Letter

Green bonds for the Paris agreement and sustainable development goals

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Abstract
The Paris Agreement under the United Nations Framework Convention on Climate Change and the Sustainable Development Goals (SDGs) of the United Nations Development Programme both entail substantial global investments through cost-efficient, long-term financing. Noted for their risk-alleviating features and appeal to institutional and socially responsible investors, green bonds are gaining prominence in climate change and sustainable development finance frameworks. This study is the first to thoroughly examine publicly reported green bond proceeds allocations from 53 organizations to projects and assets throughout 96 countries from 2008 to 2017. Green bond markets are growing rapidly, and yearly proceeds allocation trends reveal increasing disbursements to renewable energy, clean water, low-carbon transportation, and other Paris Agreement and SDG-related investment categories. Circle plot analysis reveals unique allocation trends to specific green sectors at both regional and national levels. International finance institutions allocated the largest share of proceeds by both frequency and volume, and the projects and assets financed with green bonds in this study sample are associated with over 108 million tonnes of carbon dioxide equivalent (tCO₂e) in greenhouse gas emissions reductions and over 1500 gigawatts in renewable energy capacity. The study concludes with suggestions for improving green bond post-issuance reporting and provides insights for future green bond applications in expanding Paris and SDG agendas.

1. Introduction
The Sustainable Development Goals (SDGs) within the 2030 Agenda for Sustainable Development of the United Nations Development Programme (UNDP) and the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) are two premier global initiatives for addressing the economic growth-environmental stewardship dichotomy. The former aims to eradicate poverty and hunger, promote peace, justice, and human rights, and realize environmentally-friendly, sustainable economic growth and universal prosperity (United Nations UN (2015)). The latter calls to keep 21st century global temperature rises within 2°C (above pre-industrial levels) and to finance low-carbon, climate-resilient global development (United Nations Framework Convention on Climate Change UNFCCC (2015a)). SDGs related to clean water and sanitation (SDG 6), access to next-generation energy (SDG 7), infrastructure and industrialization (SDG 9), and other targets align with the climate-focused commitments in the Nationally Determined Contributions (NDCs) to Paris Agreement. Still, both frameworks entail substantial investments. For instance, the U.N. Commission on Trade and Development estimates that meeting the SDGs requires $5 to $7 trillion in annual investments through 2030 (United Nations Conference on Trade and Development UNCTAD (2014)), while the International Energy Agency estimates that maintaining the 2°C temperature threshold of the Paris Agreement will require $3
trillion in energy-related investments by 2035 (International Energy Agency IEA (2014)). The international community is thereby pressed to mobilize large volumes of public and private capital in pursuit of far-reaching environmental agendas.

There are a number of precedent-setting environmental finance instruments that are conducive to advancing SDG and NDC-related environmental targets. Established under the UNFCCC Kyoto Protocol as an avenue for developed countries to fulfill their greenhouse gas (GHG) emission reduction commitments via qualified projects in developing countries, the Clean Development Mechanism (CDM) was ‘seen by many as a trailblazer…the first global, environmental investment and credit scheme of its kind, providing standardized emissions offset instruments, CERs [certified emissions reduction credits]’ (UNFCCC 2019a), the positive impacts that CDM projects have on sustainable development at the local level (Kolshus et al 2001; Huq 2002; Fichtner et al 2002; Anagnostopoulos et al 2004). Ellis et al (2007) observed that CDM portfolio developments resulted in greater carbon dioxide (CO2) emissions credits, increased awareness of climate change mitigation options among potential investors, and more robust climate-related institutions. Schneider, Holzer, and Hoffmann (2008) combined empirical study assessments with expert testimonies to reveal that CDM perpetuates green technology transfer by increasing commercial viability, reducing barriers to information and capital, and improving institutional frameworks. Most recently, Seres, Haites, and Murphy (2009) assessed over 3000 CDM projects and proposals to demonstrate that after a certain threshold number of projects in a given country, the transfer of emissions-reducing technologies that were previously unavailable in CDM host countries extends beyond the CDM projects themselves.

