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Abstract

Financial development supports productive investment, but financialization may undermine it. We extend this insight to the energy transition, where sustainable finance is hoped to reduce emissions, but must do so in a financialized credit system and corporate environment. We analyze the green bond market in a global sample of 147 corporates across 10 industries over 2010-2020. In a matched-firm analysis we examine the effect of green bond issuance on a firm's environmental performance post-issuance in terms of greenhouse gas emissions and energy intensity. Different from earlier findings, green-bond issuers in this sample do not significantly improve their environmental performance post-issuance, neither in the full sample nor within industries. There are large differences between industries which suggest entry points to improve the effectiveness of green bonds.

Keywords: Green Bonds, Green Finance, Carbon Emissions, Impact Investing, Sustainability-linked Debt, Climate Finance[‡]

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[‡]Abbreviations: **CBI** Climate Bonds Initiative, **CBS** Climate Bonds Standard (by CBI), **COP** Conference of the Parties, **CO2-eq** Carbon Dioxide Equivalent, **CSR** Corporate Social Responsibility, **DCM** Debt Capital Market, **EBITDA** Earnings Before Interest, Taxes, Depreciation and Amortization, **EC** European Commission, **EU** European Union, **EU GBS** European Union Green Bond Standard, **ESG** Environmental, Social and Governance, **GBP** Green Bond Principles (by ICMA), **ICMA** International Capital Markets Association, **IEA** International Energy Agency, **IPCC** Intergovernmental Panel on Climate Change, **LCA** Life Cycle Assessment, **MDB** Multilateral Development Bank, **NRBV** Natural Resource-based View, **SEC** U.S. Securities and Exchange Commission, **TEG** European Union Technical Expert Group on Sustainable Finance, **UN** United Nations, **UNFCC** United Nations Convention on Climate Change

1. Introduction

"Up until today, there was not enough money in the world to fund the transition; this is a watershed. ... The core message today is that the money is there, the money is there for the transition ...". Thus Mark Carney, UN Special Envoy for Climate Action and Finance to COP26 delegates in Glasgow, November, 2021. Green finance is widely viewed as a necessary condition and a major bottleneck for an ecological and social transition to sustainability. There was rapid growth of green finance, especially so after the Paris Agreement on Climate Change. In particular, the volume of green bonds (Heine et al. 2019; Park 2018 (climate sustainable debt instruments) accounted for about one percent of all corporate bonds in 2022 (Amundi and IFC 2021; Almeida 2020).
As yet there is a paucity of conceptual reflection on the role of sustainable fiance in general and green bonds in particular in bringing about desired changes. Surprisingly little research addresses the effectiveness of green bonds in addressing climate change (Kotchen and Costello 2018; Galarraga et al. 2017; Schmittmann and Teng 2021; though see Flammer 2019; Fatica and Panzica 2020).

The present paper aims to help fill this gap. We build on the literature on financial development. Green bonds could conceivably support greener production though capital allocation and through engagement. We also discuss systemic reasons for green bonds to be ineffective that go beyond well-know green-washing concerns, building on 'financialization' theory.

These conceptual distinctions frame an empirical analysis of green bond effectiveness that expand the small literature so far. We are the first to consider differences across issuing sectors, and we use detailed emissions and energy use data. In a global sample of 2,237 year-firm observations across 10 major industries over the period 2010-2020, we examine the relationship between a firm's green bond issuance on one hand and its self-reported emissions and energy intensity on the other hand. This firm-level analysis adresses problems related to the small scale of the green bond market.

We find that three measures of greener production — CO_2-eq emissions, energy intensity and energy consumption intensity — are not significantly lower post-issuance of green bonds than they were pre-issuance. Second, we ask if there is any change in the difference in carbon emission intensities between two matched firms, one of whom has issued a green bond. There is a marginal difference that is however not statistically significant. Third, we ask if this firm-level effect differs between industries. We find stronger effects, unsurprisingly, in the manufacturing industries than elsewhere, but with both positive and negative effects across manufacturing sectors. In terms of the literature, these result provides support for financialization concerns. On the upside, they are a tentative indication that if green bonds have effects on the firm level (rather than the project level, which we do not consider), it is through engagement rather than through capital allocation.

The remainder of this paper is structured as follows. In the next section we discuss definitions of green bonds and we survey the complex institutional context of green bond markets. In section 3 we connect to the extant literature on finance and development, highly relevant to assessing green bonds effectiveness and yet under-cited in sustainable finance assessments generally. The next sections present the empirical framework, data and analysis. We conclude with a discussion of this paper's limitations, main findings and implications, and suggestions for future research.

2. Finance and financialization: Literature embedding and institutional description

2.1. Financial development or financialization?

The growth of green finance is a special case of the growth of finance, or financial development. A long tradition in the economics literature theorizes the impacts of financial development, a strand on which the analysis of the impacts of green finance can build.

The role of finance in economic transformation was first explicitly theorized by Schumpeter (1934) followed by Goldsmith (1969) and McKinnon (1973). Although this is commonly referred to as the literature on 'finance and growth" (i.e. GDP growth), what was at stake for Schumpeter was not quantitative growth but qualitative development. Credit and other financial resources are tools to move factors of production to novel uses in the economic system. In this way credit and finance support innovations and the realization of new ideas, by placing purchasing power in the hands of those with new ideas, giving them the power to obtain resources needed to implement the new ideas (Bertocco 2009; Bezemer 2014). In later literature, this qualitative change due to ongoing innovations has been translated into quantitative change captured in GDP growth, using the assumption that innovations will increase productivity and hence GDP growth.

This sparked an empirical literature that started with Levine and King (1993). They reported that on average for dozens of countries over 1960-1989, economies with more financial development in subsequent years realized more investment, more productivity growth and higher income growth. Many cross-country studies have reproduced these results, also using sector-level data. For instance, the seminal paper by Rajan and Zingales (1998) shows that in countries with more financial development, firms that are more dependent on financial development on average increased their output growth and productivity levels faster. For reviews of the traditional 'finance and growth' literature we refer to Ang (2008) and Valickova et al. (2014).

Apparently, finance is an enabler of economic transformation, a constraint that once relaxed allows for faster growth and innovation. Similarly, green finance could spur sustainable transformation of industries if green finance is a constraint that the growth of the green bonds markets and other form of finance can relax. But this is a big if, and the empirical literature is mixed.

The finance-and-growth literature has emphasized two channels of impact for finance on economic development. The first is a liquidity effect emphasized already by Schumpeter. Bank loans, bonds and other finance are claims on financial liquidity (money and other purchasing power) which can move resources and so support economic growth and transformation. The implication for empirical research is that the actual observed flow of finance should be correlated to the development and transformation that the finance is supposed to support. This transformation is productivity growth in the traditional finance and growth literature; it is greener production in the green finance literature. This motivates our test of green bond issuance against greener production.

