; green intentions; green efforts; sustainable forestry.

JEL Codes: G12, H63, Q01, Q56, Q57

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1. Introduction

Over half of the global economy is highly or moderately dependent on nature and the goods and services it generates (known as "ecosystem services").[1] According to J.P. Morgan Asset Management, the recent losses of ecosystem services have been estimated to cause damages of USD 4 trillion to USD 20 trillion per year (Kapnick, 2022). Yet even this estimate does not cover all nature-related benefits. A significant responsibility for natural assets (or green public goods) such as biodiversity conservation and the preservation of natural resources rests with public institutions, such as governments and municipalities because private institutions like corporates invest mostly in those forms of natural capital that are direct inputs for provisioning services (such as farms, plantations, houses, and similar others) whose products are excludable (Karolyi and Tobin-de la Puente, 2023; Flammer, Giroux, and Heal, 2025; Dasgupta, 2021). Therefore, it is essential to understand the role of public organizations (such as sovereigns) and the potential risks to their external funding associated with natural assets such as biodiversity loss and the depletion of natural capital. This paper fills that gap.[2] We also evaluate whether sovereigns' intentions and efforts to mitigate these risks are priced in the cost of debt which finances these efforts.

In response to the alarming decline in biodiversity, 196 nations came together in December 2022 to endorse the Kunming-Montreal Global Biodiversity Framework (GBF).[3] This framework establishes a comprehensive global strategy to halt and reverse the degradation of natural ecosystems by 2030. A follow-up UNEP report in 2023 highlights opportunities for

[1]Source: *World Economic Forum, Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy, 2020.*

[2]We focused on biodiversity loss and the natural capital depletion risks because recent evidence shows that environmental risks extend well beyond the climate change system to include these risks as well and the economic cost of these risks would exceed the GDP loss caused in 2020 by the Covid-19 pandemic in around half the countries (Pinzon et al. 2020; Dobson et al. 2020; Tollefson 2020). In addition, the global risks survey reports from 2021 to 2025 by World Economic Forum have ranked biodiversity loss and natural capital risk as 2nd and 4th among all 33 global risks.

[3]See: `https://www.cbd.int/gbf`

responsible investors.[4] Moreover, an investor statement in 2020 on deforestation and forest fires in the Amazon, linked to the UN PRI and endorsed by 254 institutional investors with roughly US $17.7 trillion AUM, indicates their concerns about the risks of deforestation and biodiversity loss in Brazil, Bolivia, and other Amazonian countries, as well as calling for mitigating these risks.[5] In addition, Giglio, Kuchler, Stroebel, and Zeng (2026) conducted a comprehensive survey to assess perceptions of biodiversity risks among finance academics, professionals, public-sector regulators, and policy economists globally. One of their findings indicates that approximately half of the respondents believe these risks are not adequately reflected in financial markets, including sovereign debt markets, and only 14% to 19% of respondents feel that these risks are accurately priced. Taken together, given the importance of public financing and country-level actions in mitigating biodiversity loss and nature-related risks, and the need to understand whether investors price those risks and actions, we investigate the association between these risks and the pricing of sovereign green bonds in financial markets. We also analyze the environmental performance of countries that used green bond proceeds to invest in those services.

We focused on sovereign green bonds as these are financial instruments especially designed to address negative externalities, such as biodiversity loss and risks to natural capital. Since the proceeds from green bonds are intended for mitigating these negative externalities, we should not expect conventional bonds to incorporate these risks if investors are not pricing them into green bonds. Furthermore, we also investigate how "Green Intentions" and "Green Efforts" by countries may influence this pricing dynamic. A country's "Green Intentions" are reflected during the issuance of green bonds when the country discloses the categories of green projects funded by the bond proceeds. On the contrary, "Green Efforts" are evident when the country actually invests in those specified green categories.

[4]See: https://www.unepfi.org/industries/investment/stepping-up-on-biodiversity/

[5]See: https://www.unpri.org/Uploads/h/w/p/investorstatementondeforestationandforestfiresintheamazon_1oct2019_825656.pdf

To evaluate whether biodiversity and natural capital risks are incorporated into the pricing of sovereign green bonds, we analyze data from the Bloomberg Global Fixed Income Database. Our sample comprises 216 sovereign green bonds issued between 2016 and 2024, raised for green projects. We exclude 65 zero-coupon bonds, as these are essentially stripped securities that do not directly finance green projects. Most of the bonds in our sample are senior unsecured and have been issued by countries from Asia-Pacific, Europe, and Latin America. Using Artificial Intelligence (AI) techniques such as a Retrieval-Augmented Generation (RAG)-enhanced Large Language Model (LLM), we have developed a novel database focused on green projects that are financed through the proceeds of the green bonds. This database provides details about the capital allocation on these projects and their impact. To create this database, we extract information from comprehensive reports related to each bond. These reports include ESG frameworks, impact reports, capital allocation reports, external review reports, term sheets, and prospectuses. Collecting these reports is essential because the ESG framework—which outlines the categories of green projects—is provided only once. In contrast, other reports, such as impact reports, capital allocation reports, and external review reports, may be issued multiple times throughout the life of the bond. Tracking these later reports alongside the issuance date is crucial for accurately monitoring the progress of the green projects. This detailed approach enables us to evaluate whether the country's "Green Intentions", as outlined in the framework, and their "Green Efforts", as reflected in the outcomes from subsequent reports, correlate with bond pricing and to what extent these efforts help mitigate environmental externalities.

Our estimates of biodiversity loss and natural capital risk are derived from two primary sources. For the former, we use constructs on overfishing. We relied on overfishing measures for two reasons. First, overfishing drives biodiversity loss by depleting species faster than they can reproduce, disrupting food webs through trophic cascades, and wiping out non-target species as bycatch. When key species collapse, their dependent species follow,

triggering cascading extinctions that destabilize entire marine ecosystems.[6] Second, in the direct measures on biodiversity loss, such as biodiversity index or endangered species, there is less variation at the country-level, and these measures mainly capture the historical concerns and not the future concerns of the risk, which elevates the possibility of undervaluing the risk. We use three measures of overfishing from the World Development Indicators (WDI) database- percentage of agriculture and fishing in gross domestic product (GDP), logarithm of total fish production, and logarithm of wild catch fish production. Chen et al. (2025b) examine how the 2003 Yangtze River fishing ban affected public research funding and subsequent research output related to the river's fish species, highlighting a spillover effect of biodiversity conservation policy on scientific research and innovation.

For natural capital risk, we rely on country-level ESG data from the World Bank, which includes estimates on forest cover loss, the depletion rate of forests (% of gross national income (GNI)), the depletion rate of natural resources (% of GNI), and the freshwater withdrawal rate (% of internal resources). In addition to our primary risk variables, we control for bond characteristics such as maturity, amount issued, option embeddedness, and coupon type (fixed or floating). Sovereign bond pricing may be influenced by macroeconomic variables such as the debt-to-GDP ratio, GDP growth, and the terms of trade, as highlighted in previous research (Hilscher and Nosbusch, 2004; Duffie, Pedersen, and Singleton, 2003). Therefore, we also control for those variables, sourced from the World Bank database.

Our findings indicate that investors price risk to natural assets. Specifically, increases in overfishing (a risk to biodiversity conservation) and in deforestation (a risk to the preservation of natural resources) are associated with higher bond yields. In economic terms, we found that a 1% increase in risk to natural assets increases the offer yield to maturity by 21-40 basis points. Increased sovereign bond yields, linked to heightened risks to natural assets,

[6]See: `https://www.worldwildlife.org/our-work/oceans/sustainable-seafood/wild-caught-seafood/overfishing/`

indicate that investors may be concerned about the country's economic growth outlook, as resource depletion could reduce future economic growth (Stiglitz, 1974; Dasgupta and Heal, 1974). These findings are robust to the comparisons with conventional bonds issued by the same issuer in the same year and possessing similar characteristics.

As biodiversity loss and the risk to natural capital can be mitigated by initiating and implementing green projects using bond proceeds, we examine whether the intention to initiate green projects and the efforts to implement them alter the relationship between risks and bond prices. First, we measure green intentions using the ESG framework reports that the issuer provides to investors at the bond issuance. The framework highlights the green project categories in which proceeds would be used, the management of proceeds, and future green reporting. We found that mere intentions do not significantly influence investor behavior towards these risks. Next, using the impact and capital allocation reports, we measure "Green Efforts" as the actual number of green projects implemented per dollar amount of proceeds. We find that countries' green efforts are recognized by investors when they align with the direction of risks.

We understand the concerns regarding endogeneity, particularly self-selection bias. To mitigate these concerns, we use two distinct shocks to global supply chains on natural assets to model biodiversity loss and natural capital risk. For the former, we use the 2023 Peru Anchovian Crises, and for the latter, we use the European Union Deforestation Regulation (EUDR). We find reductions in bond yields after these shocks. These results contrast with those of Garel et al. (2024), which showed that investors demand a 2.2% premium for corporate biodiversity risk after the Kunming Declaration in October 2021. We hypothesized that expected bond yields would decline because these shocks highlighted biodiversity loss and natural capital risk, and that investors would anticipate regulators to intervene in the future to mitigate these risks.

To ensure that the risk to natural assets and its impact on sovereign green bond yields

do not capture the effects of geopolitical risk or climate transition risk, we show that our results are robust after controlling for these risks.

Lastly, we also assess the environmental performance of the issuers (i.e., countries). Since biodiversity loss affects carbon emissions (Weiskopf et al., 2024), we analyze carbon intensity, measured as per capita carbon emissions, for each country. We find that green-bond-issuing countries with interim and net-zero targets do not exhibit lower carbon intensity than other countries, even after a three-year period. Since carbon intensity may not be a concern for all countries and may not constitute a negative externality for each, we focus on their environmental performance based on the outcomes of projects funded by their green bonds. As 40% of sovereign green bonds are issued for sustainable forestry projects, we examine the percentage of forest area within habitable land and the loss of forest cover (in hectares) in those countries, and compare these environmental measures with those in other green bond issuers (i.e., countries). We found a 0.2 percentage-point increase in forest area as a share of habitable land and a 68.4 million-hectare reduction in forest cover loss following the green bond issuance and the investment of proceeds in sustainable forestry.

Overall, our work shows that investors care about risks to natural assets, either to the conservation of biodiversity or to the preservation of natural capital. This finding aligns with classic theoretical papers on exhaustible resources, which suggest that natural resources are crucial for a country's future economic growth.[7] We support this channel by providing a theoretical framework and empirical findings. Although the actual implementations of green projects can mitigate those risks, we found that merely expressing intentions to initiate them is insufficient to persuade investors. The efforts to implement these green projects must align with perceived risks to effectively influence investors' risk preferences. Despite commitments to net-zero emissions, the improvement in environmental performance among these countries issuing green bonds is not significant. As carbon intensity may not be a

[7]Refer to Stiglitz (1974), Dasgupta and Heal (1974), and similar others.

concern for all countries, we focus on their environmental performance measures based on sustainable forestry projects funded by their green bonds. We find increases in forest area and reductions in forest cover loss following those investments. These findings are robust across various tests.

The remainder of this paper follows this structure. Section 2 reviews the relevant literature and outlines our contributions. Section 3 presents our theoretical framework and economic channel. Section 4 describes the data and variables used in our empirical analysis. Section 5 shows the empirical design and main results for sovereign green bonds, generalizes to municipal green bonds, and includes robustness checks for the sovereign results. Section 6 concludes.

2. Related Literature and Contribution

Our research contributes to the rapidly expanding literature on the intersection of financial markets, asset prices, and environmental health. Recent studies have extensively explored the impact of risks related to climate change on financial assets (e.g., Giglio et al., 2023; Bolton and Kacperczyk, 2023; Aswani, Raghunandan, and Rajgopal, 2024a, 2024b; Aswani and Rajgopal, 2024). Comprehensive review of this body of work is provided by Giglio et al. (2021), Stroebel and Wurgler (2021), and Hong et al. (2020). Despite of these works, research into the impact of biodiversity risks on asset values and economic activity is nascent but rapidly expanding (Karolyi and Tobin-de la Puente, 2023; Giglio, Kuchler, Stroebel, and Wang, 2025; Dimson, Kacperczyk, and Starks, 2026). Notable contributions in this area include Dasgupta (2021), who offers an overview of global biodiversity and the economic drivers behind its decline, and Flammer et al. (2025), who focus on financing for biodiversity conservation projects. Recent studies on impacts of biodiversity loss mainly focus on corporate outcomes. For instance, Giglio et al. (2026) provide quantitative measures

of aggregate biodiversity risk and investigate its pricing within equity markets. Similarly, Garel, Romec, Sautner, and Wagner (2024) investigates whether corporate biodiversity footprint (CBF) (developed by Iceberg Data Lab) is associated with stock returns. Authors find no association between CBF and stock returns using the data from 2018-2021 overall but find premium of 2.2 % annual return following major biodiversity-related policy changes such as Kumming Declaration and the launch of Nature-related Financial Disclosure (TNFD) in 2021. The broader biodiversity finance literature includes Cao et al. (2026), Zhou and Almond (2026), and other contributions to the *Review of Finance* Special Issue on Biodiversity Finance.

Differentiating from previous studies, our research examines how biodiversity loss and natural capital degradation affect sovereign credit risk. We focus on sovereigns for two key reasons. First, although sovereign risk is traditionally associated with emerging economies in Latin America and Asia, the U.S. credit rating downgrade in August 2011 and the subsequent Eurozone debt crisis shifted global attention toward sovereign risk in advanced economies as well. Consequently, understanding the determinants of sovereign credit spreads and the cross-country differences in spread levels has become an important area of inquiry (Doshi et al., 2017). Second, the responsibility for providing public goods—such as biodiversity conservation and natural capital preservation - rests primarily with governments rather than corporations. Assessing how these environmental risks influence sovereign bond yields is therefore essential to determine whether international investors price such risks into sovereign debt. Moreover, because sovereign green bonds are specifically designed to finance projects that mitigate environmental externalities, analyzing their pricing dynamics and environmental implications can reveal whether investors genuinely account for these risk factors and whether countries effectively address them.

A vast body of research has examined the determinants of sovereign credit risk, identifying both country-specific and global factors. For example, Hilscher and Nosbusch (2004) find

that debt-to-GDP ratios and terms of trade account for a significant share of the variation in sovereign yield spreads. Similarly, Cantor and Packer (1996) and Kamin and von Kleist (1999) highlight the role of sovereign credit ratings as key determinants of yield spreads. Pan and Singleton (2008) document a strong relationship between sovereign credit risk and global market volatility, as captured by the VIX index. Investigating the commonality in sovereign credit spreads, Longstaff et al. (2011) use the principal components of changes in CDS spreads across 26 developed and emerging economies and show that common global factors explain a substantial portion of sovereign credit risk—more so than they do stock returns. Building on this literature, our study introduces an environmental dimension by demonstrating that risks associated with biodiversity loss and natural capital degradation represent additional, country-specific determinants of sovereign credit risk, and that the pricing of these risks is modulated by sovereigns' green project intentions and implementation efforts.

We also contribute to the growing literature on the pricing and environmental implications of green securities. Green bonds are financial instruments specifically designed to mitigate environmental externalities by channelling proceeds exclusively toward environmentally beneficial projects. Flammer (2021) finds that corporate green bonds are issued at a premium relative to traditional corporate bonds and that issuers' environmental performance improves following issuance. Aswani and Rajgopal (2025) show that the observed "greenium" in the corporate green bonds market exists primarily for financial firms, whose environmental footprint is relatively small, and that this premium does not transmit to the green loan market. They also find that neither green bond issuers nor green loan borrowers exhibit significant improvements in environmental performance within a short horizon of three to five years. Extending this line of research, Aswani and Rigobon (2025) demonstrate that the adoption of sustainable governance mechanisms—such as appointing a Chief Sustainability Officer (CSO) or establishing an ESG committee—enhances issuers' ability to

improve environmental performance following green bond issuance. In contrast, Larcker and Watts (2019), studying municipal green bonds, find no difference in the risk-adjusted pricing between green and conventional securities. Building on this literature, our study examines how risks associated with natural assets—specifically biodiversity loss and natural capital depletion—affect sovereign credit risk through the lens of green bond pricing. If investors recognize these environmental risks as material to sovereign creditworthiness, such concerns should be reflected in the pricing of sovereign green bonds earlier and more prominently than in traditional sovereign bonds.