The Green Climate Fund (GCF) is another important environmental finance mechanism. It was similarly established under the UNFCCC in 2010, but as a more direct means of funneling funds (predominately through grants and loans) into GHG emissions curbing and climate change adaptation in developing countries. Since its inception, 40 contributing countries have allocated $4.6 billion to 93 green projects, with another $1.8 billion available for implementation and an additional $10.3 billion in subsequent funding pledges. Already supporting green projects expected to reduce global CO2 emissions by 1.4 billion tonnes (Green Climate Fund GCF (2018)), the GCF will likely play important role in financing Paris Agreement and other green policy outcomes throughout the developing world.

The CDM and the GCF both highlight the diversity of options among effective environmental financing schemes. In the related context of traditional project finance, the comparative advantages of debt instruments (i.e. loans and bonds) remain important considerations in financial decision-making. Such advantages include an applicability to flexible payment schedules, various credit enhancement techniques, long-term project schedules, leverage options, and other benefits that ultimately drive down finance costs (Curley 2014). With proceeds earmarked to eligible, eco-friendly projects and assets, newly emerging green bonds stand to bring the advantages of debt instruments to the realm of environmental finance.

The Green Bond Principles (GBP) published by the International Capital Markets Association (ICMA 2018a) define green bonds as ‘any type of bond instrument where the proceeds will be exclusively applied to finance or re-finance, in part or in full, new and/or existing eligible Green Projects.’ To this end, green bonds appeal to a broad range of institutional and socially responsible investors (SRIs) seeking to bolster their portfolios with eco-friendly, fixed payment securities. An added benefit is that in cases where access to capital markets is limited, bonds can supplement municipal budget shortages in capital-intensive infrastructure finance schemes (Clapp et al 2015). Moreover, the fact that the projects they are designed to finance fall within the scope of 15 SDGs (ICMA 2018b) and are similarly relevant to the Nationally Appropriate Mitigation Actions (NAMAs) of Paris NDCs (Hatano 2018) points to their inherent compatibility with both agendas.

Although their proceeds are earmarked, green bonds are sometimes mistakenly credited for additional environmental benefits derived from the assets they finance. It is important to note, however, that bonds are primarily involved in refinancing schemes (of existing, instead of new projects) and are seldom the sole factor in the project finance decision-making process. Their environmental impacts are therefore not necessarily additional, as projects financed using green bonds often could be financed using other mechanisms. Nevertheless, their potential impacts on weighted actual costs of capital (WACC), investment scaling and planning decisions, portfolio alignments with environmental policy initiatives, and numerous additional factors affecting green investment awareness and decision-making (Dupree et al 2018) render them capable of affecting environmental investment and policy outcomes.

Though their markets are relatively nascent, the recent, precipitous rise in green bond issuances has prompted a growing number of studies into their applications and effectiveness as environmental finance instruments. Mathews and Kidney (2012) compared renewable energy and low-carbon technology projects in first and third world countries to conclude that even in the latter, climate (green) bonds attract long-term investors who view low-carbon projects as ‘safe’ investments. Ng and Tao (2016) assessed the renewable energy financing gap in Asia and found that while green bonds are capable of bridging the gap, their successful adoption should be supported through policy efforts that level the playing field for renewable energy projects, build deep capital markets,
and enhance the robustness of labelling practices. Building on the discrete time overlapping generations model utilized by Sachs (2014), Flaherty et al (2017) employed a nonlinear predictive control to find that by enabling present-day environmental investments that will largely be enjoyed and financed by future generations, climate (green) bonds are effective instruments of Pareto environmental improvements. Furthermore, using both stock market event studies and regressions of corporate green bond issuances on financial and environmental performance factors, green innovation, long-term orientation, and orientation structure among firms, Flammer (2018) demonstrated that corporate green bonds improve environmental footprints and financial performance among firms and attract environmentally aligned investors.