A different view on positive finance-growth effects in the literature emphasizes its role of resolving information frictions through engagement of financial intermediaries with borrowers (Levine, 2005). Savers have not enough information about borrowers' projects, so that they cannot make informed lending decisions. If many savers entrust this decision-making to financial intermediaries, then these can achieve the scale that allows for investing in information gathering and project selection on behalf of savers (solving adverse selection problems), as well as continued engagement with the borrowers to ensure project implementation in the interest of the lenders (solving moral hazard problems). In this way, credit relations help achieving intended outcomes — again, this would be greater productivity in the traditional literature, and greener production in the present context. Engagement runs over the duration of the loan and occurs in the context of debt relations rather than with fresh lending. The empirical implication is that past lending and current debt relations, rather than current credit flows, should correlate to desired outcomes. Both these specifications have been used in the literature (Bofinger et al., 2024)

Finally a third strand in this literature is 'financialization' rather than financial development. Whereas 'financial development' has positive connotations, 'financialization' is the term used to indicate problematic sides of the expansion of finance (Arrighi 1994; Krippner 2005; van der Zwan 2014). Taking seriously the balance sheet logic that governs financial actors such as banks and (green bond) investors invalidates the neoclassical economics logic that providers of external finance are supposed to follow (Bezemer 2014; Campiglio 2016). Financial motives such as yields and capital gains may trump real-sector aims such as investment and innovation. More borrowing and lending, with rising financial wealth and more volatile asset prices, could depress rather than support productivity growth, and bias financial returns leading to growing inequalities in wealth and income (Epstein, 2006).

Moroever, the presence of fundamental uncertainty (as opposed to calculable risks) in the economy and especially around systemic transitions, means that the information-focused view of how finance works is incorrect (Chenet et al., 2021). The information-focused view requires that we assume away fundamental uncertainty so that models with representative agents engaging in intertemporal optimization under equilibrium conditions can be used, leading to linear impacts - model features which are inappropriate to the actual workings of economic and ecological systems (Monasterolo et al., 2019).

Also these literatures is relevant to green finance studies and research into lending with purpose. The opaqueness of increasingly complex financing chains and the dominance of 'asset manager capitalism' (Braun, 2022) may preclude purposeful saving and investment behavior. In its place come increased shareholder orientation and short-termism (Lazonick, 2013) rising wealth inequality (Piketty, 2015) and falling real investment (Tori and Onaran, 2018; Krippner, 2005). These possibly negative effects of fiancialization extend to ecological impacts. For instance, Wilson and Caldecott (2023) find that the growth of passive U.S. corporate bond exchange-traded funds from 2016 to 2021 appears to have supported carbon-intensive capital flows.

The empirical implication of this view is that both past lending and current debt relations (engagement) may correlate *negatively* to desired outcomes, such as investment, productivity growth and GDP growth in the traditional literature. Indeed this has been widely reported in quantitative studies of data since the 1990s in the 'finance and growth' tradition. These show that there may be 'Too Much Finance', as in the eponymic cross-country study by Arcand et al. (2015) . Likewise firm-level studies and studies of the financial system have identified short-termism expressed in rising dividend and stock buyback policies, falling capital expenditure, and declining labour productivity (Davis, 2016). The implication for the study of green finance is that if this is the financial system in which green bonds proceeds are channeled, then any impact on greener production may be compromised by financialization tendencies.

In sum, the finance-and-growth literature provides reasons and mechanisms to identify both positive, absent and negative effects of more finance on economic development in general. In particular, for this paper, it suggests ambiguous effects of green finance such as green bonds on greener production.

2.2. The green bond market: an institutional description

Research into the impact of green bonds and their impacts must confront formidable definitional challenges. Green bonds are defined by standards such as the International Capital Market Association's (ICMA) Green Bond Principles (GBP), the Climate Bonds Initiative's (CBI) Climate Bonds Standard (CBS) and the 2023 European Union Green Bonds Standard (EU GBS) (ICMA, 2021; CBI, 2019; EC, 2021). The GBP and CBS require the use of the bond's proceeds to support climate mitigation and adaptation above some threshold reference level. Defining a reference level for bonds to be green has turned out to be contentious. To avoid this, in this paper we will use scaled CO_2-eq emissions.

Further requirements under GBP and CBS standards include project evaluation, reporting on proceeds management and independent external reviews by authorized audit and accounting firms. The EU GBS aligns with the EU taxonomy for sustainable activities. It obliges issuers to allocate 100% of the proceeds raised by the bonds to economic activities that meet the EU Taxonomy requirements by the time the bonds mature. It is comparable in approach to the current CBI and GBS standards but aims to provide a 'gold' standard.

Geddes et al. (2022) and ICMA (2022) note the danger of fragmentation of the international green bond markets and regulatory arbitrage upon EU GBS introduction. But proponents note that green capital markets are already internationally fragmented (e.g., China's deviation as discussed by Cao et al. (2021); Berrou et al. (2019)) and the EU could set a new and effective standard. In support, Gibon et al. (2020) found that integrating life cycle assessment (LCA) into green bond standards, which is part of the proposed EU legislation, could reduce the CO_2-eq per million dollars invested by a factor of 12.

Beyond definitional challenges, there are also possible inconsistencies in the implementation. This is due both to different methods implemented by analytical financial platforms and to complications in the practice of quantifying and reporting a green bond's environmental outcomes. The nine main rating agencies of standards in green finance are *Bloomberg New Energy Finance (BNEF), Reuters ASSET4, MSCI ESG, VigeoEiris, Refinitiv (Thomson Reuters), Sustainalytics, ISS-Oekom, RobecoSAM, ECPI and Bloomberg FTSE Russel* (Billio et al., 2020). Each uses its own standards for green bond certification and its own indicators, weighting factors and criteria. For example, *Refinitiv Eikon* cooperates with the CBI and their CBS, whereas BNEF assesses bonds independently according to the ICMA's GBP standard.

Measuring a green bond's impact is likewise challenging. In some cases (e.g., renewable energy), hard data on direct CO_2-eq emissions reduction can be calculated. For e.g. research and development of sustainable technologies, this is much harder. In this paper the CBI standard CBS will be used, since it is the strictest standard and it focuses on CO_2-eq emissions. All bonds with the green label in the Refinitiv Eikon data base are evaluated according to the CBS by one of the several qualified verifiers such as EY, KPMG, Sustainalytics and Deloitte. Because of the voluntary nature of the standard, the CBS standard is far from perfect. Even so, it is the best choice available at the moment of writing and also most comparable to the new EU legislation, which is expected to become the most widely used framework.

The most common method of evaluating a firm's 'green' performance is by its environmental (E), social (S) and governance (G) score(s). ESG criteria concerning the environment, E(SG), are generally divided into four pillars. For a good score, companies should i) report on carbon emissions or sustainability, ii) limit harmful pollutants and chemicals, iii) seek to lower greenhouse gas emissions and iv) use renewable energy sources (Boffo et al., 2020). In this analysis we prefer to observe emissions rather than E(SG) scores, which has several disadvantages. A firm's environmental ratings vary strongly depending on the rating agency (Chatterji et al., 2016). Low scores may well result fomr a firm neglecting to promptly or fully disclose information, rather than from emissions. The Carbon Disclosure Project (CDP) assigned *Amazon* an "F" in 2021[1], failing to respond to its request for information. Also, several scandals (such as that of *DWS*) involved ESG-labeled investments where in fact ESG factors were not considered (Reuters 2022) . Moreover ESG scores are more vulnerably to gaming, where firms target some E(SG) score elements without real change, consistent with Goodhart's Law.

Instead we observe carbon dioxide equivalent (CO_2 -eq) emissions per million dollars of revenue, as in Flammer (2019, 2021), Fatica and Panzica (2020) and Alam et al. (2019). CO_2-eq emissions is the amount of CO_2 which would have a global-warming impact equivalent to actual emissions. Greenhouse gases included in this calculation (following EPA 2023) are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCS), perfluorinated compound (PFCS), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3), taking into account differences between scope 1, 2 and 3 emissions.