We contribute towards the emerging literature on artificial intelligence applications in finance. Using a retrieval-augmented generation (RAG)-enhanced large language model (LLM), we extracted and developed a structured dataset on project categories, capital allocation, and the impact outcomes of green projects initiated with proceeds from green bonds. We used this data to estimate intentions (Green Intentions) and efforts (Green Efforts) and to check whether these estimates influence sovereign green bond pricing. We show that "green intentions" alone do not influence asset prices without "green efforts".

Lastly, we contribute to the growing literature on the impact of climate change, biodiversity loss, and natural capital risk on public debt. Painter (2020) provides evidence that counties affected by climate change pay higher underwriting fees and achieve higher yields when issuing municipal bonds than other counties. These results are significant only for long-term securities. In contrast, Larcker and Watts (2020) show that there is no green premium for municipal green bonds relative to conventional bonds. Soylemezgil and Uzmanoglu (2024) examine biodiversity risks in the US corporate bond market. Using a case study of bat populations, Nakhmurina, Manning, and Fenichel (2026) show that changes in local biodiversity can affect the borrowing costs of the US rural county government.

More broadly, the municipal bond literature has rapidly documented nature-related pricing across multiple dimensions. Chen et al. (2025a) show that conservation enforcement

around China's National Nature Reserves increases local government borrowing costs by 22.5 basis points. ten Bosch and Rizzi (2025) find that water stress raises agricultural-county municipal yields by 2.2 basis points per standard deviation. Rizzi and Lewis (2025) document that wetland loss increases school district bond spreads.

Compared to these papers, we focused on sovereign green bonds and examined how biodiversity loss and natural capital risk are priced in these bonds, and whether sovereigns' green intentions and efforts to mitigate these risks are factored into the debt valuation. Furthermore, we evaluate the changes in biodiversity and natural capital risks for which green projects (such as sustainable forestry) are initiated or implemented.

3. Natural Assets and Economic Growth - Theoretical Framework and the Channel

The economic theories on risk to natural assets can be traced back to Adam Smith but modern work begin from Hotelling (1931) and then progressed by Solow (1972), Stiglitz (1974), Dasgupta and Heal (1974) and others. This framework shows how marginal increase in risk to natural assets impact marginal economic growth. This model is motivated by Krautkraemer (1985).

$$\max \int U(C_t, N_t)e^{-\delta t}dt$$
$$\text{such that } \frac{dN}{dt} = -r_t$$
$$\text{and } C_t = \sigma e^{\gamma t} r_t + f(N_t)e^{\omega t}$$

Here,

r_t : Rate of depletion of natural assets.

δ : Discount rate

$F(P_t)$: Production function for developed product using natural assets.

σ: It is a constant that converts the rate of depletion into a consumption rate.

γ and ω : These are rates of technical progress in the natural assets sector and developed product sector. For simplicity, we are assuming them as zero i.e., $\gamma = \omega = 0$

P_t : Developed product at time t.

Assuming quantity of resources is fixed,

$$P_t - P_0 = N_0 - N_t$$
$$f(N_t) = F(N_0 + P_0 - N_t) = F(P_t)$$

For simplicity, U(C, N) = U(C) + U(N) (Additive Preferences)

Setting the Hamiltonian equation,

$$H = U(C_t, N_t) - \lambda_t r_t$$

λ_t : Shadow price of natural assets.

$$H = U(\sigma r_t + f(N_t), N_t) - \lambda_t r_t$$
$$H = U(\sigma r_t + f(N_t)) + U(N_t) - \lambda_t r_t$$

First order condition,

$$U_c(\sigma r_t + f(N_t)(\sigma - f_N(N_t)) - U_N N_t - \lambda_t = 0$$

where, $\lambda_t = \rho\lambda_t$.

At steady state,

$$\frac{U_N(N)}{\rho} = U_c(f(N))\sigma - \frac{U_c(f(N)f_N(N))}{\rho}$$

$\frac{U_N(N)}{\rho}$: Marginal benefit of natural assets.

$U_c(f(N)\sigma$: Marginal consumption from developed product.

$\frac{U_c(f(N)f_N(N))}{\rho}$: Marginal consumption from future value of natural assets (discounted to present).

This theoretical prediction shows how natural assets are associated with economic growth. The same we showed through empirics by running a regression of GDP growth on biodiversity loss and natural capital risk variables. We found the positive association between GDP growth and biodiversity loss & natural capital risk, and it is statistically significant. Refer Table B1 for details. As sovereign growth prospectus is counted in bond yield, the relationship between risk to natural assets and GDP growth shows why the former would also affect the bond yield.

4. Data

4.1. Sovereign Green Bonds

Our data on sovereign green bonds comes from the Bloomberg Global Fixed Income database. We keep only the sovereign bonds that Bloomberg classifies as green. This leads to the sample of 216 sovereign green bonds issued from 2016-2024.[8] We drop 65 zero-coupon bonds from the sample, as these are strips from the existing bonds and have no association with the green projects. The majority of these bonds are senior unsecured and issued by countries from Asia-Pacific, Canada, Europe, and Latin America. Summary Statistics of these bonds are provided in Table 1 Panel D.

[8]There are no sovereign green bonds issued prior to 2016.

4.2. Biodiversity Loss

For the sovereign biodiversity loss, we use the measures on overfishing from World Development Indicators (WDI) database of World Bank.[9] We relied on overfishing measures because overfishing drives biodiversity loss by depleting species faster than they can reproduce, disrupting food webs through trophic cascades, and wiping out non-target species as bycatch. The bottom trawling destroys critical habitats like coral reefs and seagrass beds that serve as nurseries for countless species, while the selective removal of large, fit individuals erodes genetic diversity over time. When key species collapse, others that depend on them follow, triggering cascading extinctions that destabilize entire marine ecosystems.[10]

We use three measures of overfishing - percentage of agriculture and fishing in GDP (*Agriculture and Fishing Per GDP*), logarithm of total fish production (*Total Fish Production*), and logarithm of wild catch fish production (*Wild Catch Fish*). The summary statistics of these measures is provided in Table 1 Panel C and definition of these measures is reported in Appendix A.

4.3. Natural Capital Risk

The data on nature capital indicators comes from the World Bank Sovereign ESG database. The World Bank (Gratcheva, Emery, and Wang, 2021) has compiled data on the wealth of 141 nations, divided into three major categories: human capital (discounted lifetime earnings), produced capital (e.g., machinery, buildings, urban land), and natural capital (e.g., forests, cropland, protected areas, subsoil assets). Natural capital, or natural wealth, is further divided into renewable and non-renewable resources. The term "renewables" refers to

[9]We use data on over-fishing for the biodiversity loss rather than direct measures such as biodiversity index or percentage of endangered species because there would be less variation in these variables at the country-level and also because, these measures mainly captures the historical concerns and not the future concerns of biodiversity loss. On using these variables, there is a possibility of undervaluing the risk.

[10]https://www.worldwildlife.org/our-work/oceans/sustainable-seafood/wild-caught-seafood/overfishing/

natural capital that can produce benefits in perpetuity under sustainable management. The ESG database provides time-series data on 71 environmental and social indicators across 17 groups; however, we focus only on indicators related to natural capital endowment and management. The database provides five indicators for natural capital risk: natural forest depletion rate (% of GNI), natural resources depletion rate (% of GNI), freshwater withdrawal (in %), Forest cover loss, Forest area (% of total land), and Terrestrial and marine protected area. We didn't include forest cover loss and forest area (% of total land) in the bond pricing analysis, as these variables are similar proxies to the natural forest depletion rate (% of GNI).

4.4. Control Variables

For regression analysis, we control for the bond characteristics such as maturity, coupon, option embeddedness, and whether the bond is fixed income or floating. Maturity is the number of years between the issue year and the year of maturity. Options is an indicator variable that takes the value 1 if the bond has options embedded, otherwise 0. Fixed is an indicator variable that takes the value 1 if the bond is straight (fixed-income), otherwise 0. Amount Issued is a logarithm of the amount issued by the sovereign issuing the green bond. In addition to controlling for bond characteristics, we also control for other determinants of sovereign credit risk, such as the Debt to GDP ratio, the natural logarithm of GDP, and terms of trade.

4.5. Green Intentions and Green Efforts of Sovereigns

Before issuing a green bond, the issuer establishes a general framework to identify which areas are eligible for sustainable finance and which projects qualify for funding. For instance, in 2020, Chile published a framework that included support for victims of human rights vio-

lations, as well as access to education and healthcare. In the same year, Mexico issued a bond to finance projects aligned with the UN Sustainable Development Goals (SDGs), covering areas such as education, agricultural development, healthcare, and sustainable infrastructure. Once a project receives approval from an external evaluator, funds are disbursed, and the project is monitored with periodic reporting.

We manually collected 118 impact reports, 115 capital allocation reports, 103 external review reports by auditors, 85 ESG framework reports, 39 prospectuses, and 19 term sheets for these bonds and linked them to each bond level. As there can be multiple impact reports, allocation reports, and external review reports, it is crucial to link these reports at the bond level to understand the time series of development of green projects. For instance, Belgium issued a green bond in 2019, which has one framework report, one capital allocation report, three impact reports, and one external review report. Here we have briefly discussed the types of reports and their contents.

ESG Framework Report: A green bond framework is a document created by the issuer that clearly articulates the company's proposed use of proceeds for the bond. The framework should include information on the eligible categories (as per the Green Bond Principles) under which the projects being financed or refinanced fit. This disclosure enables investors to better assess the green eligibility of the projects and make more informed investment decisions. For reference, check the snapshot from Swedish green bond's ESG framework report in Appendix.[11] For instance, Belgium's framework report of 2019 green bond suggests that the sovereign has decided to invest in five green project categories - *Energy Efficiency, Clean Transportation, Renewable Energy, Circular Economy,* and *Living Resources and Land Use.* These projects would be managed by the Belgian Debt Agency, ensuring that the allocation of proceeds will not allow for the listing of the same budget allocation twice. The report also mentions that the sovereign would provide allocation and impact reports for this bond,

[11]https://www.sustainalytics.com/esg-research/resource/corporate-esg-blog/about-green-bond-principles

and the green project categories would be verified by a third party.

Second Opinion Report (SPO): Issuers obtain a SPO on their green bond framework from an external reviewer, such as Climate Bond Initiative (CBI) or its approved agencies, to confirm its alignment with the components of the Green Bond Principles. This step adds credibility to the issuer's proposal to issue a green bond. For instance, Belgium uses the services of Sustainalytics for the green bond issued in 2019 for the second opinion on green project categories. For reference, check the snapshot from Swedish green bond's second opinion report in Appendix.

Capital Allocation Report: This report provides information on the allocation of bond proceeds, in dollar terms, on green projects and their distribution across the countries. For instance, Belgium allocates the green bond proceeds on tax exemption green investment, tax deduction and exemption on clean transportation, and reduced package charge for individual reusable drink packages. For reference, check the snapshot from Swedish green bond's capital allocation report in Appendix.

Impact Report: This report provides information on impact parameters and their values for green projects. Belgium measured the impact of the green projects using parameters such as avoided carbon emissions and reduced use of materials – soda, lime, and sand for drink packages. For reference, check the snapshot from Swedish green bond's impact report in Appendix.

We utilized the methodology for large language models (LLMs) as outlined by Aswani (2025) to extract information from various reports. The initial phase of the process involves gathering all the reports related to green bond such as impact report, capital allocation report, framework report and similar others, and converting them into plain text. To facilitate efficient processing by the large language model (LLM), this text is first segmented into chunks and subsequently broken down into tokens. The size of these tokens is limited to the maximum number of tokens that the LLM can process at one time, ensuring efficient

operation.

In the next step, using word embeddings from an LLM model, these tokens are transformed into vectors and stored in a vector database. Once this database is established, a query or prompt is entered in the LLM. To retrieve relevant pages for the model, an embedding for the query is generated. This embedding is then used to locate similar pages within the vector database based on vector similarity. This is the RAG enhanced LLM model which is used to develop data on green projects funded by the green bonds issued from 2016 to 2024. Appendix D shows a snapshot of green projects data developed using this technique. The model was fine-tuned using the five random reports, focusing on prompts related to essential information such as green project categories, the number of green projects sponsored by the bond proceeds, the amount allocated to each project, the impact outcome of the project, the country in which the green project is constructed, and similar others. For simplicity, we measure "*Green Intentions*" as the green projects' categories within the ESG framework report. These categories reflect the government's intentions regarding green initiatives in specific areas. Additionally, we quantify "*Green Efforts*" as the number of green projects initiated per dollar amount of proceeds, as detailed in the impact and capital allocation reports.

5. Empirical Design and Results

To investigate whether sovereign green credit risk (proxied as green bond yield) is associated with biodiversity loss and natural capital depletion, we begin by using a simple specification,

$$Yield_i = \alpha + \beta\, BiodiversityLoss_i\,(or\, NaturalCapitalDepletion_i) + \gamma\, X_i + \delta\, Z_i + \epsilon_i \quad (1)$$

Yield is the sovereign green bond's offer yield to maturity. *Biodiversity Loss* is a vector of agriculture and fishery as % of GDP, logarithm of total fish production, and logarithm of wild catch fish production. *Natural Capital Depletion* is a vector of natural resources depletion (in %), natural forests depletion (in %), and freshwater withdrawal (in %). X is a vector of bond characteristics such as maturity, option embeddedness, fixed/floating coupon, and amount issued. Z is a vector of macroeconomic variables, including the debt-to-GDP ratio, terms of trade, and the natural logarithm of GDP. We test this specification using primary-market yield and monthly secondary-market yield. ϵ is the error term with a normal distribution.

The green bond disclosures, such as impact reports, capital allocation reports, and second-opinion reports, are provided after the bond issuance and continue till maturity. There is a possibility that the availability of the new information from these reports can influence the relation between yield and biodiversity loss & natural capital risk. Therefore, we investigate Eq. (1) for the secondary market as well, controlling for the illiquidity measure.

$$\begin{aligned} Yield_{i,t} = \alpha + \beta\, BiodiversityLoss_{i,t}\,(or\, NaturalCapitalDepletion_{i,t}) + \\ \lambda\, Illiquidity_{i,t} + \gamma\, X_i + \delta\, Z_{i,t} + \epsilon_{i,t} \end{aligned} \tag{2}$$

Here, illiquidity risk is measured as,

$$Illiquidity = |BidYield - AskYield| \tag{3}$$

We further examine whether the sovereign's green intentions to mitigate these risks affect bond pricing. To test that, we use the following specification,

$$Yield_i = \omega_1 + \omega_2\, GreenIntentions_i(or\, Green_Efforts_i) + \omega_3\, X_i + \omega_4\, Z_i + \nu_i \tag{4}$$

Green Intentions is a vector of two indicator variables – Biodiversity and Natural Resources. Biodiversity indicator variable takes the value 1 if the bond's ESG framework report

mentions starting a green project to conserve biodiversity; otherwise, 0. Similarly, the Natural Resources indicator variable takes the value 1 if the ESG framework report mentions starting a green project to preserve natural resources; otherwise, it takes the value 0. ν is the error term with a normal distribution. "*Green Efforts*" is the number of green projects initiated per dollar amount of proceeds as detailed in the impact and capital allocation reports.

We also test whether a sovereign's green intentions impact the yield, especially when the sovereign has these risks.

$$\begin{aligned} Yield_i = \phi_1 + \phi_2 GreenIntentions_i (or\, Green_Efforts_i) * BiodiversityLoss_i \\ (or\, NaturalCapitalDepletion_i) + \phi_3 X_i + \phi_4 Z_i + \lambda_i \end{aligned} \tag{5}$$

The coefficient of interest in all the regressions is ϕ_2. The interaction term assesses whether green intentions (green efforts) improve external financing for sovereigns, particularly those facing these risks.