Many studies have also assessed the existence, scale, and effects of green bond yield premiums. Through ordinary least squares (OLS) regressions of after-tax yields and ownership concentration on green bond indicators and controls, Baker et al (2018) found that green bonds are issued at a negative premium and held in higher concentrations among investors, revealing that ‘a subset of investors is willing to sacrifice some return to hold green bonds’. Zeribib (2019) employed a matching method to compare yield spreads between green and non-green bond yields as well as two phases of regressions on green bond premiums. Their results indicated that green premiums are small and negative for Euro and US dollar (USD)-denominated bonds, suggesting they do not discourage expansions among green bond-holding investor bases. Both of these studies fall within a growing literature base which finds negative premiums among GBP-aligned green bonds (Preclaw and Bakshi 2015, Ehlers and Packer 2017, Hachenberg and Schiereck 2018), similarly suggesting investors are willing to hold green bonds at a premium.

One substantial gap in the green bond literature involves the role of green bonds in advancing specific environmental policy targets. Particularly, the degree to which green bond financing affects greenhouse gas (GHG) emissions reductions and other explicit NDC and SDG-related targets remains vaguely understood. Although some green bond issuers publish post-issuance reports which detail how proceeds are allocated and the anticipated environmental effects of underlying projects, each individual report offers merely a limited view of the role of green bonds in pursuing environmental policy objectives. A comprehensive assessment of green bond impacts would aid in measuring their effectiveness in promoting ‘financial flows consistent with climate and other sustainability objectives, in order to inform the design of policy incentives and climate actions from investors’ (Dupree et al 2018). The aim of this study, therefore, is to trace the linkages between green bond-issuing institutions, the eco-friendly investment categories to which green bond proceeds are allocated, and the anticipated environmental impacts of these investments to evaluate the role of green bond finance in advancing SDG and NDC objectives.

The remainder of this paper is structured as follows. Section 3 outlines the analytical methods employed in this study. Section 4 describes the data and resources utilized in the analyses. Section 5 provides the main results with discussions of each. Section 5 concludes with implications for future post-issuance reporting and green bond applications within SDG and Paris Agreement policy pursuits.

2. Methods

This study begins with graphical representations of green bond market activities from 2008 to 2017. First, the total annual volumes of green bonds issued, green bonds outstanding, and reported green bond proceeds allocations are graphically assessed within the context of total annual international debt securities (bonds) outstanding. Next, the total annual frequencies and volume of proceeds allocations to 10 specified green project and asset categories are graphically compared. A circle plot then provides an overview of global green bond proceeds allocations to assess domestic and transnational proceeds flows from issuing (allocating) organizations to recipient green categories. Finally, total estimated environmental impacts associated with green bond proceeds-recipient projects and assets are calculated and summarized in table 1.

3. Data

An original panel dataset was constructed using 2008–2017-year international and green bond market data from a diverse range of sources. International debt securities (bonds) outstanding data is from the Bank of International Settlements (BIS) debt securities statistics online database (2018). Fourth quarter values served as yearly proxies for the data which is conventionally reported in a quarterly format. Furthermore, total international bonds outstanding data was used to represent global bond market trends in the absence of consistent, reliable domestic bonds outstanding data.

Labelled (e.g. earmarked for green projects or assets) green bond issuance and outstanding data is from the Climate Bonds Initiative (CBI) third quarter 2018 database (2018b). To the authors’ knowledge, no similar repository of unlabelled green bonds exists, and post-issuance impact and investor reporting for unlabelled bonds was generally inaccessible, incomplete, or even nonexistent. As such, they were not included in the analyses of this study. This represented a significant data limitation, as the bulk of environmentally-aligned bonds fall into this category. Furthermore, since many of these unlabelled issuances
Table 1. Green bond proceeds allocations with reported environmental impact estimates of financed projects and assets.