The data from Refinitiv Eikon (Thomson Reuters) used in this study differentiates between scope 1, 2 and 3 CO_2-eq emissions. Scope 1 emissions are direct emissions from sources that are owned or controlled by the firm. Indirect emissions from the consumption of purchased electricity, heat or steam, which occur outside the firm at the facility where electricity, steam or heat is generated, are considered scope 2 emissions. Scope 3 emissions are indirect emissions in a firm's value chain.

As in Alam et al. (2019) , we combine emission intensity with a second measure, energy consumption intensity, which is arguably less endogenous to the decision to issue green bonds than are carbon emissions.

2.3. Issuance and impact measurement

Green bonds can be issued by institutional investors or by a corporate such as an energy provider, issuing a green bond for a project. Green bonds are primarily used to finance mitigation projects in the energy, building and transportation sectors, which constitute 85% of the use of proceeds (2020 data) (CBI, 2019, 2021). Green bonds can also go into asset-backed securities (ABS) collateralized by one or several green projects. The bond is then collateralized by a pool of green loans. For green loans, different similar standards exist, where the structure is identical to that of green bonds that were issued to finance green projects. ABS are often used to fund projects and assets such as wind farms and solar panels (nanji).

Green bond issuance proceeds in four phases. Potential issuers, working with banks underwriting the bonds, define how the proceeds will be used and the impact the bond is expected to have. Second, issuers present their green bond framework to third-party certification providers and obtain certification. Third, the borrower meets with potential investors and if they are satisfied, the bond is launched in the primary bond market. A final phase is that green bond issuers, unlike regular bond issuers, are expected to report to investors annually.

Examples for the 2007-2020 period include the following (oecd). One example is a solar plant refinancing its field through bond issuance with a pension fund (direct unlisted investments in projects). An other is a Development Bank raising 500 million dollars to fund projects that promote low-carbon and climate-resilient development (intermediated unlisted and listed investments in projects). Yet another example is a listed green project

[1] CDP. "Company Scores 2021" https://www.cdp.net/en/companies/companies-scores

bond financing a single project or a portfolio of similar or standardized projects (direct in-house listed project investments). And finally a wind farm project developer may issue a bond to expand offshore and onshore wind activities (direct in-house corporate pure-play listed debt).

A major challenge is to measure the additionality of green bonds. Some projects or assets might have been financed anyway, without green debt. The net effect of the green bonds could then be to free up funds for non-green projects. It is therefore not enough to ascertain that green finance initiatives lead to more green bonds issuing. It also needs to be ascertained that there is an impact in terms of emissions. We address this concern in our methodology described below. This challenge is also present in the finance-and-growth literature discussed above. Policy measures that successfully increase borrowing may not be successful in terms of the desired impacts. For instance, subsidized agricultural credit programs in India in the 1990s were successful in expanding borrowing by farmers but they were not successful in increasing rural investment and farm productivity (Cole, 2009). The analysis of green finance addresses old problems in new forms.

What is clear is the positive impact of the public stimulus of climate finance on private sector leverage of the private sector (Zerbib, 2019; Kotchen and Costello, 2018; Flammer, 2019), for several reasons. First, like all long-dated debt, green bonds may replace short-term bank loans, providing a better corporate financing structure if there are long-dated liability cash flows, especially in the face of refinancing risks for long-term green projects (OECD, 2021). Also, green bonds allow for a smoother integration of low-emission projects into existing asset allocation models. Third, as institutional investors are increasingly under pressure to disclose their climate-related investment strategies, issuing green bonds allow funds and firms to showcase their effort, something that financing green projects with retained profit does not. In this sense the rise of green bonds is more due to the increasing climate-awareness of pension fund savers and investors than to be explained by corporate investment goals, as Banga (2019) notes. Alternatively, climate-awareness within the issuing firm itself will also result in simultaneous reductions in emissions and capital expenditures (and borrowing) for e.g. emission and pollution control (stuart). These possibilities complicate causal attribution of emissions impacts to green bonds. In a qualitative case study on Sweden (maltais) studied the balance of these motives. They observe that issuer's incentives are dominated by business-case incentives rather than financial incentives, along with a small portion of legitimacy seeking.

Other causality measurement challenges are related to the type of project and the simultaneous behaviour of the issuer. Much of the green debt isued by financial institutions — almost half for both *HSBC* and *JPMorgan* in 2021 is for the construction of green buildings (JP Morgan 2021; HSBC 2021). This reduces the observed short term emission reduction as construction is energy-intensive, and it misses the increase the carbon efficiency n the future. In general, if financial institutions issue green debt and also increase their positions in bonds that are financing emission-intensive assets, the green-bond induced change in emissions will go unnoticed.

Alternatively, Schmittmann and Teng (2021) claim indirect channels are likely to be more important for the environmental impact of green debt. According to this study, engagement with green debt helps mainstream green and climate considerations in the financial and corporate sectors. Firms would learn through the issuing process, which requires meeting green debt requirements and building internal capacity. More broadly, guidelines and standards help advance thinking on what constitutes a green asset or project and how firms can become more climate-friendly. These effects would take more time and influence all three scopes of a firm's emissions. This is hard to analyze empirically; in the present paper, these effects are not considered.

In the face of these challenges, it is unsurprising that the empirical literature on green bond effectiveness is scarce. In particular, there is little research on the relationship between green bond issuance, energy consumption, and carbon emissions, the focus of the present paper. This is a striking contrast to the large literature addressing the relation of green bond issuance to stock performance (Zerbib, 2019; Baker et al., 2018; Karpf and Mandel, 2017), in line with the financialization view: financial metrics crowd out real metrics, also in research.

In this small body of literature on material effects papers by Flammer (2019, 2021) and Fatica and Panzica (2020), all using the same methodology, observe decreases in CO_2-eq emissions following the issuance of a green bond. But Tuhkanen and Vulturius (2020) and Ehlers et al. (2020) find that specific emission reductions are difficult to link with specific instruments, such as green bonds. We adopt the method used by Flammer (2019, 2021) so that the results are comparable to these papers. Different from them, we add energy intensity, the biggest contributor to carbon emissions.

3. Sample and research design

3.1. Sample and Variables

We collected data on all 1,744 green[2] bond issues between January 1, 2010 and January 1, 2020 from *Refinitiv Eikon*, a *Thomson Reuters* financial analytic tool[3]. We included in the sample the 4,217 (private and public) businesses[4] which reported their CO_2-eq emissions over at least all years of 2017-2021 (data collection took place in 2022). Since this sample accounts for 54.7%[5] of global CO_2-eq emissions, and considering that the actual percentage will be higher due to under-reporting, the sample is plausibly a good representation of the global universe of emitting firms. This also ameliorates selection bias concerns (firms that report their emissions are more likely to issue a green bond). The sample firms report more fre-

[2] As defined by Refinitiv's standard: CBI's Climate Bonds Standard

[3] We collected from January 1, 2007 (the date of the first green bond issuance); but as only two green bonds in the sample were issued before 2010, we winsorized the sample to 2010 till 2020.

[4] We first collected all 2,203 bonds and then excluded all issuers in the Refinitiv TRBC categories *Government Activity* and *Institutions, Associations & Organizations*

[5] Based on calculations by the IEA https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021-2

quently than all firms do: of all firms in 2020, 42.89% self-reported total CO2 emissions (and 35.52%, 35.24% and 20.71% reported separately scope 1, 2 and 3 emissions, respectively (refinitiv).