Finally, we assess the environmental performance of sovereign green bond issuers by examining whether their interim targets or net-zero commitments contribute to a reduction in carbon intensity (carbon emissions per capita) over a three-year period compared to other issuers. We use the following specification to conduct this analysis,

$$\Delta CarbonIntensity_i = \eta_1 + \eta_2 Net - Zero_Commitment_i + \eta_3 X_i + \eta_4 Z_i + \mu_i \tag{6}$$

Here, carbon intensity is carbon emissions per capita.[12] Δ is difference between third year from issuance and the year of issuance. Commitment is a vector of indicator variables – Interim Target and Net Zero Target. Interim Target takes value 1 if the sovereign has the

[12]We use carbon intensity and not level emissions because Aswani, Raghunandan, and Rajgopal (2024a, 2024b) justified that scaled carbon emissions are preferred by the investors over the level of emissions. Although choosing the carbon intensity three years from issuance is random, our results are robust to this choice.

interim target (year) of reducing the emissions; otherwise, 0. Net Zero Target takes value 1 if the sovereign has the net-zero target (year); otherwise, 0.

5.1. Mitigating Endogeneity: Two Shocks to Nature-based Global Supply Chains

As relation between sovereign bond yield and biodiversity and natural capital risks are endogenous due to self-selection bias, we mitigate these concerns using two separate shocks - one for biodiversity loss and one for natural capital risk. For the former, we use Peru Anchovian Crises 2023, and for the latter, we use the European Union Deforestation Regulation (EUDR).

Peru Anchovian Crises 2023 : Peru is not just a regional fishing power - it is the backbone of the global fishmeal and fish oil supply chain. In June 2023, Peru's Ministry of Production (PRODUCE) canceled the country's first anchovy fishing season in the north-central zone — the world's largest anchovy fishery by volume. A second season was eventually authorized in late October with a total allowable catch (TAC) of 1.68 million metric tons, well below the 2.28 million MT set for the same season in 2022. The cancellation of the first fishing season resulted in an estimated USD 1.4 billion in lost revenue from fishmeal and fish oil exports. Peru's national GDP was expected to fall between 0.3 and 0.4 percent as a direct result.

The crisis led to thousands of layoffs and affected more than 250,000 families and 3,500 small- and medium-sized enterprises that depend on industrial fishing. This crises highlighted the global food chain fragility as the heavy reliance on a single species from a single country for fisheries exposed it to systemic risk. We use this crises as a shock to our biodiversity risk constructs and conduct a difference-in-difference regressions using the indicator variable (*Anchoveta*) which takes value 1 for year 2023 and after, otherwise 0.

European Union Deforestation Regulation (EUDR) : As the exogenous shock to natural capital risk, we use EUDR. The EU Deforestation Regulation (EUDR) is a landmark piece of EU legislation aimed at ensuring that certain commodities and products sold in or exported from the EU have not contributed to deforestation or forest degradation worldwide. The regulation covers 7 key commodities- cattle, coffee, cocoa, palm oil, soy, wood, rubber, and their derived products. The companies placing these products on the EU market must ensure that products must not have been produced on land deforested after 31 December 2020, products are in compliance with the laws of the country of origin, and the companies must submit a due diligence statement with geo-referencing data, risk assessments, and mitigation measures. There are also penalties for non-compliance such as fines of at least 4% of annual EU turnover, confiscation of products and revenues, temporary exclusion from public procurement, prohibition from placing products on the market.

The EUDR has significant implications beyond Europe — it affects producer countries in Latin America, Southeast Asia, and Africa, pushing them to adopt stronger forest governance and traceability systems to maintain access to the EU market. In essence, the EUDR is a major step toward making EU supply chains deforestation-free, shifting the burden of proof onto companies to demonstrate their products don't contribute to forest loss.

The timeline of EUDR is as follows:

• 2021 — The European Commission published a proposal for the regulation in November 2021, which kicked off the legislative process.

• 2023 — The regulation was formally adopted and entered into force on 29 June 2023, after being published in the Official Journal of the EU.

• 2020 — This year is significant within the regulation itself, as the cut-off date: products must not come from land deforested after 31 December 2020.

We use the EUDR as an exogenous shock to the natural capital risk constructs and conduct a difference-in-difference regressions using the indicator variable ($EUDR$) which

takes value 1 for year 2021 and after, otherwise 0. We empirically test our hypothesis using the following specification.

$$Yield_i = \alpha + \beta_1 BiodiversityLoss_i + \beta_2 Anchoveta(EUDR) + \beta_3 Anchoveta(EUDR)X \\ BiodiversityLoss_i (or\, NaturalCapitalDepletion_i) + \gamma X_i + \delta Z_i + \epsilon_i \tag{7}$$

Furthermore, we also explore the possibility of Achovian crises (EUDR) impact on the association between bond pricing and green intentions. We test it by interacting the green intention variables in eq(3) by *Anchoveta (EUDR)* indicator variable.

$$Yield_i = \phi_1 + \phi_2 GreenIntentions_i + \phi_3 Anchoveta(EUDR) + \phi_4 Anchoveta(EUDR)X \\ GreenIntentions_i + \phi_5 X_i + \phi_6 Z_i + \lambda_i \tag{8}$$

The results for these tests are in Table 8.

5.2. Sustainable Forestry Projects and Deforestation

The deforestration is the result of market failure as the prices of forest-related products are undervalued ignoring its economic cost. Addressing the deforestation is equally crucial as the climate change considering the fact that world has lost 30 % of forest area on habitable land in last 10,000 years and 50% of it in last 100 years. According to UN Food and Agriculture Organization's (FAO) assessment, the 10 million hectares of land is cut down every year. [13] The deforestration directly impacts the timber, paper, construction, furniture, tourism, and related industries but its indirect consequences impacts every business as it releases carbon emissions in the atmosphere contributing towards climate change, increase extreme weather events, sea-level rise, and reduced agricultural productivity. The sustainable forestry is a solution to the loss in forest coverage and can provide economic benefits while

[13] `https://ourworldindata.org/deforestation`

protecting forests. The Sustainable forestry practices include selective logging, reforestation, and forest conservation. These practices help to maintain forest health, protect biodiversity, and provide a sustainable supply of forest products. [14]

From the 151 sovereign green bonds issued, excluding zero coupon bonds, 59 (40 %) green bonds proceeds are used for sustainable forestry projects. These projects are initiated by Canada, Brazil, China, Hungary, India, Indonesia, Nigeria, and Chile (see, Figure 4 for details). It is not surprising that the sustainable forestry projects are initiated at Europe, South America, Asia, Africa, and in Canada as these continents (or countries) have the greatest share of forest area, and therefore, the forest depletion or deforestation affects these areas more than others. To examine whether initiating the sustainable forestry projects help these sovereigns, we investigate the changes in forest area percentage of habitable land and the loss of forest cover (in hectares) in the sovereigns which used green bond proceeds for these projects compare to sovereigns which used the bond proceeds for other projects.

$$\begin{aligned} ForestArea\,(ForestCoverLoss)_{i,t} = \alpha_i + \beta_{i,t}\, SustainableForestryCountry_i \\ (Post - GreenBondIssunace_{i,t}) + \gamma_c + \gamma_y + \epsilon_{i,t} \end{aligned} \tag{9}$$

Here, *Sustainable Forestry Country* is an indicator variable which takes value 1 if the country has issued at least one green bond to support the projects related to sustainable forestry and 0 for countries which issued green bonds for other projects. *Post-Green Bond Issuance* is the indicator variable which takes the value 1 for years post green bond issuance supporting sustainable forestry projects; otherwise 0. Results for these tests are in Table 10.

[14] https://climate.sustainability-directory.com/question/what-are-the-economic-impacts-of-deforestation/

5.3. Results and Discussion: Sovereign Green Bonds

Figure 1 illustrates the yearly and country-level distribution of sovereign green bond issuances. There is a sharp increase in issuances starting in 2018, especially of fixed and floating types. Reaching a peak in 2022-2023, with over 50 sovereign green bonds issued. Most of these bonds have been issued by countries in Europe, the Asia-Pacific, Canada, and Central America. Notably, Hong Kong (China), Canada, India, Chile, Hungary, and Indonesia have issued a considerable number of these bonds.

Figure 2 shows the credit rating of these bonds. In the sample, 63 % are rated; among these, 40 are rated AA, 12 are rated BBB, 8 are rated BBB-, and 3 are rated differently. Figure 3 shows the variation in biodiversity loss and natural capital risk with economic growth (proxied as the logarithm of gross domestic product (GDP)). Two hypotheses exist on the relationship between GDP and biodiversity/natural capital risk. The first hypothesis suggests that GDP is high for high biodiversity /natural capital risk, because countries grow using these resources. This leads to an increase in biodiversity / natural capital risk with GDP. The second hypothesis proposes that GDP is high in countries with low biodiversity loss and natural capital risk because they have access to capital to conserve (or preserve) biodiversity (natural resources). Graphs in Figure 3 support the first hypothesis, as the logarithm of wild catch fish production (Figure 3(a)) and forest cover (Figure 3(b)) have increased linearly with the logarithm of GDP.

Table 1 reports the characteristics and summary statistics of these bonds. Table 1 Panel A reports the distribution based on coupon type. Of the 216 sovereign green bonds, 151 are fixed (or floating) bonds, and 65 are stripped (or zero-coupon bonds). Panel B reports the distribution of green certifications for these bonds. Roughly 98% are green-certified by the Climate Bond Initiative (CBI) or its approved agencies. Panel C provides the distribution on maturity of these bonds. About 96% of these bonds expire on maturity, and only 3-4%

are option embedded and can be called before maturity. The maturity of these bonds ranges from 1 to 50 years, but most mature in 2, 3, 5, 7, 10, and 30 years. Panel D reports the summary statistics of the bond characteristics. The average yield and amount issued of these bonds are 4.3% and 3.1 billion USD. The average coupon for these bonds is 3.4%. Other bond characteristics include indicator variables for option embeddedness, green certification, and for a straight (or fixed income) bond.

Table 2 presents the summary statistics for biodiversity loss and natural capital risk measures. The average percentage of agriculture, forestry, and fisheries in GDP among these sovereign nations is 6.713%, with a maximum of 28.345%. The average values for the logarithm of total fish production and wild catch fish production are 14.676 and 13.576, respectively. On average, the depletion rate of natural resources in these countries is 1.2%, with some countries experiencing a maximum depletion rate of 14% due to extensive resource extraction. For the countries issuing green bonds, the average forest area represents 31% of total land area, while the maximum recorded is 68%. The average depletion of natural forests accounts for 4.2% of Gross National Income (GNI). Another key measure of natural capital risk is total annual water withdrawal as a percentage of internal resources. The average water withdrawal is 1.77%, with some countries reaching a maximum of 77.5%. These variables provide diverse estimates of biodiversity and natural capital risk.

Table 3 presents information about green reporting and disclosures by the sovereign green bond issuers. During the bond issuance process, the issuer provides a framework outlining the green project categories, which are based on the Green Bond Principles developed by the International Capital Market Association (ICMA). While we have access to information on green project categories for all the bonds from database, we managed to collect framework reports for 85 of these bonds. The allocation of proceeds to green projects is detailed in capital allocation reports. In some cases, the capital allocation report and the impact report are issued together. We have obtained 113 capital allocation reports related to these

bonds. Some sovereign issuers have released multiple capital allocation reports from the date of issuance to maturity to update stakeholders on the management of proceeds. To share the progress of the green projects with the investors, the sovereign provides impact outcomes in impact reports. These outcomes include metrics such as carbon emissions avoided, kilowatt-hours (KWH) of energy generated using renewable resources, green infrastructure developments, and the number of buses or trains operating on renewables as part of smart transportation projects. We have collected 118 impact reports for these 85 bonds. Additionally, we gathered 39 prospectuses and 19 term sheets, which, while not directly useful for our analysis, assist in verifying information such as bond characteristics from term sheets against Bloomberg data or matching mentions of green projects in the framework with those in the prospectuses.

Panel B shows the green project categories in the ESG framework reports. It also reflects the sovereign's intentions to begin green projects in these categories to mitigate risks in these areas. Although renewable energy, energy efficiency, and smart transportation projects are common among the green bond issuers, the ESG frameworks of sovereign issuers suggest that 77% and 54% of these projects would be related to biodiversity conservation and preservation of natural resources. The investment in green projects in these categories is much higher for sovereigns than for corporates, which supports the notion that public goods such as biodiversity conservation and natural resources preservation rely on the support from public organizations such as sovereigns and municipalities (local government).

Table 4 Panel A presents the regression results of offer yield to maturity on the biodiversity risk measures for the primary bond market. Columns (1) to (3) show results without any controls, while Columns (4) to (6) show results incorporating bond-level controls. Columns (7) to (9) results include bond-level controls along with error clustering at the country and year level. Our findings indicate that the yield increased by 40 - 50 basis points due to the biodiversity risk (proxies by measures of over-fishing) and these results are statistically

significant. We confirm these results across all three specifications.

Panel B of the table reports the results of the primary market yield concerning natural capital measures. For this analysis, we focused on three specific measures of natural capital risk: natural forest depletion (as a percentage of total area), natural resources depletion (as a percentage of GNI), and freshwater withdrawal (as a percentage of internal resources). We found that the yield is positively associated with all three natural capital risk measures, and these results are consistent across all three specifications. Economically, our findings suggest that a 1% increase in natural resource depletion results in an increase of 98 basis points in the offer yield to maturity, while a 1% increase in the natural forest depletion rate raises the offer yield by 32 basis points. Similar results we found for fresh water withdrawl (in %). The negative response from debt holders to both biodiversity loss and natural capital risk measures indicates that investors are concerned about the risks to natural assets which is closely tied to country's economic growth.

Table 5 Panel A reports the regression results of secondary market yield on biodiversity loss and natural capital risk measures. We have 3,681 monthly yield values for 127 bonds from 2016-2024. Like regression for primary market yield, our specification for this test includes the bond level controls and error clustering at the country level and year level. We found that biodiversity loss and natural capital risk are positively associated with yield. For instance, the 1 % increase in logarithm of wild catch fish production increases the yield by 21.9 basis points and 1 % increase in natural forest depletion increases the yield by 40 basis points. We found the similar results for other variables. These results are in line with primary market results and support the theoretical predictions of Stiglitz (1974), Dasgupta and Heal (1974), Dasgupta and Heal (1974) and others on exhaustible natural assets. Stiglitz (1974) concluded that stocks of natural assets are complementary to capital markets and instability in the natural assets market would impact capital markets.

In Panel A, the bond yield is unadjusted to the liquidity risk. However, as past literature

has showed that illiquidity explains 30-40% of bond yield, it is crucial to adjust yield to liquidity risk. We adjust the yield to illiquidity risk controlling for other bond characteristics and country and year level error clustering. To better understand the impact of biodiversity loss and natural capital risk on sovereign green bond yield , we rerun the eq (1) controlling for illiquidity (*Illiquidity*) measure. The results are in Table 5 Panel B and Panel C. Similar to Panel A results, we find that the biodiversity loss and natural capital risk factors increase the liquidity-adjusted yield. We find that biodiversity risk factors affects the liquidity-adjusted yield by 15-17 basis point. The natural resources depletion and natural forest depletion affect the liquidity-adjusted yield by 43 basis point and 78 basis point. These results are statistically significant. Table 5 Panel B shows the results of biodiversity loss and Panel C shows the results of natural capital risk. Overall, the Table 4 and Table 5 results suggest that risk to natural assets has an impact on the sovereign green bond yield in the primary as well as in the secondary market.

Table 6 reports the regression results of yield on the sovereign's green intentions to initiate a biodiversity or natural resources management projects. Sovereigns share this information with investors at the issuance of green bonds, using the ESG framework. As discussed in Section 3, the ESG framework includes details on green project categories in which sovereigns have decided to use the proceeds. We use this information from the framework report to generate two indicator variables. Biodiversity is an indicator variable that takes value 1 if the framework reports the biodiversity as a green project category; otherwise, it takes the value 0. Similarly, Natural Resources is the indicator variable, which takes the value 1 if the framework report has natural resources management as the green project category; otherwise, it takes the value 0. Table 6 indicates that sovereign intentions to initiate green projects, including those focused on biodiversity, have no significant impact on bond yields. Testing for the effect of intentions to address natural capital risks also shows no impact on green bond yields, even in countries with these risks. This suggests that investors care less

about the intentions of green bond issuers reported in framework reports. Consequently, it is essential to assess whether the impact outcomes of these projects are reflected in bond pricing in the secondary market, as information about capital allocation, project development, and impact achievements becomes available post-issuance.