| Institutions       | Years             | Amount$ | Frequency | Annual GHG emissions reduced/avoided (tCO₂e) | RE capacity added (MW)$ | Annual RE generation added (MWh)$ | Annual energy savings (MWh) |
|--------------------|-------------------|---------|-----------|---------------------------------------------|-------------------------|-----------------------------------|-------------------------------|
| ABN AMRO           | 2015–2016         | $1,516,348,341 | 9         | 22,332                                      |                         | 22,419                            | 91,507                        |
| ASE                | 2015              | $279,403,821    | 10        | 114,000                                     |                         |                                   |                               |
| ADB                | 2009, 2012–2016   | $988,349,554    | 18        | 3,207,161                                   | 302                     | 841,280                           | 277,676                       |
| ADB                | 2010–2016         | $1,404,080,121  | 35        | 10,618,300                                  | 3,173                   | 9,903,720                         | 4,276,632                     |
| Bank of America    | 2013–2016         | $1,365,025,154  | 16        | 1,331,800                                   |                         |                                   |                               |
| BRF S.A.           | 2016              | $8,343,574      | 16        | 7,545                                       | 900                     | 49,200                            | 42,608                        |
| City of Gothenburg | 2013–2015         | $399,562,801    | 11        | 7,088                                       |                         |                                   | 26,500                        |
| City of Paris      | 2016              | $148,777,442    | 9         | 27,889                                      |                         |                                   | 44,833                        |
| EBRD               | 2012–2013         | $177,089,604    | 6         | 199,060                                     |                         |                                   |                               |
| EIB                | 2016–2017         | $5,195,725,181  | 99        | 11,594,244                                  | 3,721                   | 39,711                            |                               |
| Fortum Värme       | 2015              | $272,673,210    | 6         | 641,000                                     |                         |                                   | 71,000                        |
| Groupe BPCE        | 2013–2016         | $143,985,312    | 15        | 282,365                                     | 220                     | 428,822                           |                               |
| Heras P.A.         | 2008–2017         | $500,751,227    | 21        | 1,138,571                                   | 3,158,597               | 141                               |                               |
| HSBC               | 2016              | $799,716,471    | 21        | 7,067,500                                   | 2,663                   |                                   |                               |
| Île-de-France      | 2014–2017         | $1,601,338,139  | 120       | 232,207                                     |                         |                                   | 141                           |
| IFC                | 2015–2017         | $3,144,251,904  | 101       | 8,456,329                                   | 3,842                   | 10,193,347                        | 638,397,712                   |
| KBN                | 2008–2016         | $1,694,585,748  | 63        | 40,789                                      | 348,000                 |                                   | 148,657                       |
| Kommuninvest       | 2016–2017         | $2,107,885,659  | 146       | 514,944                                     |                         | 2,058,640                         | 137,104                       |
| NAB                | 2017              | $872,368,012    | 31        | 2,062,663                                   |                         |                                   | 12,647,084                    |
| FMO                | 2011–2017         | $835,838,806    | 88        | 373,333                                     | 2,571                   | 1,502                             |                               |
| NIB                | 2011, 2013–2017   | $2,377,744,037  | 53        | 616,800                                     | 1,174,736               | 3,416,000                         |                               |

(continued on next page)
| Institutions                  | Years          | Amount $\text{USD}$ | Frequency | Annual GHG emissions reduced/avoided (tCO$_2$e) | RE capacity added (MW) | Annual RE generation added (MWh) | Annual energy savings (MWh) |
|-------------------------------|----------------|----------------------|-----------|-----------------------------------------------|------------------------|---------------------------------|------------------------------|
| Ontario Financing Authority   | 2014–2016      | $119,183,038         | 14        | 40,000                                        | 0.042                  | 48                              | 2,434                        |
| Örebro Municipality           | 2017           | $219,768,683         | 9         |                                               |                        |                                 |                              |
| Regency Centers, L.P.         | 2015–2017      | $2,837,581,787       | 11        | 6,643,136                                     | 1,657                  | 8,991,370                       | 5,907                        |
| Southern Company              | 2015           | $524,768,641         | 7         | 16,195                                        |                        |                                 |                              |
| TD Bank                       | 2015–2017      | $5,043,550,771       | 8         | 7,460,000                                     | 6,156                  | 14,160                          | 26,781                       |
| TenneT Holding B.V.           | 2008–2016      | $7,473,235,366       | 83        | 42,939,116                                    | 3,781                  | 18,158,260                      | 80,810,670                   |
| World Bank IBRD               | 2015           | $86,479,944          | 2         | 2,300,000                                     | 132                    |                                 |                              |
| Yes Bank                      | 2008–2017      | $43,953,358,968      | 1,041     | 108,754,366 tCO$_2$e                           | 1,551,854 MW           | 57,303,917 MWh                  | 737,235,746 MWh             |

**Source:** Created by authors based on post-issuance and investor reports of the 53 institutions assessed in this study.