If there were multiple green bond issues per year within one firm, these were aggregated into one annual observation. All bond-year observations were matched to individual firms. This resulted in a sample of 1,762 firm-year observations from 2010 to 2020 and 224 green bond issuance-year observations from 2010 to 2020.

Table 1
Sample description

Panel A				Panel B			
Year distribution				Sample sector composition			
Year	N[1]	Mean[2]	%[3]	TRBC sect.	N[1]	Mean[2]	%[3]
2010	1	200	0.00	Healthcare	1	746	0.00
2013	1	296	0.00	Technology	20	8750	0.12
2014	10	1033	0.00	Consumer c[4]	20	20719	0.28
2015	13	2089	0.02	Consumer nc	13	4227	0.04
2016	19	2509	0.03	Energy	12	1632	0.01
2017	28	988	0.02	Materials	15	4369	0.04
2018	55	3423	0.13	Financials	32	2127	0.05
2019	85	5618	0.32	Industrials	41	7966	0.22
2020	112	6404	0.48	Utilities	72	2181	0.10
				Real Estate	98	2188	0.14

Notes	Panel C			
	Regional distribution			
	Region	N[1]	Mean[2]	%[3]
1. Represents the number of green bond issues	Americas	79	1053	0.06
2. Measured as value of total proceeds in millions of dollars	Europe	142	877	0.08
3.Represents the share of value of green bonds issued	Asia	48	9746	0.31
4. Consumer c/nc denote cyclical and noncyclical	Africa	1	560	0.00
	Japan	54	15191	0.55

We analyze the 147 firms that correspond to one or several of the 224 firm-year-bond issuance announcements during the period[6]. In table 1, panel A presents summary data of the distribution of bonds issued in the 2010-2020 period for all years. Panels B and C of Table 1 provide an overview of the distribution of issues per economic sector and region, respectively.

The original sample's sectoral distribution is tilted towards financials and firms in the real estate and utilities industries; geographically, Asia and Europe dominate. This differs from the sample that will be analyzed, which includes industrial, real estate, utility, and noncyclical consumer sectors, and most of the bonds' issuance value is issues by Asian firms. The difference is due to selection on firms that disclose their emissions, which is more common in Asian firms. The industry and regional differences between the original and study samples could introduce biases due to regional differences in compliance with standards and in emission behavior differences between industries (e.g., financials cannot reduce their emissions as much as real estate firms.)

[6] The original green bond sample encompassed 655 firms and measured a mean issue value of 2553 dollars. Thus, the sample represents 22.4% and 19.7% of all firms and value of issues, respectively

We define CO_2-eq emissions intensity as CO_2-eq emissions scaled by the firm's yearly revenue or by average total assets. Scaling limits the statistical heterogeneity (Lee and Min, 2015) and it captures emissions and energy use relative to the scale of production output (revenue) and relative to production processes (assets). In the same way, energy intensity is defined as yearly energy consumption scaled by yearly revenue or by average total assets.

None of the dependent variables distributions are normal; all are skewed to the left, so we applied log-transformations. In further analysis we also use annual changes and changes in the difference between paired firms. Definitions, summary statistics and abbreviations for all dependent variables before transformation are in Table 2.

The independent variable of interest is a firm's annual green bond(s) issuance proceeds in dollars per year. Panel A of Table 4. reports the key statistics. To reduce omitted variable bias we include control variables due to

The original (unmatched) sample has 1,757 observations, but we lose observations (approximately 4.8%) due to missing control variable observations, weakening the statistical power of the analysis. We address this problem using imputation (van Buuren and Groothuis-Oudshoorn, 2011). Using appropriate confidence intervals (Granger et al., 2019; Jäger et al., 2021), this produces unbiased estimates in the within-effect analysis.

We observe that all correlations between variables are below 0.4 (only one dependent variable is shown since the correlations are similarly low for all eight dependent variable.) The variance inflation factors (VIFs) in table 3 are all below .05 (the corresponding values read: 2: 1.011531, 3: 1.011841, 4: 1.011276, 5: 1.019729, 6: 1.049736, 7: 1.002948, 8: 1.007959 & 9: 1.021502). The overall mean is at least 1.016, so that multicollinearity is not a concern. We observe a weak and insignificant correlation between lagged green bond issuance and carbon intensity, which does not bode well for green bond effectiveness.

3.2. Model and estimation method

As in Flammer (2021) and in line with Maul and Schiereck (2017), regression and matching models are applied to examine the relationship between environmental performance (emissions and energy use) and green bond issuance. We analyze the within-firms effect and hence we use industry fixed effect (since energy intensities vary

Table 2
Dependent variable definitions

Notation	Variable name	N	Mean	Std. Dev.	Min	Max
CO2/rev S(1)	Carbon intensity scope 1 per revenue	1788	428	1242	0.0	9810
CO2/rev S(1,2)	Carbon intensity scope 1 and 2 per revenue	1761	419	1154	0.0	9882
CO2/rev S(3)	Carbon intensity scope 3 per revenue	1473	533	1521	0.0	16939
CO2/as S(1)	Carbon intensity scope 1 per assets	1788	147	407	0.0	4677
CO2/as S(1,2)	Carbon intensity scope 1 and 2 per assets	1761	145	382	0.0	4695
CO2/as S(3)	Carbon intensity scope 3 per assets	1473	243	689	0.0	9946
Energy/rev	Energy intensity per revenue	1777	5711	30359	0.0	644658
Energy/as	Energy intensity per assets	1777	2023	8881	0.0	143920

Carbon emissions for scopes are measured in CO_2-eq tonnes. Revenue and assets are measured in millions of dollars. Energy is measured in gigajoules.

across industries) and time effects[7]. We estimate

$$y_{it} = \sum_{\tau=1}^{2} \beta_\tau (Green\_Bond(t-\tau))_i + \lambda_1 (Firm\_Controls)_{it} + \lambda_2 (Sector\_Effect)_c + \lambda_3 (Year\_Effect)_t + \epsilon_{it} \quad (1)$$

where subscripts i, t and c represent firm, year and TRBC sector, respectively. y_{it} represents environmental performance (e.g., CO_2-eq emissions per million dollars of revenue or energy consumption per million dollars of assets) and α_i represents firm fixed effects. The variable $(Green\_Bond(t-\tau))_i$ represents green bond issuance proceeds in the τ years preceding year t $(\tau = 1, 2)$, allowing for a time lag between bond issuance and change in environmental performance. Lagging also supports the assumption of strict exogeneity.

3.3. Matching

Causal inference is challenging in time-series cross-sectional data, as it relies on comparing treated and control observations within a unit (Imai and Kim, 2019). But since green bond issuance is endogenous to the firm's performance, unobservables influence the relation between the issuance of green bonds and firm characteristics. Also non-green bond issuance could conceivably affect environmental performance.

Matching reduces this bias. We will test for differences in environmental performance between two matched, highly similar firms, one a green bond issuer and the other a non-green bond issuing firm. In this way we control for many (but not all) unobserved firm characteristics, in particular unobserved non-green bond effect. In the matching procedure, we select firms that issued bonds in the same year, which are in the same TRBC industry and the same geographic region. This ensures that both firms faced the same business environment. We then further match on firm size, Tobin's Q, ROA, leverage and the firm's E and ESG ratings. This addresses concerns that green bond-issuing firms have better access to capital markets due to size and leverage, or are more profitable, or more promising (ROA and Tobin's Q). Including the E and ESG rating ensures that treated and control firms have similar environmental performance. For each of the variables, we include values in the year preceding the green bond issue.