Table 7 presents the results concerning the impact of bond issuers' green initiatives on secondary market yields. The green initiatives (green efforts) are quantified by the number of green projects funded for each dollar raised. This approach benefits investors, as diversifying green projects reduces risk compared to investing all proceeds into a single project. The regression analysis indicates that green efforts are negatively correlated with bond yields. The increase in green efforts lowers bond yields. Nevertheless, the results are prominent when these efforts align with efforts to mitigate risks to natural assets.

To address endogeneity, we use Peru Achovian Crises 2023 as a shock to biodiversity loss, and EUDR as a shock to natural capital risk. We examine whether these shocks altered the relationship between sovereign green bonds yield and biodiversity & natural capital risks. Results are reported in Table 8 Panel A and Table 8 Panel B. We find a reduction in yield after these shocks, compared to before, for biodiversity loss and natural capital risks. These results contrast with those of Garel et al. (2024), which showed that investors demand a 2.2% premium for corporate biodiversity risk after the convention. We hypothesized that bond yields would decline because these shocks highlighted the biodiversity loss and natural capital risk and investors knew that regulators would intervene after these shocks to mitigate these risks. We also investigate whether green intentions matter for the bond yield after these shocks, we don't find any robust results for that. These results are in Table 8 Panel C.

So far, we have investigated the impact of biodiversity & natural capital risks on sovereign green bond pricing and compared it with conventional bonds. Nevertheless, it is also essential to check whether the issuance of green debt improves the environmental performance of these sovereigns. Table 9 illustrates the impact of green bond issuances on carbon intensity,

measured as carbon emissions per capita, for issuers with net zero commitments versus those without. Table 9 Panel A outlines the types of commitments made by green bond issuers regarding carbon emission reduction. Notably, 44% of these bonds are issued by entities with net-zero targets, primarily aimed at 2050, although some have targeted 2040 or 2070. These issuers also establish interim targets for emission reductions, focusing on years such as 2025 or 2030. Panel B presents the regression results concerning the relationship between carbon intensity and the commitments made by green bond issuers. Our findings suggest that setting both interim and net-zero targets does not significantly reduce the carbon intensity of these issuers compared to their counterparts.

Since carbon intensity may not be a concern for all sovereigns, we focus on their environmental performance based on the projects funded by their green bonds. Approximately 40% of 151 green bonds, or 59 bonds, are used for sustainable forestry projects. Therefore, we examine the percentage of forest area in habitable land and the loss of forest cover (in hectares) in these sovereigns and compare them with other green bond issuers. Table 10 shows the results for these measures. We find that green bond issuers who invested in sustainable forestry projects have 2.5% more forest area and a high forest cover loss of 159 million hectares compared to those who invested in other projects. To gain deeper insights, we analyze these parameters both before and after green bond issuances for the sovereigns that invested in sustainable forestry. After issuing green bonds and investing in sustainable forestry, these sovereigns experienced a 0.2% increase in forest area and a reduction of 68.4 million hectares in forest cover loss.

Moreover, we conducted an external validity test of sovereigns' green intentions using the Sustainable Development Goals (SDGs) they have adopted. Since green bond issuers have also adopted SDGs, and two of these are related to biodiversity and natural capital risks, this provides a setting to verify the results in Table 6. SDG 14, "Life below Water," supports biodiversity by promoting the conservation and sustainable use of oceans, seas, and marine

resources for sustainable development, protecting and restoring marine ecosystems, ending harmful fisheries subsidies, reducing marine pollution, and conserving coastal areas, among other goals. Similarly, SDG 15, "Life on Land," promotes natural capital by advocating for the end of desertification, the conservation and restoration of forests, wetlands, mountains, and drylands, reducing habitat loss, and restoring degraded land, among other objectives. There are 67 green bonds related to SDG 14 and 119 related to SDG 15. We examine whether adopting these SDGs influences bond pricing in the primary and secondary markets. The results are presented in Table 11. We find no effect of these SDGs on sovereign green bond yields, neither in the primary nor in the secondary market. These findings also confirm our results in Table 6, which suggest that green intentions are insufficient to influence the pricing of sovereign green bonds.

5.4. Robustness Checks and Additional Tests: Sovereign Green Bonds

5.4.1. Geopolitical Risk

There is a possibility that positive association between green bond yield and risk to natural assets exists because of missing variable, such as geopolitical risk, in our empirical specification. Thus, this positive association reflects geopolitical risk and not the biodiversity & natural capital. To mitigate such concerns, we include geopolitical risk index as a control variable in our main specification and reconduct the analysis. Geopolitical risk index is based on Caldara and Iacoviello (2022). Even controlling for this measure of geopolitical risk, we found the same results that yield is positively associated with biodiversity loss and natural capital risk.

5.4.2. Transition Risk due to Climate Change

Similar to geopolitical risk, another possibility is that positive relation between yield and biodiversity loss & natural capital risk is due to missing transition risk measure in the regression specification. To alleviate such issues, we rerun the main regression controlling for transition risk measure. The transition risk measure is adaptive capacity of sovereigns' to tackle climate change. It is one of the components of Notre Dame Global Adaptation Initiative's (ND-GAIN) Country Index. We found the same results even controlling for this measure which confirms our main results are not influenced by the exclusion of transition risk in the regression specification.

5.4.3. Green Bonds vs. Conventional Bonds

To assess whether risks to natural assets are more strongly incorporated into sovereign green bond pricing than into otherwise comparable conventional sovereign debt, we next examine their effect on the yield differential between the two. Table 12 compares sovereign green bonds with matched conventional bonds issued by the same sovereign in the same year and with similar bond characteristics, using nearest-neighbor matching that pairs 150 green bonds with 184 conventional bonds. The results indicate that risks to natural assets are more strongly reflected in green bond pricing than in otherwise comparable conventional debt. In Panel A, which examines the primary market, the interaction between the green-bond indicator and the biodiversity-risk measures is positive and statistically significant for agriculture and fishing as a share of GDP, total fish production, and wild catch fish production; the interaction with natural resources depletion is likewise positive and significant, while the interactions with natural forest depletion and freshwater withdrawal are positive but not precisely estimated. Panel B shows a similar, and if anything stronger, pattern in the secondary market: the interaction terms between the green-bond indicator and agricul-

ture and fishing per GDP, total fish production, wild catch fish, natural resources depletion, and natural forest depletion are all positive and highly significant. Taken together, these results suggest that sovereign green bonds internalize risks to natural assets more strongly than matched conventional bonds, consistent with the view that green securities are more directly tied to the environmental risks they are intended to address.

6. Conclusion

Our paper explores whether public debt pricing is influenced by risk to natural assets such as biodiversity and natural capital, a crucial issue highlighted by Giglio et al. (2026) and Flammer et al. (2025). We specifically focus on sovereign green bonds because the responsibility for providing public goods, such as biodiversity conservation and natural capital preservation, rests primarily with governments rather than corporations. Assessing how these environmental risks influence sovereign bond yields is therefore essential to determine whether international investors price such risks into sovereign debt. Moreover, because the sovereign green bonds are specifically designed to finance projects that mitigate environmental externalities, analyzing their pricing dynamics and environmental implications can reveal whether investors genuinely account for these risk factors and whether countries effectively address them. Analysis of sovereign green bonds issued between 2016 and 2024 shows that bond yields are increasing in both biodiversity loss, proxied by overfishing measures, and natural capital risk, proxied by natural resource depletion, forest depletion, and freshwater withdrawal. Economically, a 1% increase in risk to natural assets is associated with a 21 to 40 basis-point increase in bond yield. These findings remain robust when sovereign green bonds are compared with matched conventional bonds issued by the same sovereign in the same year and with similar characteristics, and they are further reinforced by the municipal bond evidence, where risks to natural assets are likewise positively associated with green bond yields in both the primary and secondary markets. Overall, the evidence indicates

that risks to natural assets are priced in public green debt markets and are reflected more strongly in green securities than in otherwise comparable conventional debt.

Compared to corporate green bonds, 70% of these bonds are associated with projects related to biodiversity conservation and natural resource management. Our investigation assesses whether biodiversity loss and natural capital risk affect bond pricing and whether sovereign's green intentions' and 'green efforts' impact this relationship. Using the large language models (LLMs), the "Green Intentions" are estimated from ESG framework reports, which detail the types of green projects the sovereign intends to develop. "Green Efforts" are measured through capital allocation and impact reports and proxied as number of green projects implemented per dollar amount of the bond proceeds. By manually linking each report to the bond level, we track the timing of capital allocation and impact reports from issuance to maturity. Using this novel data, we found that mere intentions do not significantly influence investor behavior towards these risks and that the green efforts by the sovereigns are recognized by the investors if the efforts are aligned with mitigating biodiversity loss and natural capital risk.

Regarding the environmental performance of issuers, we find that green bond-issuing sovereigns with interim and net-zero targets do not have lower carbon emissions per capita compared to others, even after a three-year span. Since carbon intensity may not be a concern for all issuers, we focus on their environmental performance based on the projects funded by their green bonds. As 40% of sovereign green bonds are used for sustainable forestry projects, we examine the percentage of forest area in habitable land and the loss of forest cover (in hectares) in these sovereigns and compare them with other green bond issuers. We discovered a 0.2 percentage-point increase in forest area and a reduction of 68.4 million hectares in forest cover loss following the issuance of green bonds and investment in sustainable forestry.

Overall, our work shows that investors price the risk to natural assets—both biodiversity

loss and natural capital depletion into sovereign green bond yields. This finding aligns with classic theoretical papers on exhaustible resources, which suggest that natural resources are crucial for a country's economic growth. Although green projects can be implemented to mitigate these risks, we discovered that merely expressing intentions to initiate such projects is insufficient to persuade investors. The efforts to implement these green projects must align with the perceived risks in order to influence investors' risk preferences effectively. Despite commitments to net-zero emissions, the improvement in environmental performance among these sovereigns issuing green bonds is not significant. As carbon intensity may not be a concern for all sovereigns, we focus on their environmental performance based on the sustainable forestry projects funded by their green bonds. We find the increase in forest area and reduction in loss of forest cover following these investments. These findings are robust to a battery of checks.

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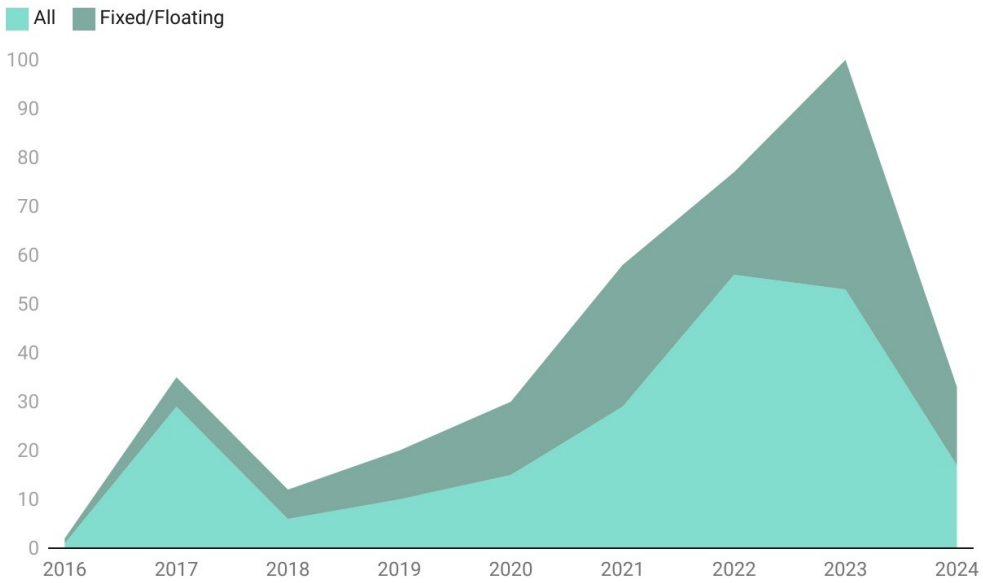
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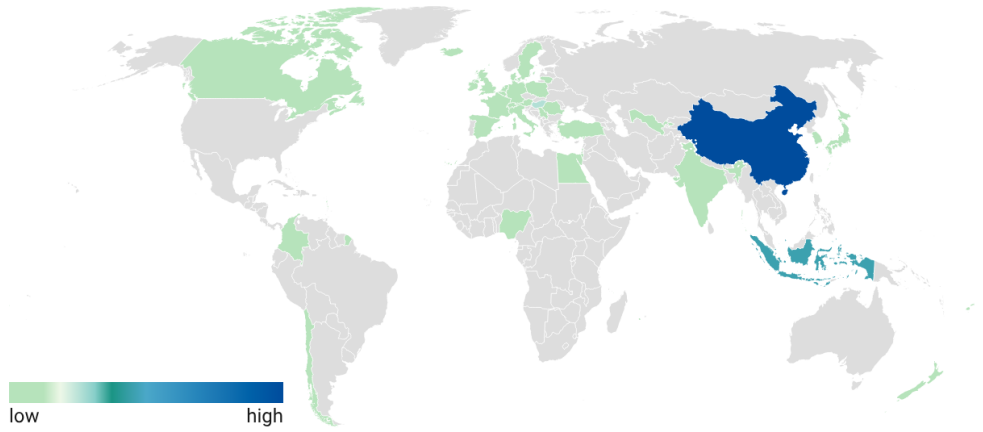
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a) Yearly Distribution of Sovereign Green Bonds



b) Country-level Distribution of Sovereign Green Bonds

Figure 1: **Yearly and Country Level Distribution**. Figure 1 a shows the yearly distribution of all sovereign green bonds as well as for fixed (of floating) coupon type. Figure 1 b shows the country level distribution of sovereign green bonds.

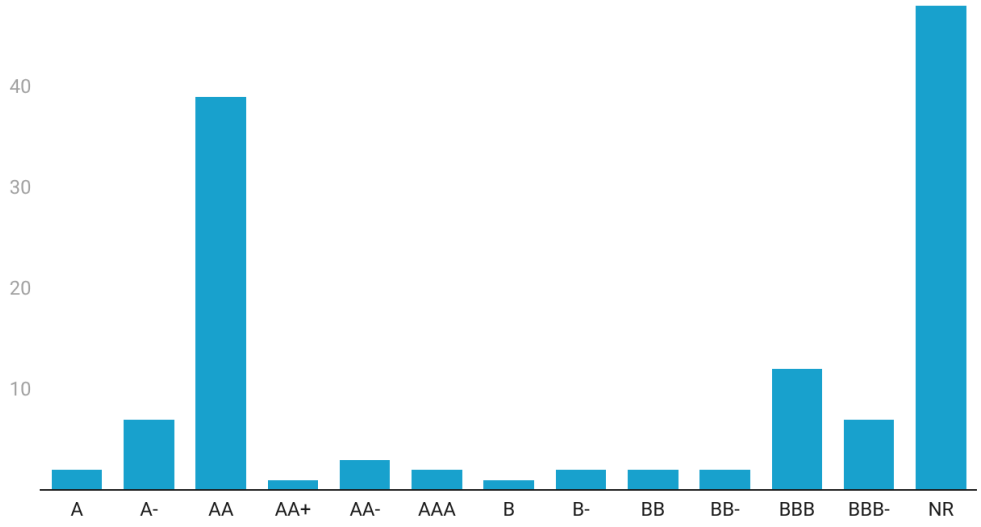
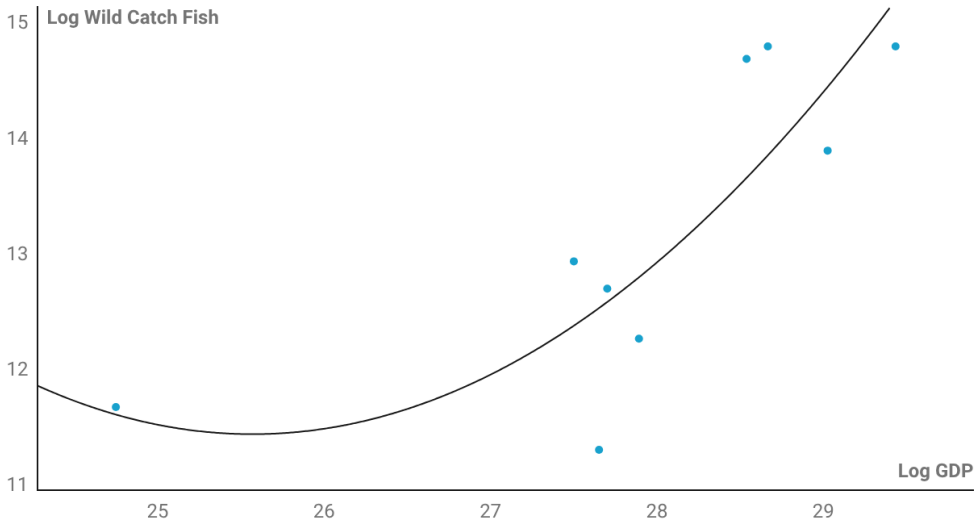
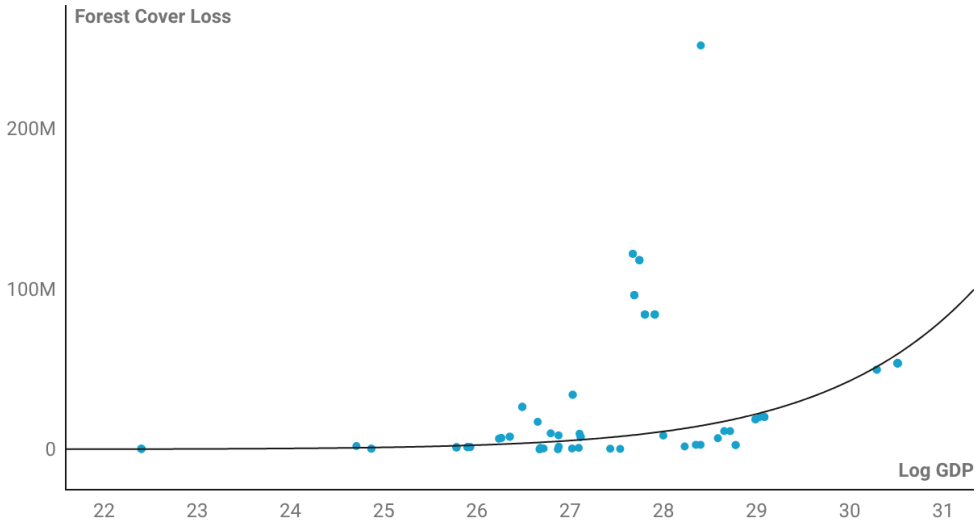