- Allocation amounts expressed in constant 2010 USD;
- Annual greenhouse gas (GHG) emission reductions measured in tonnes of carbon dioxide equivalent (tCO$_2$e);
- Renewable energy (RE) capacity added measured in megawatts (MW);
- Annual RE generation and energy savings measured in megawatt hours (MWh).
took place in countries that are of critical importance to Paris and SDG outcomes, their inclusion would enhance the results of this study. For example, data gaps and reporting shortages for unlabelled (or not conventionally labelled) Chinese issuances prevented more thorough evaluations of the massive Chinese market that injected $960 billion into 7826 low-carbon projects between 2016 and 2017 alone (United Nations Environment Programme UNEP (2017)).

Green bond proceeds allocations and environmental impacts were calculated by the authors using annual or semi-annual post-issuance and investor reports published by 53 green bond issuing organizations (see table S2 in the supplementary materials section is available online at stacks.iop.org/ERL/14/064009/mmedia). These organizations were among the 103 listed in a comprehensive overview of the publicly-available green bond post-issuance reporting complied by the CBI (2017b). From among these potential sources, data was selected based upon the availability of complete information regarding (1) the names, domiciles, and institutional structure of organizations that distributed green bond proceeds; (2) the location, green category (e.g. renewable energy, clean water, low-carbon transportation, etc), and environmental impacts of projects or assets financed (at least partially) with the proceeds; and (3) the year, frequency, and volume of the proceeds allocations. Notably, an additional 41 green bond-issuing institutions from the source list provided no reporting as of the data collection period of this study. The fact that only about half (53 out of 103) of the organizations that did report did so thoroughly enough to allow for the assessments of this study draws attention to the severe lack (and need) of clear, consistent, instructive reporting.

4. Results and discussion

4.1. Green bond market growth and increasing proceeds allocations

Figure 1 demonstrates the upscaling of the labelled green bond market from 2008 through 2017. Specifically, it juxtaposes the total annual volumes of green bonds issued, green bonds outstanding, and reported green bond proceeds allocations with the total annual volumes international bonds outstanding. Note that the dashed line indicates a vast gap in the monetary volumes recorded on the y-axis. Volumes recorded below the line remain within the $160 billion ballpark of peak, 2017-year green bond issuances, while those recorded above the line extend from $19.35 trillion to the nearly $21.5 trillion peak of international bonds outstanding. Moreover, although the monetary values in original data sources were expressed nominally, those in figure 1 and all subsequent figures, tables, and discussions are expressed in constant 2010 USD.

International bond volumes outstanding generally hovered around $20 trillion, starting at a local low of $19.1 trillion in 2008 and peaking at over $21.1 trillion by the fourth quarter of 2017. The volume of green bonds outstanding began at $230 million in 2010 and rose sharply from around $4.8 billion in 2013 to roughly $142 billion by 2017 (as of Q3 2018) (CBI 2018b). The latter growth represents nearly 3000% increase over four years. Annual green bond
issuances showed similar patterns, experiencing a nearly 12000% increase from just over $1.2 billion in 2011 to just under $143 billion by 2017. Overall, the total volume of green bonds outstanding during this period amounted to over $291 billion, accounting for a small percentage (1.38%) of all international bonds outstanding as of 2017 alone. In the absence of any radical upswings or downturns in international bond markets, sustained upscaling of green bonds by these magnitudes (e.g. thousand-percent increases) could make them account for more substantial proportions of international bond issuances and volumes outstanding in the years to come.

Figure 1 also displays shifts in the amounts of reported proceeds allocations from green bond issuers, as well as the volume of those allocations that were reported alongside environmental impacts. Note that the latter are a subset of the former and are therefore not stacked. Years where these allocations outstrip total labelled green bond issuances (e.g. in 2008, 2009, and 2011) depict cases where either (1) proceeds from previous year issuances were carried over and applied in subsequent years, surpassing the volume of issuances in the latter (as took place in all three years) or (2) allocations to projects or assets were listed alongside green bond allocations in reporting sources and may have been financed by unlabelled green bonds or some other unspecified finance mechanism in conjunction with later green bonds (as took place in 2008 and 2009). Outside of these few exceptional cases, proceeds allocations resulted from CBI-recognized, labelled bond issuances.