An important condition for this method to work is that over time, there is a within-firm trend in the dependent variable (emissions or energy intensity). Observations from other, similar firms can be used to estimate a firm-specific time trend (imai). We can then assess the quality of matches by examining the balance of confounders, comparing treated observations with matching control observations based on specific criteria in Table 5. The effect of green bond issuance is conditional, so that we can indeed interpret it as the effect of issuance for an individual firm.

Because we examine the average treatment effect of green bond issues between firms, we can use more matching approaches without losing consistency of the estimators (Greifer and Stuart, 2021). We matched firms on three variables (year, TRBC industry and region) which increases precision but reduces the credibility of the inference by increasing bias (Imbens and Wooldridge, 2009). In this case it is best to use nearest-neighbor, optimal, and genetic matching to allow some customizations of covariates on which to match. We chose optimal pair matching (ho, hansen) which selects those matches that collectively optimize the sum of the absolute pair distances in the matched sample. Since this method matches units with similar values on all the covariates, it produces closer pairs than using propensity score matching, which produces similar values on the propensity score but not on the covariates. We define a matching criterion using the robust Mahalanobis distance based on covariates' ranks and including ties as a correction. The robust Mahalanobis distance is especially suitable for our sample with outliers and rare categories (Rosenbaum, 2010).

Table 5 shows a summary of the matching results, with self-explanatory variable names. For each of the 224 green bond issues, a firm issuing a non-green bond in the same year is added to the sample. Columns (1) and (2) present the mean values of matching criteria for the original sample of green bond issuers and for the sample of matched firms in 2020, respectively. Columns (3)-(6) exhibit statistics for the differences between the original and added samples.

Judged by mean values, firms match well on return on assets, ESG score and total assets. There are some dif-

[7] The *plm* package designed by Croissant and Millo (2008) was used. The FE model relies on assumptions of strict exogeneity ($E[\epsilon_{it}|X, a_i] = 0$) and time-constant unmeasured heterogeneity. FE estimation is appropriate for large panels Woolridge (2002) and two-way FE estimation is consistent for unbalanced panels, even when selection is correlated with additive, unobserved heterogeneity (Wooldridge, 2021). A Hausman test confirms that fixed effect are appropriate, rejecting the null-hypothesis that random effects is the preferred model (Chi-square = 46.345, degrees of freedom = 7, p-value = 7.489e-08). Since green bonds are typically issued by international firms and proceeds are used globally, we do not include country fixed effects. To ensure robustness, alternative specifications and subsamples were analyzed using 'feasible GLS' FE regressions. Here we plugged in annual changes and the differences between matched pairs of the two first dependent variables in table 2. Feasible GLS FE regression is a two-step procedure: first a model is estimated by fixed effects, then its residuals are used to estimate the error covariance matrix. Within each group of observations, the error covariance structure is fully unrestricted. As a result, this framework is robust to intragroup heteroskedasticity and serial correlation.

Table 3

Bivariate correlations

		1	2	3	4	5	6	7	8	9
1	CO2/rev S(1)	1.00								
2	green.bond	−0.08	1.00							
3	green.bond.1lag	−0.04	**0.48**	1.00						
4	green.bond.2lag	−0.01	0.01	−0.01	1.00					
5	c.cap.int	**−0.12**	**−0.14**	−0.05	0.07	1.00				
6	c.ln.assets	**−0.13**	**0.42**	**0.21**	0.09	**−0.17**	1.00			
7	c.btm	0.03	−0.05	−0.03	−0.00	**−0.13**	**−0.17**	1.00		
8	c.leverage	−0.05	0.03	0.03	0.01	**0.23**	0.04	**−0.15**	1.00	
9	c.roa	−0.08	−0.02	0.01	0.03	**0.14**	−0.01	0.09	**0.12**	1.00

Bold figures denote correlations with a significance level at the 5% level or below.

Table 4
Descriptive statistics of the independent variables

Variable	N	Mean	Std. dev.	Min	Max
Variables of interest					
green.bond	324	4618	15105	22	200000
green.bond.1lag	322	4024	10500	22	100000
green.bond.2lag	236	4631	11542	22	100000
Control variables					
c.cap.int	2602	6.28	12.77	-58.58	533.91
c.ln.assets	2604	25.13	2.48	15.15	32.98
c.btm	2354	2.05	6.11	-107.88	217.39
c.leverage	2594	-5.92	683	-34705	1415
c.roa	2580	0.04	0.05	-0.25	0.56

All values in the Mean, Std. Dev., Min and Max columns for bond variables are in million of dollars

ferences in Tobin's Q, environmental score and leverage, in the order of 5-8%. Standardized mean differences are small, except for total assets. The size of firms is larger for green bond issuers. The variance ratio in column (4) is defined as the ratio of the variance of a covariate in the green bond sample to that in the sample of matched firms. Variance ratios are ideally close to 1 which is true for all variables except leverage and return on assets, where the variance is larger in the matched-firms sample. Empirical cumulative density functions (eCDFs) of each covariate between groups allow assessment of imbalances across the entire covariate distribution of that covariate, rather than just its mean or variance. The mean and maximum eCDF differences in columns (5) and (6) show that the distributions are very similar for all matching covariates but somewhat less for return on assets. We conclude that overall, the two matched samples are highly similar.

4. Results and interpretation

4.1. Environmental performance

Regression results are reported in Table 6. While the sample includes all 224 issuer-year-bond units , the number of observations in each regression varies with data availability. We report on scope-1 emissions in columns (1) and (4) and on scope-1 plus scope-2 emissions in columns (2) and (5), scaled by assets and by revenues respectively. Unsurprisingly, the regressions on scope-3 emissions in columns (3) and (6) have lower R^2 value. These emissions related to a firm's value chain are only indirectly linked to its own investment and its financing. In the other models, the coefficients on total assets and return on assets are both significant and negative, indicating a positive relation between size and market valuation on one hand and environmental performance on the other. The coefficient on leverage is never significant. The effect of capital intensity is positive as expected, but it matters how performance is measured. The effect is significant only with regard to scope 1-plus-scope-2 emissions and with regard to energy intensity, both relative to revenues.

The key findings are in the top rows. Coefficients on the two lags of green bond issuance proceeds are both insignificant, in all eight regressions. Neither for emissions nor for energy efficiency variables in columns (7) and (8) are the coefficients significant. Firms financed by green bonds do not show cleaner production or more efficient energy use. This finding is consistent with Tuhkanen and Vulturius (2020) and Ehlers et al. (2020), but in contrast to Flammer (2021) and Fatica and Panzica (2020) who report improved environmental performance by firms post green bond issuance

We undertook a number of additional specifications and robustness tests on the total sample. They are reported here without tables, with the results available on request. We studied the possible effect of *changes* over time in emissions, rather than emission *levels* as a result of green bond issuance, again scaled by assets and by revenues. Just like the regressions in levels, this did not yield significant results.

Further, we considered a possible signaling effect, captured by a binary variable that indicates not Dollar amounts of green bonds issuance, but whether a firm did or did not issue green bonds. Rather than the capital allocation effect tested so far, where the improvement in environmental performance is assumed to be proportional to the amount of green bond finance, this specification tests if green bond issuing is perhaps a signal (not a cause) that this firm is improving its environmental performance, without capital allocation effects of green bonds necessarily being a bottleneck factor in achieving the better performance, as suggested by Fatica and Panzica (2020). This model shows only weakly significant negative correlations of one-year lagged green bond proceeds on emissions scaled by revenues and by assets.