Figure 2: Credit Ratings of Sovereign Green Bonds. This figure shows the distribution of credit ratings of sovereign green bonds. 37 % green bonds are not rated, and among the rated bonds, 30% are rated AA.



a) Log GDP vs Biodiversity Risk



b) Log GDP vs Natural Capital Risk

Figure 3: Biodiversity and Natural Capital Risk versus Gross Domestic Product (GDP). This figure compares the biodiversity risk and natural capital risk with the natural logarithm of GDP. Biodiversity Risk is measured as natural logarithm of wild catch fish production. Natural Capital Risk is measured as forest cover loss (as % of territorial area).

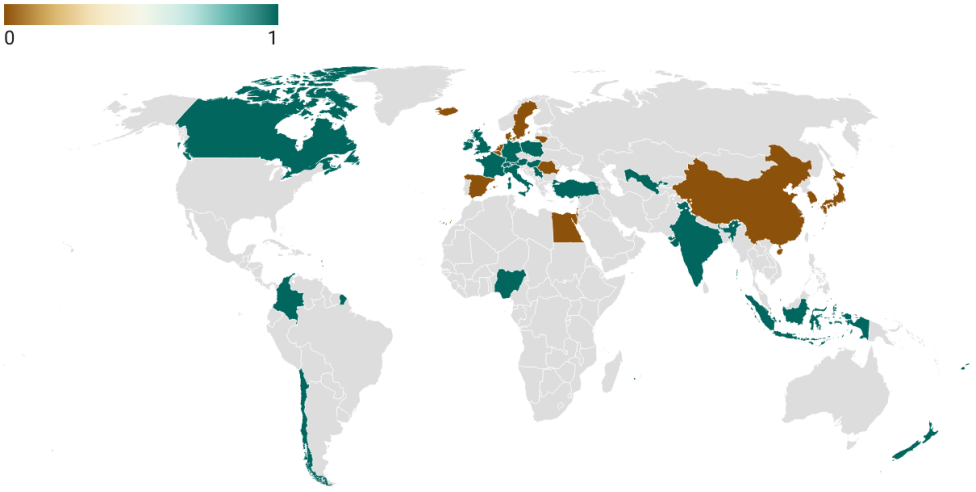


Figure 4: **Sustainable Forestry using Sovereign Green Bonds**. This figure shows the countries which use the green bond proceeds for sustainable forestry projects compare to countries which use the green bond proceeds for other projects.

Table 1
Sovereign Green Bond Characteristics

Panel A: Coupon-Type

Coupon Type	Frequency	Percentage
Fixed/Floating	151	69.91
Zero Coupon	65	30.09
Total	216	100

Panel B: Green Certification

Certified	Freq.	Percent	Cum.
N	2	1.32	1.32
Y	149	98.68	100
Total	151	100	

Panel C: Bond Maturity

Maturity Type	Frequency	Percent
Maturity	146	96.69
Callable	5	3.31
Total	151	100

Panel D: Summary Statistics

Variable	Mean	Std. Dev.	Max
Yield	4.373	2.645	18.138
Amount Issued (million USD)	3,151	6,125	37,861
Coupon	3.437	2.817	16.25
Fixed	0.947	0.225	1
Certified	0.987	0.115	1
Option	0.033	0.180	1

Notes. **Sovereign Green Bond Characteristics.** This table provides the bond characteristics of sovereign green bonds. Panel A shows the distribution of coupon types. As green reports are available only for fixed/floating coupon type bonds and not for zero coupon (or strip) bonds, the paper focuses on the former. Panel B provides the distribution of green certification. Panel C provides distribution based on maturity type. Panel D provides summary statistics. Yield is offering yield to maturity (%). Amount Issued is in million USD. Coupon is in percentage. Fixed equals 1 if fixed income, 0 for floating. Certified equals 1 if certified by CBI or affiliated agencies. Option equals 1 if option embedded. Details in Appendix A.

Table 2
Biodiversity and Natural Capital Risk Indicators

Biodiversity Risk			
Indicator	Mean	Standard Deviation	Maximum
Agriculture and Fisheries Per GDP	6.713	5.118	28.345
Total Fish Production	14.676	3.226	18.334
Wild Catch Fish Production	13.576	2.940	16.467

Natural Capital Risk			
Indicator	Mean	Standard Deviation	Maximum
Natural resources depletion (% of GNI)	1.216	1.83	14
Net forest depletion (% of GNI)	4.2	19.7	1
Annual freshwater withdrawals, total (% of internal resources)	1.33	8.957	77.5

Notes. **Biodiversity and Natural Capital Risk Indicators**. This table provides the summary statistics of biodiversity and natural capital risk measures. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, annual fresh water withdrawals as percentage of internal resources. Further details on variable definition are provided in Appendix A.

Table 3
Sovereign Green Projects: Disclosure and Category

Panel A: Distribution of Disclosures on Sovereign Green Bonds

Index	Type of Report	# Numbers
1	Impact Reports	118
2	Allocation reports	115
3	External Review	103
4	ESG Framework	85
5	Prospectus	39
6	Term Sheet	19

Panel B: Sovereign Green Project Category

Green Project Category	# Numbers	Percentage
Biodiversity	116	77
Natural Resources and Management	82	54
Energy Efficiency	136	90
Pollution Prevention and Control	92	61
Climate Change Adaptation	109	72
Circular Economy	89	59
Renewable Energy	144	95
Green Buildings	95	63
Clean Transportation	146	97
Sustainable Water Management	113	75

Notes. **Sovereign Green Projects: Disclosure and Category**. Panel A shows the distribution of reports provided by the sovereigns' issuing green bonds. In the green reports, sovereign issues ESG framework, allocation reports, impact reports, prospectuses, external review, and term sheets. The ESG framework provides a description of the green categories and the project's intended purpose. Second Opinion Report (SPO) provided by the auditor to verify whether those projects are aligned with green bond principles (developed by ICMA). Impact report provides details on the impact of these projects measured as carbon emissions avoided, electricity generation using renewable sources, and similar measures. Allocation reports provide the details on capital allocation for the green projects using the bond proceeds. The Term Sheet provides the final contractual terms related to the bond. These reports are hand-collected and used to develop a structured database on green projects using Artifical Intelligence (AI) model as suggested in Aswani (2024). This database is matched at the bond level. Panel B shows the distribution of green project categories provided in the ESG Framework as per green bond guidelines suggested by ICMA.

Table 4
Is Sovereign Sustainable Bond Pricing Associated with Biodiversity and Nature Capital Loss?

Panel A: *Primary Market Bond Yield and Biodiversity Loss*

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield	(6) Yield	(7) Yield	(8) Yield	(9) Yield
Agriculture and Fisheries Per GDP	0.435***			0.435***			0.509***		
	(0.035)			(0.092)			(0.118)		
Total Fish Production		0.596***			0.596***			0.501**	
		(0.152)			(0.131)			(0.204)	
Wild Catch Fish Production			0.459***			0.459**			0.400*
			(0.144)			(0.148)			(0.185)
Observations	126	116	116	126	116	116	126	116	116
R-squared	0.562	0.128	0.091	0.562	0.128	0.091	0.601	0.144	0.134
Bond Level Controls	No	No	No	No	No	No	Yes	Yes	Yes
Error Clustering	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: *Primary Market Bond Yield and Natural Capital Depletion*

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield	(6) Yield	(7) Yield	(8) Yield	(9) Yield
Natural Resources Depletion (in %)	1.001***			1.001***			0.987***		
	(0.085)			(0.096)			(0.095)		
Natural Forests Depletion (in %)		0.320**			0.320***			0.321***	
		(0.140)			(0.036)			(0.037)	
Fresh Water Withdrawal (in %)			0.064***			0.064***			0.061***
			(0.024)			(0.008)			(0.008)
Observations	127	127	127	127	127	127	127	127	127
R-squared	0.523	0.04	0.054	0.523	0.04	0.054	0.53	0.102	0.111
Bond Level Controls	No	No	No	No	No	No	Yes	Yes	Yes
Error Clustering	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes

Notes. **Sovereign Bond Pricing and Biodiversity/Natural Capital Risk**. This table shows the regression results of the association between bond yield and biodiversity and natural capital risk in the primary market. Panel A shows the regression of bond yield on biodiversity risk measures. Panel B shows the regression of bond yield on natural capital risk measures. In Panel A, Columns (1) – (3) show the regression results without controlling for bond level controls and without error clustering at the country level. Columns (4) – (6) show the results with country-level error clustering but without controlling for bond-level controls. Columns (7) – (9) show the results with bond-level controls as well as with country-level error clustering. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. In Panel B, Columns (1) – (3) show the regression results without controlling for bond level controls and without error clustering at the country level. Columns (4) – (6) show the results with country-level error clustering but without controlling for bond-level controls. Columns (7) – (9) show the results with bond-level controls as well as with country-level error clustering. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

Table 5
Secondary Market of Sovereign Sustainable Bond and Biodiversity & Natural Capital Risk

Panel A: *Liquidity Un-adjusted Bond Yield and Biodiversity & Natural Capital Risk*

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield	(6) Yield
Agriculture and Fisheries Per GDP	0.417**					
	(0.135)					
Total Fish Production		0.326*				
		(0.145)				
Wild Catch Fish Production			0.219*			
			(0.110)			
Natural Resources Depletion (in %)				1.303**		
				(0.500)		
Natural Forests Depletion (in %)					0.404***	
					(0.088)	
Fresh Water Withdrawal (in %)						0.070***
						(0.020)
Observations	3,655	3,648	3,648	3,681	3,681	3,681
R-squared	0.347	0.088	0.075	0.087	0.066	0.065
Bond Level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: *Liquidity Adjusted Bond Yield (LAY) and Biodiversity Risk*

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield	(6) Yield
Illiquidity	12.344	17.240*	17.433**	17.885**	18.470**	17.511*
	(7.878)	(7.267)	(7.017)	(6.053)	(7.097)	(7.657)
Agriculture and Fisheries Per GDP	0.185**			0.170*		
	(0.072)			(0.079)		
Total Fish Production		0.179*			0.197**	
		(0.079)			(0.078)	
Wild Catch Fish Production			0.140			0.150*
			(0.083)			(0.074)
Observations	1,874	1,863	1,863	1,874	1,863	1,863
R-squared	0.239	0.183	0.145	0.287	0.204	0.163
Bond Level Controls	No	No	No	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes	Yes	Yes	Yes

Table 5
Secondary Market of Sovereign Sustainable Bond and Biodiversity & Natural Capital Risk – *Cont.*
Panel C: *Liquidity Adjusted Bond Yield (LAY) and Natural Capital Risk*

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield	(6) Yield
Illiquidty	14.268*	16.092*	15.550**	19.643**	14.708	14.594
	(7.390)	(6.890)	(5.944)	(6.060)	(8.849)	(8.146)
Natural Resources Depletion (%)	0.575**			0.432**		
	(0.231)			(0.173)		
Natural Forest Depletion (%)		0.668			0.787*	
		(0.461)			(0.413)	
Fresh Water Withdrawl (%)			0.012			0.011
			(0.007)			(0.007)
Observations	1,890	1,890	1,890	1,890	1,890	1,890
R-squared	0.178	0.107	0.131	0.258	0.124	0.143
Bond Level Controls	No	No	No	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes	Yes	Yes	Yes

Notes. **Secondary Market of Sovereign Sustainable Bond and Biodiversity & Natural Capital Risk** This table shows the regression results of the association between secondary market bond yield and biodiversity & natural capital risks. Panel A reports the results of illiquidity un-adjusted yield on biodiversity & natural capital risks. Panel B reports the results of illiquidity adjusted yield on biodiversity risk factors. Panel C reports the results of illiquidity adjusted yield on natural capital risk factors. Illiquidity adjusted yield (LAY) is residual from panel regression of bond yield on illiquidity risk. The illiquidity risk is measured as the absolute value of bid yield minus ask yield ($|BidYield - AskYield|$). Yield is the monthly offer yield to maturity, measured in percentage. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, annual freshwater withdrawals as percentage of internal resources. All regressions have bond-level controls and country-level error clustering. Bond level controls comprise - logarithm of amount issued, indicator variable for whether the bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Details of the variables are provided in Appendix A. *, **, *** shows the statistical significance at 10 %, 5 %, and 1% level.

Table 6
Sovereign's Green Intentions and Bond Pricing

Panel A: *Bond Pricing and Sovereign Green Intention to Mitigate Biodiversity and Natural Capital Risk*

	Primary Market				Secondary Market			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
VARIABLES	Yield	Yield	Yield	Yield	Yield	Yield	Yield	Yield
Biodiversity	-0.399		-0.720		-1.802		-2.929	
	(0.875)		(0.902)		(2.659)		(3.371)	
Natural Resources		0.813		1.032		0.485		0.994
		(0.689)		(0.788)		(1.304)		(1.706)
Observations	130	130	130	130	3,690	3,690	3,690	3,690
R-squared	0.0036	0.0238	0.0705	0.0971	0.009	0.001	0.079	0.06
Bond Level Controls	No	No	Yes	Yes	No	No	Yes	Yes
Error Clustering	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: *Biodiversity Risk, Green Intentions, and Primary Market Bond Pricing*

	(1)	(2)	(3)
VARIABLES	Yield	Yield	Yield
Biodiversity	0.517	1.181	-1.136
	(0.522)	(3.275)	(3.776)
Agriculture and Fisheries Per GDP	0.540***		
	(0.119)		
Biodiversity x Fisheries Per GDP	-0.043		
	(0.121)		
Total Fish Production		0.571	
		(0.300)	
Biodiversity x Total Fish		-0.087	
		(0.202)	
Wild Catch Fish Production			0.324
			(0.250)
Biodiversity x Wild Catch Fish			0.080
			(0.251)
Observations	126	116	116
R-squared	0.604	0.145	0.134
Bond Level Controls	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes

Table 6
Sovereign's Green Intentions and Bond Pricing – *Cont.*
Panel C: *Natural Capital Risk, Green Intentions, and Secondary Market Bond Pricing*

VARIABLES	(1) Yield	(2) Yield	(3) Yield
Natural Resources	0.448	1.386	2.258
	(1.555)	(1.602)	(2.685)
Natural Resources Depletion (in %)	1.05		
	(1.575)		
Resources Depletion x Natural Resources	0.248		
	(1.412)		
Natural Forest Depletion (in %)		0.469***	
		(0.044)	
Forest Depletion x Natural Resources		0.103	
		(1.153)	
Fresh Water Withdrawal (in %)			0.078***
			(0.009)
Water Withdrawal x Natural Resources			-0.033
			(0.054)
Observations	3,681	3,681	3,681
R-squared	0.089	0.072	0.079
Bond Level Controls	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes

Notes. **Green Intentions and Sovereign Bond Pricing.** This table provides the regression results of bond yield on sovereign's green intentions related to biodiversity and natural capital risk. Panel A shows the regression results of sovereign yield on green intentions measured as a vector of indicator variables- *Biodiversity* and *Natural Resources*. *Biodiversity* is an indicator variable which takes value 1 if the sovereign's green project is related to biodiversity; otherwise, 0. *Natural Resources* is an indicator variable which takes value 1 if the sovereign's green project is related to risk to natural resources management; otherwise, 0. ESG framework report by green bond issuing sovereign provides the intentions to allocate the capital in the green projects aligned with green bond principles. Yield is monthly offer yield to maturity, measured in percentage. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual freshwater withdrawals as percentage of internal resources. All regressions have bond level controls and country-level error clustering. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Details of the variables are provided in Appendix A. *, **, *** shows the statistical significance at 10 %, 5 %, and 1% level.