The earliest allocations, including those reported with environmental impact estimates, were from the World Bank International Bank for Reconstruction and Development (IBRD) in 2008. Over time, allocation and impact reporting increased and became more thorough, especially among particular institutions. Similar to the growth of total green bond issuance and amounts outstanding, reported allocations increased abruptly from 2013 onward, rising from $2.3 billion to roughly $17 billion by 2016. To a substantial yet lesser degree, allocations with reported environmental impacts also increased, surpassing $9.4 billion in 2016 after barely exceeding $2 billion in 2013. While the specifics of where these green bond proceeds were allocated are evaluated in subsequent sections, one key take away from figure 1 is that there has been a massive gap between green bonds market growth (i.e. in issuances and outstanding) and reported proceeds allocations. In the long run, this could run counter to the aim of bolstering the eco-friendly image of green bonds and potentially result in missed opportunities attract broader institutional investor bases.

4.2. Comparative magnitudes among category-specific proceeds allocations

Drawing connections between green bond issuances and eventual environmental outcomes presents multiple challenges. To begin with, green bond proceeds earmarked at issuance may only reflect intended uses without guaranteeing allocations to specific undertakings with predetermined green impacts. Furthermore, many issuers earmark proceeds for a variety of project or asset types (e.g. clean energy, transportation, or water infrastructure, etc.) within a single issuance, adding complexity to a priori funding estimates for each recipient investment. The first step in assessing the linkages between green bond issuances and the environmental impacts attributable to financed projects, therefore, is to evaluate the actual magnitudes of proceeds allocations to specific green sectors.

Figure 2 reveals the annual trends in both the frequencies and volumes of green bond proceeds allocated to multiple green categories. Note that the total allocation volumes correspond to the ‘Green Bond Allocations’ volumes depicted in figure 1, with 2017-year estimations added to account yet unpublished reporting data as of the assessment period of this study. Green categories were created with dual consideration of the ICMA Green Bond Principles (2017) and the CBI Climate Bond Taxonomy (2018a). Listed alphabetically, they include ‘Clean Water & Wastewater Treatment,’ ‘Climate Change Adaptation,’ ‘Eco-Efficient Technologies & Processes,’ ‘Ecosystem & Resource Management,’ ‘Energy Efficiency,’ ‘Green Building Infrastructure,’ ‘Low-Carbon Transportation,’ ‘Multi-Sector Financing,’ ‘Renewable Energy,’ and ‘Waste Management & Recycling.’

Allocations between 2008 and 2012 were few in number and small in magnitude, generally remaining under $2.5 million through less than 50 disbursements per year. Thenceforth, they surged beyond $16 billion through over 450 disbursements per year by 2016. While allocation frequencies leveled off from 2015 onward, volumes continued to rise. This discrepancy between frequency and volumes suggests institutions provided larger volumes per allocation, which is sensible in the backdrop of the more than thousand-percent expansions of the green bonds issuance and volumes outstanding depicted in figure 1. More generally, rising proceeds allocations coincided with the labelled green bond market expansion that was catalysed by the establishment of the GBP in 2014 (Ehlers and Packer 2017). A broad array of additional factors also helped to propel the expansion of the labelled green bond market, including the 1) application of diverse bond instruments (see table S1 in the supplementary materials section).

There were substantial differences in the proceeds allocated to each green category. ‘Renewable Energy’ and ‘Clean Water and Wastewater Treatment’ each received the largest, roughly 32% shares of the total number of allocations. Allocations to the former surged from 7 in 2008 to 171 by 2016, largely reflecting the increasing role played by IFIs in clean energy finance schemes throughout developing countries. Allocations to the latter, which rose from 2 in 2009 to surpass 216 through 2015, mainly reflect recent (2014
to 2017-year) municipal bond financing of local water authorities in the United States (as the US municipal green bond market issuance surged from roughly $3 billion to roughly $10 billion over the same period) (Chiang 2017). Other notable increases included the number of allocations to ‘Green Building Infrastructure,’ ‘Low-Carbon Transportation,’ and ‘Energy Efficiency’ categories. The first peaked at 109 instances by 2017, while the latter two respectively peaked at 40 and 35 instances by 2016.