Next, we tested if green bonds are significant in accounting for the change in the difference of CO_2-eq emission intensities between each pair of matched firms. We find that the coefficient of the first lag for the green bond variable is negative and significant in explaining CO_2-eq emissions relative to assets (but not revenues). Thus, in this sample, issuing a green bond explains part of the difference in scope 1 carbon efficiency between issuer and non-issuers. However, the economic significance is minor. Assuming a green bond issuing firm issues the sample-average amount of 2500 million dollars in bonds, a green bond accounts for 2.5 percentage points of difference in yearly carbon efficiency change.

In Table 7, the value of the green bond issuance in a year is scaled by the total amount of (non-green labeled) long term debt issued in that year. This tests whether the share of green debt in all long debt matters, rather than its level or its growth. But across all examined categories, the proportion of green bonds within total long-term issued debt is not a significant explanatory factor for carbon intensity.

4.2. Industry differences

We now move to industry-specific analysis. It might be the case that there are results from green bond issuance in some industries but not in others, resulting in the insignificant or at best very small overall effect observed in tables 6 and 7 and the robustness checks just discussed.

In order to investigate this, the feasible GLS (FGLS) FE model was first employed on the differences between matched pairs of issuers and non-issuers in four separate industry samples that form the majority of the total sample, namely Industrials, Consumer Non-Cyclicals, Fi-

Table 5

Summary statistics of matching results (2020)

	Means GB Issuers (1)	Means Non-GB Issuers (Matched) (2)	Std. Mean Diff. (3)	Var. Ratio (4)	eCDF Mean (5)	eCDF Max (6)
m.e.score	0.707	0.675	0.157	1.051	-0.056	0.015
m.roa	0.026	0.026	0.002	0.694	0.025	0.100
m.esg.score	0.678	0.669	0.050	1.045	-0.021	0.042
m.tobinq	9.267	8.640	0.033	1.633	-0.011	0.029
m.ln.assets	25.435	24.920	0.217	1.054	-0.060	0.004
m.leverage	7.316	5.999	0.094	0.542	-0.027	0.011

Note that since exact matching was used for the matching variables *TRBC economic sector* and *region*, they are left out of the comparison.

Table 6

Does more green bonds issuance result in better environmental performance than in matched firms?

	Dependent variable (log):							
	CO2/rev S(1)	CO2/rev S(1,2)	CO2/rev S(3)	CO2/as S(1)	CO2/as S(1,2)	CO2/as S(3)	Energy/rev	Energy/as
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
green.bond.1lag	−0.00001	−0.000005	0.00002	−0.00001	−0.00001	0.00002	−0.000004	−0.00001
	(0.00001)	(0.00001)	(0.00002)	(0.00001)	(0.00001)	(0.00002)	(0.00001)	(0.00001)
green.bond.2lag	−0.00001	0.000003	0.000002	−0.00001	−0.000002	−0.000004	0.00001	0.000003
	(0.00002)	(0.00001)	(0.00002)	(0.00002)	(0.00001)	(0.00002)	(0.00001)	(0.00001)
c.btm	−0.010	−0.004	0.016*	−0.010	−0.001	0.016*	−0.002	0.002
	(0.007)	(0.005)	(0.009)	(0.007)	(0.005)	(0.009)	(0.008)	(0.008)
c.roa	−9.145***	−7.348***	−4.472***	−9.145***	−6.017***	−2.936**	−7.340***	−6.200***
	(0.808)	(0.651)	(1.276)	(0.808)	(0.658)	(1.298)	(0.710)	(0.710)
c.ln.assets	−0.735***	−0.710***	−0.643***	−0.735***	−0.695***	−0.620***	−0.718***	−0.690***
	(0.019)	(0.015)	(0.029)	(0.019)	(0.015)	(0.030)	(0.016)	(0.016)
c.cap.int	−0.001	0.003***	0.002	−0.001	−0.0003	−0.001	0.003***	−0.0004
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
c.leverage	0.0001	−0.00001	0.00003	0.0001	0.00003	0.0001	−0.00001	0.00003
	(0.0001)	(0.00005)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TRBC sector fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,098	3,036	2,403	3,098	3,037	2,404	3,082	3,082
R^2	0.695	0.678	0.366	0.695	0.699	0.422	0.610	0.626
Adjusted R^2	0.692	0.675	0.359	0.692	0.696	0.415	0.606	0.623
F Statistic	436.694***	396.209***	85.719***	436.694***	436.864***	108.338***	297.808***	319.844***

Note that /rev and /as represent dependent variables scaled by revenue and assets respectively. All dependent variables are log transformed. X in S(X) denotes the scopes of carbon emissions included in the calculation of the dependent variable.
Standardised beta coefficients are reported at the 1%, 5% and 10% levels of significance with ***, **, * respectively.

nancials and Real Estate.

The results, available on request, are not encouraging. For Consumer non-Cyclicals, for instance, the first-lag coefficients, both those scaled by assets and by revenues are positive and significant, but the second-lag coefficients are negative, significant and of nearly identical size. This means that the effect after two years is insignificantly different from zero. For Industrials and also Financials, the coefficients are negative if scaled by revenue and positive if scaled by assets; for Real Estate, they are all insignificant. In sum, the separate industry-level effects of green bonds on carbon emission, even though sometimes significant, are inconsistent between and within industries, between lags and scaling choices, and insignificant after two years. For reasons of space we do not report these results in a separate table

An alternative approach to estimating industry-level effects, which yields less ambiguous results, is to interact industry dummies with green bond issues (i.e., money values). Table 8 reports in the upper panel the coefficient for an industry dummy's coefficient. This reports the average difference in emissions between green bond issuing and non-issuing firms scaled by revenue (left-hand column) and scaled by assets (right hand column). Note that the coefficients do not reflect the emission effect of green bonds in that industry. They show the effect in the industry relative to the sample-average for all other industries — which we know to be small or nonexistent from Tables 6 and 7.

The top panel of the Table shows that the Utilities, Basic Materials and Energy industries have large positive coefficients. This makes sense since they are comparatively the most emission intensive. Higher levels of emissions result in larger emission differentials between issuing and non-issuing firms than the average in other sectors. Financials and Real Estate unsurprisingly emit less than the average.

The middle and bottom panels of Table 8 report the industry-specific difference in emissions between matched firms (bond issuers versus non-issuers) per dollar green bond value, one and two years post-issuance, relative to the average of that difference per dollar green bond value in all other industries and years. Again, the sign tells us the (lagged) green bond effect, *not* on that industry's issuer/non-issuer emission differential, but on its differential *relative to* the differential in the rest of the sample.

For emissions scaled by revenues, the first-lag coefficients are all negative but never significant at conventional levels (except for the Utilities coefficient which is very weakly significant). This suggests little difference across industries one-year post issuance between firms that do and those that do not issue green bonds.

The second-lag coefficient is always very significant (except for Consumer non-Cyclicals), with the signs of all coefficients negative except for Financials and Consumer non-Cyclicals. (Real Estate is omitted due to lack of ob-

Table 7

Does more green bonds issuance relative to total long-term debt issuance result in better environmental performance than in matched firms?