Table 7
Green Efforts, Green Intentions, and Sovereign Bond Yield

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield
Number of Green Projects (per USD)	-0.004*	-0.012***	-0.015***	0.087	-0.023***
	(0.002)	(0.003)	(0.004)	(0.068)	(0.006)
Biodiversity				0.711	
				(0.700)	
Biodiversity X Number of Green Projects				-0.100	
				(0.066)	
Natural Resources					-0.214
					(0.549)
Natural Resources X Number of Green Projects					0.010*
					(0.006)
Observations	63	63	63	63	63
R-squared	0.040	0.200	0.373	0.400	0.404
Bond Controls	No	Yes	Yes	Yes	Yes
Country-level Controls	No	No	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes	Yes	Yes

Notes. **Green Efforts, Green Intentions, and Sovereign Bond Pricing.** This table provides the regression results of bond yield on sovereign's green efforts related to biodiversity and natural capital risk. Columns (1) - (3) reports the regression results of yield on green efforts (*Green Efforts*) with and without bond-level and country-level controls. Columns (4) - (5) report the results of yield on the interaction of green intentions and green efforts. *Green Efforts* is measured as number of green projects developed by the sovereign using the sustainable debt proceeds i.e., number of green projects per USD of proceeds amount. The green intentions is measured as a vector indicator variables - *Biodiversity* and *Natural Resources*. Biodiversity is an indicator variable which takes value 1 if the sovereign's green project is related to biodiversity; otherwise, 0. Natural resources is an indicator variable which takes value 1 if the sovereign's green project is related to risk to natural resources management; otherwise, 0. All regressions have bond level controls and country-level error clustering. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Details of the variables are provided in Appendix A. *, **, *** shows the statistical significance at 10 %, 5 %, and 1% level.

Table 8
Natural Assets and Sovereign Green Bonds: Resolving the endogeneity Issues

Panel A: *Anchovian Crises, Sovereign Green Bond Yield, and Biodiversity Risk*

VARIABLES	(1) Yield	(2) Yield	(3) Yield
Anchoveta	0.287	7.700**	8.900***
	(0.372)	(2.248)	(2.239)
Agriculture and Fisheries Per GDP	0.511***		
	(0.118)		
Anchoveta x Fisheries Per GDP	-0.004		
	(0.012)		
Total Fish Production		0.564**	
		(0.169)	
Anchoveta x Total Fish		-0.477**	
		(0.155)	
Wild Catch Fish Production			0.510***
			(0.124)
Anchoveta x Wild Catch Fish			-0.603**
			(0.167)
Observations	126	116	116
R-squared	0.603	0.202	0.212
Bond Controls	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes

Panel B: *European Deforestration Regulation (EUDR), Sovereign Green Bond Yield, and Natural Capital Risk*

VARIABLES	Yield	Yield	Yield
EUDR	0.087	0.066	-1.208
	(0.269)	(0.578)	(0.675)
Natural Resources Depletion (in %)	1.863***		
	(0.209)		
EUDR x Natural Resources Depletion (in %)	-0.913***		
	(0.199)		
Natural Forest Depletion(in %)		0.311***	
		(0.038)	
EUDR x Natural Forest Depletion (in %)		-0.037	
		(0.409)	
Fresh Water Withdrawl			0.001***
			(0.000)
EUDR x Fresh Water Withdrawl			0.028**
			(0.009)
Observations	127	127	127
R-squared	0.563	0.111	0.328
Bond Controls	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes

Table 8. Natural Assets and Sovereign Green Bonds: Resolving the endogeneity Issues – *Cont.*

Panel C: *Anchovian Crises, EUDR, Green Intentions, and Sovereign Green Bond Yield*

VARIABLES	(1) Yield	(2) Yield
Anchoveta	-1.644	
	(1.395)	
Biodiversity	-1.118	
	(1.505)	
Anchoveta x Biodiversity	2.035	
	(1.418)	
EUDR		-2.278
		(1.331)
Natural Resources		-1.352
		(1.013)
EUDR x Natural Resources		3.020*
		(1.308)
Observations	130	130
R-squared	0.100	0.132
Bond Controls	Yes	Yes
Error Clustering	Yes	Yes

Notes. **Natural Assets and Sovereign Green Bonds: Resolving the endogeneity Issues**. This table reports the regression results of sovereign bond yield on biodiversity & natural capital risks resolving the endogeneity issues using the Peruvian Achovian Crises 2023 and European Deforestration Regulation (EUDR). Panel A compares the regression results of bond yield on biodiversity risks post Peruvian Achovian Crises 2023. The coefficient of interaction term of each biodiversity risk dimension with Peruvian Achovian Crises 2023 (*Anchoveta*) is of interest. *Anchoveta* is indicator variable which takes value 1 if the bond is issued post 2022; otherwise 0. *Biodiversity Risk* is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Panel B compares the regression results of bond yield on natural capital risks post EUDR. The *EUDR* is indicator variable which takes value 1 if the bond is issued in year 2021 or after; otherwise 0. *Natural Capital Risk* is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual freshwater withdrawals as percentage of internal resources. Panel C compares the regression results of yield on green intentions post Peruvian Achovian Crises 2023 and European Deforestration Regulation (EUDR). The green intentions is measured as a vector indicator variables - *Biodiversity* and *Natural Resources*. Biodiversity is an indicator variable which takes value 1 if the sovereign's green project is related to biodiversity; otherwise, 0. Natural resources is an indicator variable which takes value 1 if the sovereign's green project is related to risk to natural resources management; otherwise, 0. Bond controls comprise bond maturity, amount issued, indicator variable for fixed coupon, and indicator variable for option embeddedness. Country controls comprise natural logarithm of GDP and Debt to GDP ratio. The specification also includes clustering the error at country level. Details of the variables are provided in Appendix A. *, **, *** are significance level at 10%, 5%, and 1%.

Table 9
Environmental Performance of Sovereign Green Bond Issuers

Panel A: *Distribution of Carbon Commitments*

Carbon Commitments of Green Bond Issuers			
Commitments	Number of Bonds	Percent	Cumulative
Carbon neutral(ity)	59	39.07	39.07
Climate neutral	13	8.61	47.68
Emissions intensity target	2	1.32	49.01
Emissions reduction target	8	5.3	54.3
Net zero	67	44.37	98.68
Other	2	1.32	100
Total	151	100	

Panel B: *Carbon Intensity of Green Bond Issuers: Are Net-Zero Committers Doing Better?*

	(1)	(2)	(3)	(4)
VARIABLES	ΔCarbon Intensity	ΔCarbon Intensity	ΔCarbon Intensity	ΔCarbon Intensity
Interim Target	-0.092	-0.07		
	(0.207)	(0.152)		
Net Zero Target			-0.174	-0.104
			(0.223)	(0.166)
Constant	0.278	-1.939**	0.509	-1.841**
	(0.264)	(0.848)	(0.389)	(0.863)
Observations	23	23	23	23
R-squared	0.284	0.658	0.3	0.662
Bond Controls	Yes	Yes	Yes	Yes
Country Controls	No	Yes	No	Yes

Notes. **Environmental Performance of Sovereign Green Bond Issuers**. This table shows the regression results of environment performance of green bond issuing sovereigns. Panel A reports the distribution of carbon emissions related commitments of green bond issuers. Panel B reports the regression results of change in carbon emissions intensity on interim target and net zero target indicator variables. Δ is difference between third year from issuance and the year of issuance. Interim Target is an indicator variable which takes value 1 if the sovereign has the interim target year for reducing emissions; otherwise, 0. Net Zero Target is an indicator variable which takes value 1 if the sovereign has the net zero target year for reducing emissions; otherwise, 0. Bond controls comprise bond maturity, amount issued, indicator variable for fixed coupon, and indicator variable for option embeddedness. Country controls comprise natural logarithm of GDP and Debt to GDP ratio. Details of the variables are provided in Appendix A. *, **, *** are significance level at 10%, 5%, and 1%.

Table 10
Sustainable Forestry and Sovereign Green Bond Issuance

Panel A: *Sustainable Forestry Projects by Sovereign Green Bond Issuers*

Sustainable Forestry	Freq.	Percent	Cum.
0	92	60.93	60.93
1	59	39.07	100
Total	151	100	

Panel B: *Need of Sustainable Forestry for Sovereign Green Bond Issuers*

	Country Comparison		Pre and Post Green Bond Issuance			
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Forest Area (%)	Forest Cover Loss	Forest Area (%)	Forest Cover Loss	Forest Area (%)	Forest Cover Loss
Sustainable Forestry Country	2.551**	159,156.029**				
	(0.047)	(7,173.653)				
Post-Green Bond Issuance			6.920***	-17,261.821	0.209*	-68,358.027***
			(2.145)	(46,255.929)	(0.114)	(20,550.373)
Observations	544	544	320	320	320	320
R-squared	0.005	0.031	0.020	0.000	0.997	0.944
Country	No	No	No	No	Yes	Yes
Year	Yes	Yes	No	No	No	No
Error Clustering	Yes	Yes	Yes	Yes	Yes	Yes

Notes. **Sustainable Forestry and Sovereign Green Bond Issuance**. Panel A shows the distribution of bonds targetting sustainable forestry projects using the proceeds amount. Panel B Columns (1) - (2) report the regression results of forest area percentage of land (Forest Area (%)) and forest cover loss in hectares (Forest Cover Loss) on countries which target sustainable forestry projects using the green bonds proceeds versus the countries which issued green bonds but did not target sustainable forestry projects. Panel B Columns (3) - (6) report the regression results of forest area percentage of land (Forest Area (%)) and forest cover loss in hectares (Forest Cover Loss) on post green bond issuances in countries which target sustainable forestry projects using the green bond proceeds. Columns (3) -(4) show results without country fixed effects and columns (5) -(6) show results with country fixed effects. *Sustainable Forestry Country* is an indicator variable which takes value 1 if the country has issued atleast one green bond to support the projects related to sustainable forestry and 0 for countries which issued green bonds for other projects. *Post-Green Bond Issuance* is the indicator variable which takes the value 1 for years post green bond issuance supporting sustainable forestry projects; otherwise 0. Empirical specification also includes error clustering at country level and year level. Details of the variables are provided in Appendix A. *, **, *** are significance level at 10%, 5%, and 1%.

Table 11
Sustainable Development Goals (SDGs) and Sovereign Green Bond Pricing: External Validity of Green Intentions

Panel A: *Distribution of SDG 14 ("Life Below Water") and SDG 15 ("Life over Land")*

SDG 14	Freq.	Percent
0	84	55.63
1	67	44.37
Total	151	100

SDG 15	Freq.	Percent
0	32	21.19
1	119	78.81
Total	151	100

Panel B: *Impact of SDGs on Sovereign Green Bond Pricing*

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield
SDG_14	0.525		-0.227	
	(0.662)		(0.536)	
SDG_15		-0.911		-0.976
		(1.162)		(1.257)
Observations	3,690	3,690	130	130
R-squared	0.066	0.076	0.061	0.078
Bond Controls	Yes	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes	Yes

Notes. **Sustainable Development Goals (SDGs) and Sovereign Green Bond Pricing**. Panel A shows the distribution of bonds based on "Life on Land" (Sustainable Development Goal (SDG) 15) and "Life below Water" (Sustainable Development Goal (SDG) 14). SDG 14 covers biodiversity issues and SDG 15 covers natural resources management issues. Adoption of these SDGs helps to test the impact of green intentions on bond pricing. Panel B reports the regression results of these SDGs on sovereign green bond pricing. Panel B Columns (1) - (2) report the impact of these SDGs on secondary market yield, and Columns (3) - (4) report the impact of these SDGs on primary market yield. Bond controls comprise bond maturity, amount issued, an indicator variable for fixed coupon, and an indicator variable for option embeddedness. Empirical specification also includes error clustering at the country level and the year level. Details of the variables are provided in Appendix A. *, **, *** are significance level at 10%, 5%, and 1%.

Table 12
Sovereign Green Bond vs. Conventional Bonds:
Risk to Natural Assets and Sovereign Debt
Panel A: Primary Market

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield	(6) Yield
Green Bond	-1.049	-4.745**	-4.611**	-1.072	-1.372	-1.360
	(0.907)	(1.757)	(1.783)	(1.203)	(1.317)	(1.530)
Agriculture and Fishing Per GDP	-0.119					
	(0.083)					
Green Bond x Fishing Per GDP	0.155**					
	(0.051)					
Total Fish Production		-0.386				
		(0.269)				
Green Bond x Total Fish Production		0.307***				
		(0.080)				
Wild Catch Fish			-0.299			
			(0.206)			
Green Bond x Wild Catch Fish			0.322**			
			(0.104)			
Natural Resources Depletion				-0.989*		
				(0.503)		
Green Bond x Natural Resources Depletion				0.977**		
				(0.332)		
Natural Forest Depletion					-1.131	
					(1.150)	
Green Bond x Natural Forest Depletion					1.519	
					(1.164)	
Fresh Water Withdrawl						-0.008
						(1.656)
Green Bond x Fresh Water Withdrawl						0.082
						(1.664)
Observations	204	178	178	221	221	221
R-squared	0.660	0.670	0.666	0.702	0.144	0.146
Bond Level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Country Level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes	Yes	Yes	Yes

Table 12. Sovereign Green Bond vs. Conventional Bonds: Risk to Natural Assets and Sovereign Debt – *Cont.*

Panel B: Secondary Market

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield
Green Bond	-1.083***	-1.810***	-2.812***	-0.201**	1.326***
	(0.067)	(0.465)	(0.340)	(0.100)	(0.211)
Agriculture and Fishing Per GDP	5.964***				
	(0.831)				
Green Bond x Fishing Per GDP	0.197***				
	(0.016)				
Total Fish Production		-27.903***			
		(5.286)			
Green Bond x Total Fish Production		0.236***			
		(0.021)			
Wild Catch Fish			-15.243***		
			(2.937)		
Green Bond x Wild Catch Fish			0.314***		
			(0.024)		
Natural Resources Depletion				-2.434***	
				(0.316)	
Green Bond x Natural Resources Depletion				1.533***	
				(0.169)	
Natural Forest Depletion					-0.069***
					(0.004)
Green Bond x Natural Forest Depletion					0.225***
					(0.071)
Observations	6,408	6,034	6,034	6,928	6,928
R-squared	0.692	0.500	0.493	0.511	0.421
Bond Level Controls	Yes	Yes	Yes	Yes	Yes
Country Level Controls	Yes	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes	Yes
Month - Year	Yes	Yes	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes	Yes	Yes

Notes. **Natural Assets and Sovereign Green Bond Yield versus Conventional Bond Yield**. This table shows the regression results of the comparing the yield of green bond with conventional bond and natural capital risk. Panel A reports the results for primary market and Panel B reports the results for secondary market. Green Bond is an indicator variable which takes value 1 if the bond is green bond; otherwise 0 for conventional bond. Columns (1) – (3) show the regression results for biodiversity loss measures. Columns (4) – (6) show the results for natural capital risk measures. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. All specification include bond level and country level controls. Bond level controls comprise the logarithm of the amount issued, an indicator variable for whether the bond is fixed income or floating (Fixed), and the years in maturity of the bond (Maturity). Country level controls include logarithm of gross domestic product (GDP), debt to GDP ratio, and trade to GDP ratio. Country is country-level fixed effect and Month-Year is date-level fixed effect. Error clustering are at country and year level. Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

Appendix A

Index	Variable Name	Definition	Source
1	Annual freshwater withdrawals, total (% of internal resources)	Annual freshwater withdrawals refer to total water withdrawals, not counting evaporation losses from storage basins. Withdrawals also include water from desalination plants in countries where they are a significant source. Withdrawals can exceed 100 percent of total renewable resources where extraction from nonrenewable aquifers or desalination plants is considerable or where there is significant water reuse. Withdrawals for agriculture and industry are total withdrawals for irrigation and livestock production and for direct industrial use (including withdrawals for cooling thermoelectric plants). Withdrawals for domestic uses include drinking water, municipal use or supply, and use for public services, commercial establishments, and homes.	World Bank
2	Adjusted savings: natural resources depletion (% of GNI)	Natural resource depletion is the sum of net forest depletion, energy depletion, and mineral depletion. Net forest depletion is unit resource rents times the excess of roundwood harvest over natural growth. Energy depletion is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years). It covers coal, crude oil, and natural gas. Mineral depletion is the ratio of the value of the stock of mineral resources to the remaining reserve lifetime (capped at 25 years). It covers tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite, and phosphate. This indicator is expressed as a percentage of Gross National Income (GNI) which is the total income earned by all residents within an economic territory during an accounting period.	World Bank
3	Adjusted savings: net forest depletion (% of GNI)	Net forest depletion is calculated as the product of unit resource rents and the excess of roundwood harvest over natural growth. This indicator is expressed as a percentage of Gross National Income (GNI) which is the total income earned by all residents within an economic territory during an accounting period.	World Bank
4	Terrestrial and marine protected areas (% of total territorial area)	Terrestrial protected areas are totally or partially protected areas of at least 1,000 hectares that are designated by national authorities as scientific reserves with limited public access, national parks, natural monuments, nature reserves or wildlife sanctuaries, protected landscapes, and areas managed mainly for sustainable use. Marine protected areas are areas of intertidal or subtidal terrain–and overlying water and associated flora and fauna and historical and cultural features–that have been reserved by law or other effective means to protect part or all of the enclosed environment. Sites protected under local or provincial law are excluded.	World Bank
5	Agriculture and Fisheries per GDP	This indicator measures the contribution of agriculture, forestry, and fishing sectors to the economy as a percentage of GDP.	World Development Indicators
6	Total Fish Production	A natural logarithm of total fish production in metric tonnes (MT).	World Development Indicators
7	Wild Catch Fish Production	A natural logarithm of total wild catch fish production in metric tonnes (MT).	World Development Indicators
8	Yield	Bond yield, measured in %.	Bloomberg and LSEG
9	Coupon	Coupon of the issued bond. Measured in Percentage.	Bloomberg and LSEG
10	Amount Issued	Amount issued using the sovereign green bond.	Bloomberg and LSEG
11	Maturity	Difference of years between maturity date and issue date.	Bloomberg and LSEG
12	Biodiversity	Indicator variable which takes value 1 if the green-bond issuing sovereign intend to begin a biodiversity project using the bond proceeds; otherwise 0.	Green Bond Disclosures
13	Natural Resources	Indicator variable which takes value 1 if the green-bond issuing sovereign intend to begin a natural resources management project using the bond proceeds; otherwise 0.	Green Bond Disclosures
14	Illiquidity	Absolute value of bid yield minus ask yield. The yield is measured in percentage.	Bloomberg
15	Green Efforts	Number of green projects implemented per dollar value of proceeds.	Green Bond Disclosures and Bloomberg
16	Forest Area	Forest area as percentage of habitable land.	World Bank
17	Forest Cover Loss	The loss of forest cover in hectares.	World Bank
18	Gross Domestic Product (GDP)	The gross domestic product (GDP) of a country, measured in USD.	World Bank
19	Terms of Trade	The terms of trade of a country, measured in percentage.	World Bank
20	Debt to GDP Ratio	The ratio of debt to GDP of a country.	World Bank
21	Kunming	An indicator variable that takes the value 1 if a bond is issued after 19th December 2022; otherwise 0.	Bloomberg and LSEG
22	Interim Target	An indicator variable that takes the value 1 if a sovereign has an interim target (year) for carbon neutrality; otherwise, 0.	
23	Net Zero Target	An indicator variable that takes the value 1 if a sovereign has an net-zero target (year) for carbon neutrality; otherwise, 0.	
24	Sustainable Forestry Country	An indicator variable that takes the value 1 if a sovereign used green bond proceeds for a sustainable forestry project; otherwise, 0.	Green Bond Disclosures and Bloomberg
25	Post-Green Bond Issuance	An indicator variable that takes the value 1 if the year is the same or post-green bond issue year for the green bond issuing sovereigns who invested on sustainable forestry projects; otherwise, 0.	Green Bond Disclosures and Bloomberg
26	SDG_14	An indicator variable that takes the value 1 if the green-bond issuing sovereign has adopted sustainable development goal (SDG) 14 i.e., "Life below Water" ; otherwise, 0.	Green Bond Disclosures
27	SDG_15	An indicator variable that takes the value 1 if the green-bond issuing sovereign has adopted sustainable development goal (SDG) 15 i.e., "Life on Land" ; otherwise, 0.	Green Bond Disclosures
28	Green Bond	An indicator variable that takes the value 1 if the bond is green bond; otherwise 0 for conventional bond.	

Appendix B

Table B1 - Natural Assets and Economic Growth

Panel A: Biodiversity Loss and Economic Growth

VARIABLES	(1) GDP Growth	(2) GDP Growth	(3) GDP Growth	(4) GDP Growth	(5) GDP Growth	(6) GDP Growth
Agriculture and Fishery Per GDP	0.046***	0.033*				
	(0.011)	(0.017)				
Total Fish Production			0.083**	0.102***		
			(0.034)	(0.034)		
Wild Catch Fish					0.060**	0.063**
					(0.029)	(0.029)
Transition Risk		1.138		2.822***		2.735***
		(0.887)		(0.538)		(0.539)
Observations	2,074	2,074	2,070	2,070	2,061	2,061
R-squared	0.198	0.199	0.192	0.200	0.192	0.199
Year	Yes	Yes	Yes	Yes	Yes	Yes
Hubber-White SE	Yes	Yes	Yes	Yes	Yes	Yes

Panel B: Natural Capital Risk and Economic Growth

VARIABLES	(1) GDP Growth	(2) GDP Growth	(3) GDP Growth	(4) GDP Growth	(5) GDP Growth	(6) GDP Growth
Natural Resources Depletion (in %)	0.100***	0.079**				
	(0.035)	(0.039)				
Natural Forest Depletion (in %)			0.161***	0.112***		
			(0.029)	(0.035)		
Fresh Water Withdrawl (in %)					0.000	0.000
					(0.000)	(0.000)
Transition Risk		1.969***		1.967***		2.753***
		(0.673)		(0.656)		(0.551)
Observations	2,039	2,039	2,039	2,039	1,980	1,980
R-squared	0.195	0.198	0.193	0.196	0.189	0.197
Year	Yes	Yes	Yes	Yes	Yes	Yes
Hubber-White SE	Yes	Yes	Yes	Yes	Yes	Yes

Notes. **Natural Assets and Economic Growth**. This table shows the regression results of the GDP growth on biodiversity and natural capital risks. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. Panel A reports the results for biodiversity loss and Panel B reports the results for natural capital risk. In Panel A, column (1) and column (2) show the regression results for biodiversity risk using *Agriculture and Fisheries per GDP*. Column (3) and column (4) show the regression results for biodiversity risk using *Total Fish Production*. Column (5) and column (6) show the regression results for biodiversity risk using *Wild Catch Fish Production*. In Panel B, column (1) and column (2) show the regression results for natural capital risk using *Natural Resources Depletion (in %)*. Column (3) and column (4) show the regression results for natural capital risk using *Natural Forest Depletion (in %)*. Column (5) and column (6) show the regression results for natural capital risk using *Fresh Water Withdrawl (in %)*. Transition risk is adaptive capacity measure from ND-GAIN Country Index. All specifications include year fixed effect and Hubber-White standard error correction. Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

Table B2: **Natural Assets and Sovereign Green Bond Yield**

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield	(6) Yield
Agriculture and Fishery Per GDP	0.229*					
	(0.099)					
Total Fish Production		0.248**				
		(0.094)				
Wild Catch Fish			0.219**			
			(0.074)			
Natural Resources Depletion (in %)				0.296		
				(0.217)		
Natural Forest Depletion (in %)					0.236***	
					(0.036)	
Fresh Water Withdrawl (in %)						0.039***
						(0.006)
Maturity	0.016	0.013	0.012	0.018	0.019	0.020
	(0.010)	(0.018)	(0.017)	(0.015)	(0.015)	(0.015)
Amount Issued (Log)	0.293***	0.120	0.058	0.070	0.075	0.083
	(0.082)	(0.100)	(0.073)	(0.079)	(0.093)	(0.096)
Fixed	0.599	0.630	0.520	0.452	0.543	0.551
	(0.481)	(0.553)	(0.531)	(0.487)	(0.557)	(0.557)
Coupon	0.619***	0.827***	0.832***	0.707***	0.843***	0.840***
	(0.100)	(0.090)	(0.086)	(0.197)	(0.075)	(0.076)
Option	0.631	-0.171	-0.095	0.363	0.690	0.693
	(0.515)	(0.976)	(0.883)	(0.739)	(0.640)	(0.641)
GDP (Log)	-0.237**	-0.533***	-0.438***	-0.124***	-0.146**	-0.141**
	(0.070)	(0.101)	(0.042)	(0.029)	(0.047)	(0.047)
Debt to GDP	-0.003	-0.001	-0.001	-0.005	-0.008**	-0.008**
	(0.003)	(0.005)	(0.005)	(0.003)	(0.003)	(0.003)
Observations	126	116	116	127	127	127
R-squared	0.798	0.760	0.762	0.769	0.768	0.766
Error Clustering (Country & Year)	Yes	Yes	Yes	Yes	Yes	Yes

***Notes.*Natural Assets and Sovereign Green Bond Yield**. This table shows the regression results of the association between bond yield and biodiversity and natural capital risk. Columns (1) – (3) show the regression results for biodiversity loss measures. Columns (4) – (6) show the results for natural capital risk measures. Columns (7) – (9) show the results with bond-level controls as well as with country-level error clustering. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. Transition risk is adaptive capacity measure from ND-GAIN Country Index. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Country level controls include logarithm of gross domestic product (GDP), debt to GDP ratio, and trade to GDP ratio. Error clustering are at country and year level. Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

Table B3: **Natural Assets, Geopolitical Risk, and Sovereign Green Bond Yield**

VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield	(6) Yield
Geopolitical Risk Index	-0.442	-0.888	-0.953	-0.308	-1.349*	-1.371*
	(0.897)	(0.750)	(0.832)	(0.531)	(0.634)	(0.626)
Agriculture and Fishery Per GDP	0.146*					
	(0.076)					
Total Fish Production		0.272**				
		(0.085)				
Wild Catch Fish			0.193			
			(0.119)			
Natural Resources Depletion (in %)				0.607*		
				(0.317)		
Natural Forest Depletion (in %)					0.263***	
					(0.036)	
Fresh Water Withdrawl (in %)						0.045***
						(0.006)
Observations	110	104	104	114	114	114
R-squared	0.591	0.589	0.581	0.636	0.637	0.636
Country Level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Bond Level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Error Clustering (Country & Year)	Yes	Yes	Yes	Yes	Yes	Yes

Notes. **Natural Assets, Geopolitical Risk, and Sovereign Green Bond Yield**. This table shows the regression results of the association between bond yield and biodiversity and natural capital risk adjusting for geopolitical risk. Columns (1) – (3) show the regression results for biodiversity loss measures. Columns (4) – (6) show the results for natural capital risk measures. Columns (7) – (9) show the results with bond-level controls as well as with country-level error clustering. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. Geopolitical risk is geopolitical risk index from Caldara and Iacaviello (2022). Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Country level controls include logarithm of gross domestic product (GDP), debt to GDP ratio, and trade to GDP ratio. Error clustering are at country and year level. Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

Table B4: **Natural Assets, Climate Transition Risk, and Sovereign Green Bond Yield**

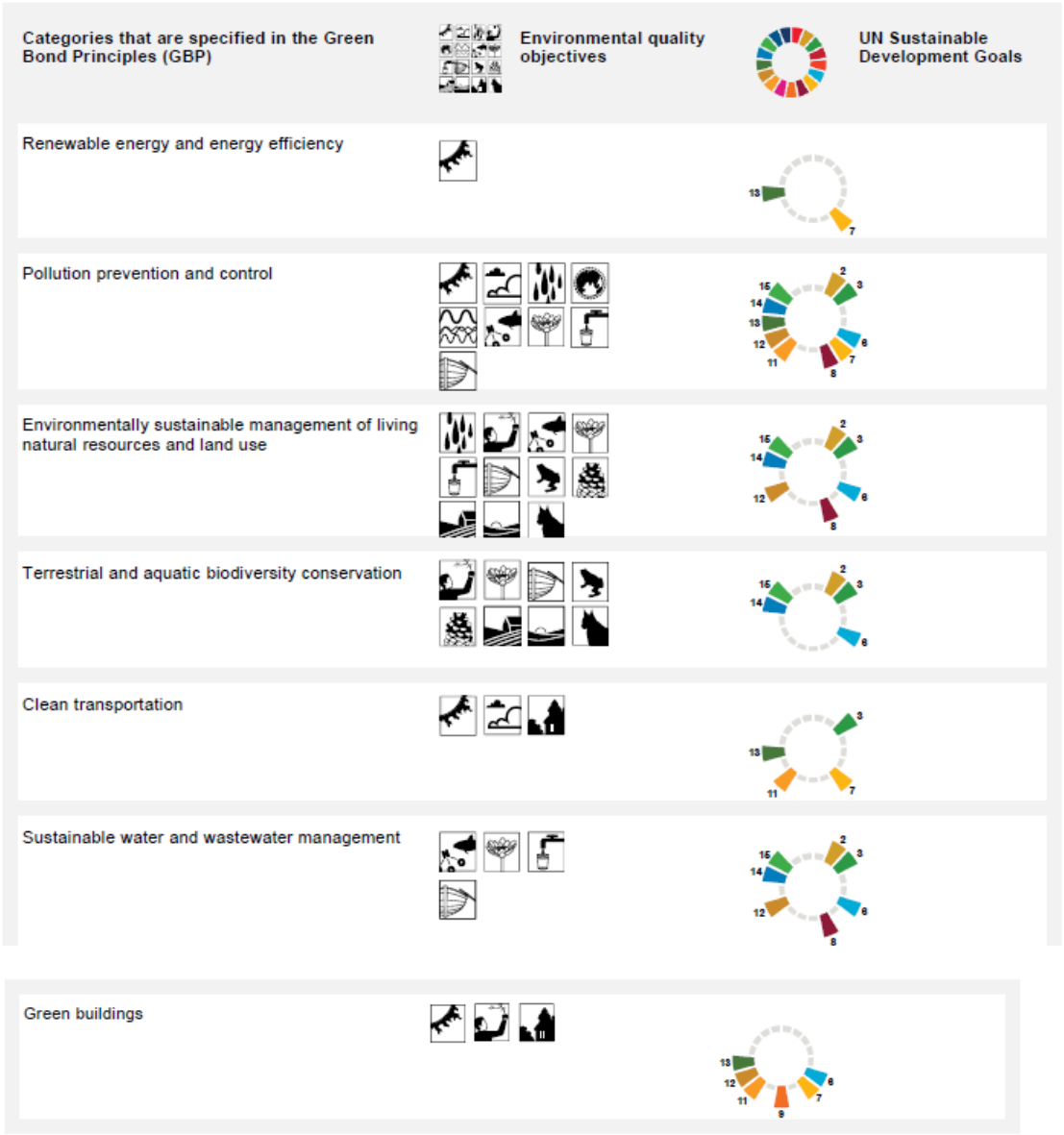
VARIABLES	(1) Yield	(2) Yield	(3) Yield	(4) Yield	(5) Yield	(6) Yield
Climate Transition Risk	1.924	6.762*	6.566*	7.479*	7.634*	7.802*
	(3.797)	(2.976)	(3.047)	(3.429)	(3.422)	(3.400)
Agriculture and Fishery Per GDP	0.201*					
	(0.096)					
Total Fish Production		0.075				
		(0.104)				
Wild Catch Fish			0.091			
			(0.078)			
Natural Resources Depletion (in %)				0.278		
				(0.181)		
Natural Forest Depletion (in %)					0.230***	
					(0.031)	
Fresh Water Withdrawl (in %)						0.040***
						(0.006)
Observations	126	116	116	127	127	127
R-squared	0.800	0.783	0.784	0.804	0.805	0.805
Bond Level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Error Clustering	Yes	Yes	Yes	Yes	Yes	Yes