	Dependent variable (log):							
	CO2/rev S(1)	CO2/rev S(1,2)	CO2/rev S(3)	CO2/as S(1)	CO2/as S(1,2)	CO2/as S(3)	Energy/rev	Energy/as
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
green.bond.debt.1lag	0.014	−0.004	0.089	0.036	0.047	0.014	0.005	0.086
	(0.057)	(0.045)	(0.130)	(0.050)	(0.050)	(0.057)	(0.046)	(0.132)
green.bond.debt.2lag	−0.030	−0.043	0.113	0.033	0.062	−0.030	−0.019	0.135
	(0.101)	(0.081)	(0.137)	(0.089)	(0.089)	(0.101)	(0.082)	(0.139)
c.mtb	−0.010	−0.004	0.016*	−0.002	0.002	−0.010	−0.001	0.017*
	(0.007)	(0.005)	(0.009)	(0.008)	(0.008)	(0.007)	(0.005)	(0.009)
c.roa	−9.164***	−7.349***	−4.454***	−7.328***	−6.192***	−9.164***	−6.023***	−2.925**
	(0.808)	(0.651)	(1.276)	(0.710)	(0.709)	(0.808)	(0.658)	(1.298)
c.ln.assets	−0.739***	−0.711***	−0.638***	−0.718***	−0.690***	−0.739***	−0.697***	−0.616***
	(0.019)	(0.015)	(0.029)	(0.016)	(0.016)	(0.019)	(0.015)	(0.029)
c.cap.int	−0.001	0.003***	0.002	0.003***	−0.0003	−0.001	−0.0003	−0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
c.leverage	0.0001	−0.00001	0.00003	−0.00001	0.00003	0.0001	0.00003	0.0001
	(0.0001)	(0.00005)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Observations	3,098	3,036	2,403	3,082	3,082	3,098	3,037	2,404
R^2	0.695	0.678	0.366	0.610	0.627	0.695	0.699	0.422
Adjusted R^2	0.692	0.675	0.359	0.606	0.623	0.692	0.696	0.415
F Statistic	436.342***	396.209***	85.753***	297.844***	320.001***	436.342***	436.781***	108.409***

Note that /rev and /as represent dependent variables scaled by revenue and assets respectively. All dependent variables are log transformed. X in S(X) denotes the scopes of carbon emissions included in the calculation of the dependent variable.
Standardised beta coefficients are reported at the 1%, 5% and 10% levels of significance with ***, **, * respectively.

servations.) The interpretation is that the difference in emission between green-bond issuers and matched non-issuing firms is larger (more negative) in all sectors than the average, except for Financials and Energy firms, where green bonds issuers emit more than the average, relative to their matched firms.

The salient finding is not, obviously, that some industries are below and others above the average of the difference in emissions between issuer and non-issuer firms, but that the size of these relative positions is widely varying. The largest negative coefficient is for Basic Materials, the next largest is Utilities, and the next is tied between Industrials and Consumer Cyclicals which is ten times smaller than the Basic Materials relative effect. Then follows Energy. This ordering indicates where green bonds are potentially more effective, namely in Basic Materials, Utilities, Industrials, in descending order of potential green bond effectiveness — bearing in mind that the overall, total-sample effectiveness was found to be nil.

The right-hand column corroborates these patterns and also shows that the measurement of emission matters to the findings. Scaled by assets, both the first-lag and the second-lag coefficients are highly significant and negative. Here it is striking, first, how similar in size the first-lag coefficients are (all between -0.27 and -0.29 except Utilities with -0.33). Second, it is noteworthy how much smaller the second-lag coefficients are. They are around an order ten smaller than the first-lag coefficients, with the exception of Basic Materials which has a coefficient -.185 in the second lag, compared to -0.28 for the first lag. The largest relative negative effects are in Basic Materials, Utilities and Energy, consistent with the above ranking based on scaling by revenues. This is also consistent with the high levels of emissions (and therefore much scope for reduction) in Energy and Basic Materials shown in the top panel of Table 8.

In summary, while neither in the full sample nor within industry samples, significant effects of green bonds issuance on emission intensity could be detected, there are significant differences between industries. This means that the prospects of reducing emissions through issuing green bonds are not supported by the empirical evidence in the analysis reported in Tables 6 and 7 ; but if it is done, the analysis reported in Table 8 cautiously suggests sectors in which effectiveness could potentially be realized. All in all, a cautious conclusion.

Table 8
Industry dummy results from FGLS fixed effect regression

	CO2/rev S(1)		CO2/as S(1)	
	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)
Technology	90.269	0.000	70.814	0.000
Consumer Non-Cyclicals	28.189	0.187	77.299	0.000
Consumer Cyclicals	80.281	0.000	94.167	0.000
Energy	118.294	0.000	111.354	0.000
Basic Materials	354.364	0.000	241.476	0.000
Industrials	10.680	0.618	67.543	0.000
Financials	−40.639	0.057	34.348	0.000
Utilities	1947.838	0.000	626.060	0.000
Real Estate	−99.039	0.000	10.918	0.075
1-lag Technology	−0.018	0.870	−0.279	0.000
1-lag Consumer Non-Cyclicals	−0.011	0.917	−0.277	0.000
1-lag Consumer Cyclicals	−0.015	0.889	−0.278	0.000
1-lag Energy	−0.004	0.972	−0.275	0.000
1-lag Basic Materials	−0.028	0.792	−0.286	0.000
1-lag Industrials	−0.020	0.851	−0.280	0.000
1-lag Financials	0.012	0.912	−0.268	0.000
1-lag Utilities	−0.178	0.099	−0.331	0.000
1-lag Real Estate	−0.011	0.921	−0.276	0.000
2-lag Technology	−0.005	0.000	−0.002	0.000
2-lag Consumer Non-Cyclicals	0.002	0.142	−0.004	0.000
2-lag Consumer Cyclicals	−0.031	0.000	−0.011	0.000
2-lag Energy	−0.023	0.000	0.034	0.000
2-lag Basic Materials	−0.387	0.000	−0.185	0.000
2-lag Industrials	−0.031	0.000	−0.010	0.000
2-lag Financials	0.003	0.000	0.003	0.000
2-lag Utilities	−0.098	0.000	−0.047	0.000

The 1-lag and 2-lag additions represent the transformation of the dummy variables of industry multiplied with the value of the issued bond lagged one or two years. Note that /rev and /as represent dependent variables scaled by revenue and assets respectively. All dependent variables are log transformed. S(1) denotes the scope 1 carbon emissions.

5. Discussion and conclusions

Regulatory pressure following the Paris Climate Conference is encouraging firms to increase energy efficiency and reduce carbon emissions through more sustainable production and investment. Green finance is argued to be a bottleneck factor, and its estimated market size has doubled each year thus far. This paper has shed light on the effectiveness of green bonds, expanding on the few papers which, so far, have analyzed the issue. The present analysis is the first to consider differences across issuing sectors. Also, we use detailed emissions data not utilized before.

Different from other studies, we take a systemic view. The size and complexity of the financial system have rendered it increasingly ineffective in supporting productivity and innovation, as research especially since the great financial crisis has highlighted. It is therefore no foregone conclusion that green finance should lead to greener production – a perspective typically missed in the sustainable finance literature. Green finance, just as finance in general, can boost fees, capital gains, profits and dividends without changing the productive processes they are supposed to support. Green bonds, a global market, is perhaps more susceptible to this than green finance in more local and shorter financial supply chains.