Notes. **Natural Assets, Transition Risk, and Sovereign Green Bond Yield**. This table shows the regression results of the association between bond yield and biodiversity and natural capital risk adjusting for transition risk. Columns (1) – (3) show the regression results for biodiversity loss measures. Columns (4) – (6) show the results for natural capital risk measures. Columns (7) – (9) show the results with bond-level controls as well as with country-level error clustering. Biodiversity Risk is measured as (a) Agriculture and Fisheries per GDP, (b) Total Fish Production, and (c) Wild Catch Fish Production. Natural Capital Risk is measured as natural resources depletion as percentage of gross national income, net forest depletion as percentage of gross national income, and annual fresh water withdrawals as percentage of internal resources. Transition risk is adaptive capacity measure from ND-GAIN Country Index. Bond level controls comprise - logarithm of amount issued, indicator variable for whether bond is fixed income or floating (Fixed), indicator variable for whether the bond is callable or not (Option), and years in maturity of the bond (Maturity). Country level controls include logarithm of gross domestic product (GDP), debt to GDP ratio, and trade to GDP ratio. Error clustering are at country and year level. Details of the variables are provided in Appendix A. *, **, *** show the statistical significance at 10 %, 5 %, and 1% levels.

Appendix C

Swedish Green Bond Disclosure Documents

Figure 3. Eligible categories: the Swedish environmental quality objectives with mapping to the categories in the GBP and related SDGs [24]



Notes. **ESG Framework of Swedish Green Bond.** This figure shows the green project categories mentioned in the ESG Framework issued by the Swedish government.

Sweden

Green Bond Second Opinion

4 June 2020

Sweden, a north European country of some 10 million people, has long been at the forefront of sound environmental policies. Sweden aims at being greenhouse gas neutral by 2045 and having net negative emissions thereafter. The green bond framework is broad, covering several green bond principle categories and targets both climate and nature and marine preservation.

The majority of funds in the first round of allocations are planned for clean transportation, with a focus on maintenance and operation of electrifed railways. Most direct fossil fuel projects are excluded, including diesel trains. Since 20 percent of the Swedish railway tracks are not electrified there could however be investments that indirectly support diesel driven railways. Also support to plug-in hybrids and gas powered vehicles that could run on natural gasand fossil fueled machinery and vehicles in the management of living resources and land use are eligible under the framework. The framework supports technological breakthroughs in fossil fuel sectors such as fossil-free steel production (through use of hydrogen), CCS in refineries and cement industry. The framework does not exclude expenditures used to finance emissions reductions projects in other countries as long as these projects fulfil the criteria specified in the framework. Projects in existing large hydro power are eligible while new large hydro- and geothermal-power as well as nuclear power are excluded from the framework.

Sweden has a comprehensive and transparent regime for selecting and reporting on environmental targets with good use being made of independent oversight and advice. Administrative costs (max 10 percent) associated with funded programs as well as support to NGOs and membership fees in international organisations, are eligible. Tax reduction schemes are excluded. The reporting scheme is good and comprehensive, although it does not follow the Green Bond Principle project categories. We encourage the issuer to highlight in the annual report fossil fuel aspects of eligible expenditures, such as maintenance of railway tracks that are not yet electrified. We find the governance procedures to be **Excellent**.

SHADES OF GREEN

Based on our review, we rate Sweden's green bond framework **CICERO Dark Green.**

Included in the overall shading is an assessment of the governance structure of the green bond framework. CICERO Shades of Green finds the governance procedures in Sweden's framework to be **Excellent**.



GREEN BOND PRINCIPLES

Based on this review, this Framework is found to be in alignment with the principles.

Notes. **Second Opinion Report of Swedish Green Bond.** This figure shows the snapshot from the second opinion report issued by the CICERO (green auditor) for Swedish government's green bond.

Allocation of proceeds

The table below presents how the proceeds from the issue have been allocated and how the appropriation items are sorted in relation to the Green Bond Principles and the environmental quality objectives. Eligible green expenditure shows the definitive outcome. The figures for 2020 in the green framework are forecast figures, and thus differ from the outcome.

		2019			2020				
Green Bond Principles categories	Eligible green expenditures	Outcome eligible green expenditures (million SEK)	Expenditures allocated from the green bond (million SEK)	Allocation, %	Outcome eligible green expenditures (million SEK)	Expenditures allocated from the green bond (million SEK)	Allocation, %	Environmental quality objective	SDG
Renewable energy and energy efficiency	Energy technologies	730	730	100 %	814	189	23 %		
Pollution prevention and control	Climate bonus	1,280	1,280	100 %	2,078	482	23 %		
	Climate investments	569	569	100 %	1,009	234	23 %		
	Green Industry Leap	41	41	100 %	165	38	23 %		
Environmentally sustainable management of living natural resources and land use	Measures to improve the environment in agriculture	180	180	100 %	169	39	23 %		
Terrestrial and aquatic biodiversity conservation	Protection of valuable natural environments	977	977	100 %	878	204	23 %		
	Measures for valuable natural environments	862	862	100 %	1,146	266	23 %		
Clean transportation	Maintenance of state transport infrastructure, Railways	9,779	9,779	100 %	11,557	2 683	23 %		
Sustainable water and wastewater management	Measures for marine and aquatic environments	1,151	1,151	100 %	1,277	296	23 %		
		15,567	15,567		19,093	4,433			

Sustainable water and wastewater management

A project concluded in 2020 reports that 3,400 kilos of phosphorous have been reduced or fixed by means of aluminium deposits and phosphorous fixation.[78] Phosphorous fixation measures aim to bring the aquatic environment to a more natural state in terms of eutrophying substances, with a greater depth of visibility, lower algal bloom and contribution to a lower nutrient load on downstream watercourses.[79]

Out of the 24 projects that were launched in 2020 focusing on increased nutrient recirculation, grants have been awarded for mussel cultivation, blue cover crops or other recirculation methods. The total expected environmental impacts of these projects have either been presented in number of harvested cubic metres (a total of 1,227 cubic metres) or in total weight expressed in tonnes (a total of 1,090 tonnes).

Subsidies for fishery management

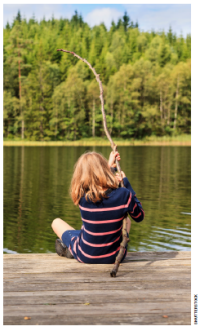
Grants have been awarded for measures that promote fishery management, primarily in waters with public fishing rights.[80] The measures are crucial for both fishery management and for preserving biodiversity, sustaining natural ecosystem services and for functioning green infrastructure. Grants to 50 per cent of the approved cost of the measure are commonly awarded, although higher grants can be awarded if special grounds exist. Special grounds could be that the measure is of significant public interest, such as preserving an endangered species, or measures that promote fishery management in areas with free fishing using handheld equipment.

The fishery management grant in 2019 amounted to SEK 20 million, and SEK 29 million in 2020.[81] The grant has enabled cooperation over county borders, such as pikeperch surveys in lakes Hjälmaren and Mälaren. Completed fishery management projects have resulted in, for example, the reintroduction of salmon in the river Dalälven, the reintroduction of the freshwater pearl mussel in the river Lärjeån, culling of whitefish to preserve char in lake Grundsjön and ecosystem-based fishery management in lake Hjälmaren.

Liming of lakes and watercourses

The grant helps to fulfil the environmental quality objectives *Sustainable lakes and watercourses* and *A rich diversity of plant and animal life*.[82] In 2019, the total cost of liming activities was just over SEK 158,000 thousand, and in 2020 funds of just over SEK 173,096 thousand were used to this end.[83] In total, 97,256 tonnes of lime were spread in 2019 and 100,536 tonnes in 2020.[84]

The counties' liming actions are aimed at maintaining values-in-use and preserving endangered species and biodiversity. According to the county administrative boards, the activities take high priority and are an important measure in sustaining populations of fish, crayfish and freshwater pearl mussels that are worthy of protection. Liming is also of great importance to recreational fishing. According to the county administrative boards, an average of 70–80 per cent of limed objects help to sustain recreational and sport fishing. Liming, fishery management and measures to improve the physical environment could boost tourism thanks to better fishing opportunities and good aquatic environments in general, which could have the indirect effect of curbing depopulation in rural areas.[85]



Notes. **Capital Allocation of Swedish Green Bond.** These figures show the snapshots from the capital allocation report issued by the Swedish government in relation to their green bond.

Output and impact reporting

The compilation of outputs and impacts is based on the reporting available from other government agencies and is not necessarily exhaustive. Reporting can thus differ between each appropriation. The appropriation headings are sorted according to the Green Bond Principles.

Outputs and impacts in brief

Subsidies to promote the use of solar cell technology were disbursed to over 27,000 individuals, municipalities and businesses in 2019 and 2020.

The energy storage subsidy for self-generation of renewable electricity was disbursed to 1,041 private individuals.

The climate bonus (Bonus Malus) has helped to increase the proportion of plug-in electric vehicles and natural gas vehicles as a percentage of newly registered cars, from 6.5 per cent in the first half of 2018 to over 25 per cent in the first half of 2020.

The financed measures of the Climate Leap are expected to lead to an average reduction in emissions of 1.5 kg and 1.7 kg of carbon dioxide per invested krona for 2019 and 2020, respectively and reduce climate-impacting emissions by 133,571 and 405,030 tonnes of carbon dioxide equivalents per year for 2019 and 2020, respectively.

It is estimated that the **research grant of the Green Industry Leap** could contribute to negative emissions in the amount of 2 million tonnes of carbon dioxide equivalents annually, and its contribution to pilot and demonstration plants for fossil-free steel has the potential to reduce Sweden's total carbon emissions by 10 per cent annually.

Subsidies for methane gas reduction have helped to bring about a total reduction in emissions of over 53,000 tonnes of carbon dioxide equivalents.

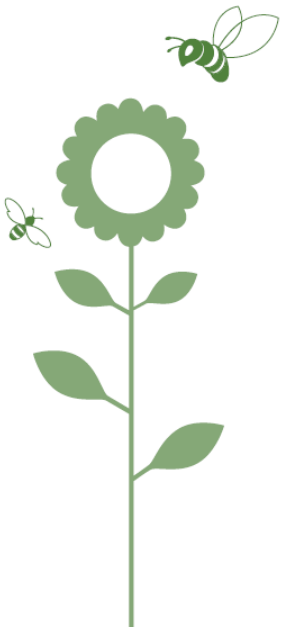
Subsidies for biogas production have helped to bring about a total reduction in emissions of 296,000 tonnes of carbon dioxide equivalents.

Protection of valuable natural environments has, in 2019 and 2020, contributed to the formation of 312 new nature reserves, covering 204,000 hectares, and the protection of 450 hectares through voluntary nature conservation agreements between the state and landowners.

Measures for valuable natural environments have helped to restore 10,600 hectares of wetlands and recover the pollinating anthophora plagiata bee species from its critical endangerment status.

Railway maintenance has been used for improving the standard and accessibility of railway transport by replacing 190 kilometres of track in 2019 and 2020, 130 kilometres of overhead contact wires and 19 bridges.

Measures for marine and aquatic environments have mainly been used for projects to reduce eutrophication. In 2019 and 2020, 595 projects were launched.



Notes. **Impact Report of Swedish Green Bond.** This figure shows the snapshot from the impact report issued by the Swedish government in relation to their green bond.

Appendix D

Structured Data on Green Projects using LLM and Agentic AI:
Capital Allocation and Impact Outcomes

Bond ISIN	Date	Countries	Output Indicators	Impact Indicators	Values of Impact Indicators
BE0000346552	20220916	Belgium	The output indicators for the eligible categories of the projects are: - Subsidies to SNCB: - Infrastructure Fee: number of passengers using railway infrastructure - Rolling Stock: number of new M7 trains purchased - Subsidies to Infrabel (Investment Programme): - Railway Infrastructure: maintenance costs of railway infrastructure - Maintenance: energy consumption of railway maintenance ateliers - Capacity Expansion: number of passengers using new railway infrastructure - ETCS Investments: modal shift related to railway infrastructure capacity expansion due to ECTS	1. Reduced CO2 emissions 2. Increased energy efficiency 3. Reduced water consumption 4. Reduced waste production 5. Increased recycling rates 6. Improved biodiversity 7. Improved air quality 8. Reduced noise pollution 9. Improved public health	- 28kt for avoided CO2 emissions for projects in operation; - 12kt for estimated annual avoided CO2 emissions for projects under development; - 144M EUR for the impact of the new capacity that will be available due to the new M7; - 302M EUR for the impact of the energy consumption reduction of the new rolling stock (other than M7); - 94M EUR for the impact of the energy consumption of railway stations; - 88M EUR for the impact of the energy savings of the maintenance ateliers of SNCB/NMBS based on energy consumption figures; - 413M EUR for the impact of the modal shift related to railway infrastructure capacity expansion due to ECTS.
CH0440081567	20230430	Switzerland	Share of electrified railway network Passenger transport on railways (billion passenger-km) Freight transport on railways (billion ton-km)	- Reduction of CO2 emissions - Number of beneficiaries	Reduction of CO2 emissions: 2.8 million tons Number of beneficiaries: 51,340
COL17CT03797	20230323	Colombia	The output indicators for the eligible categories of the projects are as follows: - Waste and circular economy: - Number of waste treatment plants installed. - Number of products with recycled content. - Number of new compost facilities. - Sustainable agricultural production, with low emissions and adapted to climate change: - Area of land under sustainable agriculture practices. - Reduction in the use of chemical fertilizers and pesticides. - Increase in the use of organic fertilizers. - Ecosystem services and biodiversity: - Area of protected areas. - Number of species protected. - Number of protected areas managed sustainably. - Non-conventional energy sources, energy efficiency, and connectivity: - Capacity of renewable energy installed. - Number of energy efficiency projects implemented. - Increase in the use of public transportation. - Sustainable water management, use and sanitation: - Reduction in water pollution. - Increase in the use of treated water. - Increase in the number of people with access to sanitation services. - Clean and sustainable transport: - Reduction in the use of private vehicles. - Increase in the use of public transportation.	- Waste and circular economy: - Waste reduction - Recycling rate - Composting rate - Sustainable agricultural production, with low emissions and adapted to climate change: - Reduction in GHG emissions - Increase in agricultural productivity - Increase in soil carbon sequestration - Ecosystem services and biodiversity: - Increase in biodiversity - Improvement in ecosystem services - Reduction in deforestation - Non-conventional energy sources, energy efficiency, and connectivity: - Increase in the use of renewable energy sources - Reduction in energy consumption - Increase in energy efficiency - Sustainable water management, use and sanitation: - Reduction in water pollution - Increase in water availability	4.384.724 covered hectares with surveillance 15,233 hectares of ecosystems conserved or undergoing restoration 29 sanitized hectares of illicit crops

Notes. **Green Projects Database.** This figure shows the snapshot from the structured data on green projects, sponsored by sovereign green bonds, gathered using retrievable-augmentative generative (RAG) based large-language model (LLM) and agentic artificial intelligence (AI).