We provide a careful discussion of standards, definitions and regulatory initiatives in the green bond market. We collected data on all 1,744 green bond issues over 2010-2022 by 4,217 (private and public) businesses which reported their CO2-eq emissions over at least all years of 2017-2021, scaled by assets and by revenues. In a matched-pair difference-in-difference analysis, the evidence suggest that green bonds have a minimal and insignificant effect on carbon emission intensities and energy consumption. This result holds up for other specifications, namely analyzing changes over time in emissions, rather than emission levels; analyzing changes in the difference of CO_2-eq emission intensities between each pair of matched firms; and analyzing a possible signaling effect, captured by a binary variable that indicates not Dollar amounts of green bonds issuance, but whether a firm did or did not issue green bonds. In all specifications, the effects are not significant or, in the last regression statistically significant but substantially very small, and this only when scaling by assets, not revenues. In an additional analysis we find that the coefficients do differ by industry, nothwithstanding the absence of total-sample effects.

These findings are consistent with prior work which fails to link emission reductions to green debt instruments at the firm level (Ehlers et al. 2020; Tuhkanen and Vulturius 2020) and they contradict studies that do report a link (Flammer 2021; Fatica and Panzica 2020). Such differences are unsurprising between studies that use different samples, and given the large differences between industries reported in this paper, as well as the sensitivity of results to lag length and scaling by revenues versus scaling by assets. This literature and still nascent and not yet converging to a consensus view.

Taking a systemic view, as argued in this paper's introduction and in section 2, matters to the interpretation of the results. The green bond market, and by extension the emerging sustainable finance system, can be viewed as situated on a spectrum between financial development (supporting the substantive, real-sector goals it ostensibly serves) and financalization (supporting financial aims and financial-sector success, and possibly undermining substantive, real-sector goals such as green innovations and investment, or scaling down of dirty production). Where on this spectrum the green bond market is, is a topic for another paper. But this critical perspective suggests as a possible interpretation of the results that, just as in the case with finance in general (Arcand et al., 2015), there is perhaps no paucity of green finance but rather too much financialization in this market.

This perspective is typically missing in the empirical sustainable finance literature, so that any shortcoming of sustainable finance lead to calls for more and better financial instruments, without considering the wider system in which green finance is to function. If the financial sector and the economy are financialized, the need is for less (private) finance and for financial structures which take balance sheet dynamics seriously and respond to rather than crowd out real (economic and more widely ecological) needs. Public-sector (national and supranational) financing mechanisms such as proposed by Cingolani and Toporowski (2024) and Grafton et al. (2004) often meet these requirements, although they also run into other problems of a political (**?**) and international-coordination nature.

It is also important to note this study's methodological limitations, which will help to direct future research. This study focuses primarily on firms in rich and middle-income countries, while green finance could have a more profound impact in developing economies. also, w capture only a very limited part of the ecological impact. citepopescu suggest that when including scope 3 in addition to scope 1 and 2 emissions, GHG emissions of investment funds (also sustainable funds) is two to three times larger. Plausibly, this holds for green bonds as well.

The sample of firms that report their emissions is not large. Also, we have used one standard for green bonds, which restricts and inevitably biases the type of bonds included in the research. Although restricting the study to these firms and these bonds improved reliability —- for instance, since their reports were verified — it also introduced self-selection bias and decreased the sample size. There is a pressing need to develop larger reliable data bases on green finance for future research. Future research should also begin to trace longer-term implications of green bonds, beyond the two-year window of this study.

While the matching used in this study helps mitigate the endogeneity of corporate green bonds, it does not substitute for an experiment. Future developments in the green bond market may provide alternative empirical settings that could help deepen our understanding of green bonds. For example, the environmental impact of European green bonds could be compared before and after the introduction of EU climate finance regulation

Further, even within this sample, our understanding of the linkages between finance and production is incomplete. Firms engaged in green and non-green activities may finance either with green bonds or with non-green bonds, or with other external finance, or with retained profit. Finance observed at the firm level is fungible across projects in and of itself, although creditor demands and regulation may impose reporting that restricts fungibility. A quantitative study like this might be usefully supplemented by case studies which trace more completely the financial flows to and within firms, to understand better what green bonds finance. This would also more explicitly connect to the corporate financialization literature which has developed analytical models to analyze firms' capital flows and their effects on employment, productivity, profit and other outcomes. This type of analysis could be expanded to ecological outcomes.

Conversely, while there are benefits to zooming in on intrafirm capital flows, zooming out into the financial ecosystem of investment chains would bring in the actors (creditors, rating agencies, asset managers) which, as the financialization literature suggests, between them determine much of any green bond effectiveness. This is a testable hypothesis, but it cannot be addressed using only issuer data.

The findings of this study may inform the design of the governance of the green bond market. The current regime is based on private initiatives and certification by independent third parties. Clearer regulation by central governments and regulators might improve transparency.

Making ground on these issues will be vital for ensuring that the growth of green finance will be accompanied by actual greener production.

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6. Appendix

6.1. Detailed Definitions Variables

Source: Refinitiv Eikon

Revenue Revenue from all of a company's operating activities after deducing any sales adjustments and their equivalents. (Refinitiv Eikon)

CO2-eq Scope 1 Direct of CO2 and CO2-eq emissions in tonnes, direct emissions from sources that are owned or controlled by the company. (Refinitiv Eikon)

CO2-eq Scope 2 Indirect CO2 and CO2-eq emissions from consumption of purchased electricity steam or heat which occur at the responsible facility. (Refinitiv Eikon)

CO2-eq Scope 3 Emissions from contractor-owned vehicles, employee business travel, waste disposal, outsourced activities, product use by customers, production of materials, electricity purchased for resale. (Refinitiv Eikon)

ROA/pre-tax ROA Income before/after tax divided by average total assets. (Refinitiv Eikon)

Current assets Sum of cash and short-term investments, net total receivables, total inventory, total prepaid expenses and other current assets. (Refinitiv Eikon)

Assets Average of total assets of a company. (Refinitiv Eikon)

ESG score Overall company score based on self-reported information of the three pillars. (Refinitiv Eikon)

Environmental pillar score Measures a company's impact on living and non-living natural systems including the air, land and water as well as complete ecosystems. IT reflects how well a company uses best management practices to avoid environmental risks and capitalize on environmental opportunities in order to generate long term shareholder value. (Refinitiv Eikon)

TRBC economic In our sample the TRBC range consists of the following 10 economic sectors: Healthcare, Technology, Consumer Non-Cyclicals, Consumer Cyclicals, Energy, Basic Materials, Financials, Industrials, Utilities and Real Estate (Refinitiv Eikon)

TRBC Financials This economic sector consists of the following business sectors: Banking & Investment Services, Insurance, Collective Investments, Investment Holding Companies (Refinitiv Eikon)

TSCS Time-series cross sectional (Refinitiv Eikon)

EBITDA EBIT for fiscal year plus the same period depreciation and supplementals. (Refinitiv Eikon)

Total debt Total debt outstanding includes short-term and long-term debt. (Refinitiv Eikon)

BTM Average of total equity divided by current total shares outstanding. (Refinitiv Eikon)

Liabilities Sum of total liabilities and total equity. (Refinitiv Eikon)

Energy use Total direct and indirect energy consumption in gigajoules. Purchased and produced energy included. Coal gas and nuclear not considered under total energy use. (Refinitiv Eikon)

Energy purchase Direct purchased in gigajoules. If the company reports purchased electricity/heat/steam as indirect energy then reclassify the reported figure as direct energy purchased. Direct energy can appear in primary (natural gas) or intermediate (electricity for lighting) forms. Includes purchased, extracted (coals, oi, gas), harvested (biomass), collected (solar wind) or brought in via other sources. (Refinitiv Eikon) university of groningen / faculty of economics and business

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