By allocation volume, the trends were similar. The $26.7 billion provided to ‘Renewable Energy’ accounts for nearly half of the total allocations. ‘Green Building Infrastructure,’ ‘Low-Carbon Transportation,’ and ‘Energy Efficiency’ also received substantial volumes that increased over time. Specifically, allocations to the first of these grew from just over $107 million in 2009 to peak at over $2.8 billion by 2017. Over the same period, allocations to the second grew from $946 million in 2008 to peak at over $2.5 billion by 2016, while allocations to the third grew from just over $9 million to peak at over $684 million by 2015.

By contrast, the ‘Climate Change Adaptation’, ‘Eco-Efficient Technologies & Processes,’ ‘Ecosystem Preservation & Resource Management,’ ‘Multi-Sector Financing,’ and ‘Waste Management & Recycling’ categories received far fewer allocations by both volume and frequency. Indeed, few of their yearly allocations surpassed 10 in number or millions of USD in volume, and total allocations for each remained well within a comparatively lower threshold of $1 billion over 50 allocations. A few key factors help to explain these developments.

First, GHG emissions reductions are long-established, priority objectives among environmental policies, so it is reasonable that ‘Renewable Energy,’ ‘Low-Carbon Transportation,’ and other categories with measurable mitigation effects would receive comparatively greater shares of proceeds. As an example, SDG 13 (‘Climate action’) calls for $100 billion in yearly contributions by 2020 to affect GHG emission reductions throughout developing countries, while GHG emissions reduction targets ranging from 25% to 40% are common among Paris Agreement NDCs (United Nations UN (2015), UNFCCC 2019b). The fact that energy accounts for roughly 60% of global greenhouse gas emissions (United Nations Development Programme UNDP (2019)) likely underlies the large magnitude of allocations to the ‘Renewable Energy’ category in particular.

At the same time, a lack of investor familiarity and other investment barriers may have resulted in substantially smaller allocations to the other categories. Despite their green alignment, issues with government support (e.g. lack of long-term political commitment, regulatory instability), investor capability (e.g. regulatory barriers, lack of sector expertise, short-term mindsets), and investment conditions (e.g. lack of appropriate investment mechanisms, shortage on infrastructure data, lack of transparency and negative perceptions of infrastructure value) among the many traditional obstacles to institutional investors’ infrastructure allocations (Kaminker and Stewart 2012)
likely influenced the degree to which proceeds were applied to the more recently developed, rather unconventional categories (such as ‘Ecosystem Preservation & Resource Management’). Ultimately, however, divergences in categorical allocations imply the existence of policy-driven green bond allocation priorities (e.g. to reduce GHG emissions). Moreover, growing allocation trends across green categories suggests there is potential to apply greater magnitudes of proceeds in the future to finance a broader base of green categories.

4.3. Geographic distribution of reported proceeds allocations
The majority of all green bond listing and trading takes place in the Börse Frankfurt, Luxembourg Stock Exchange, Borsa Italiana, China Interbank, London Stock Exchange, Euronext Paris, SGX (Singapore), Shanghai Stock Exchange, Nasdaq Stockholm, and Nasdaq Oslo international exchanges (Environmental Finance 2019). With issuances and allocations occurring across national borders, it can be difficult distinguish where green bond finance originates (i.e. the green bond issuing institutions) from where it is applied (i.e. the underlying green projects and assets). This section assesses both the geographic distribution of proceeds allocations to specific green sectors and the prominent institutions and supportive policies of each locale. Then, section 4.4 reveals the cumulative environmental impact estimates associated with the proceeds-recipient projects and assets. Together, these results shed light on the extent to which projects and assets fully or partially financed with green bonds are conducive to SDG and Paris Agreement policy objectives.

Figure 3 provides a bird’s-eye view of green bond proceeds flows from issuing organizations to recipient projects. Nine international finance institutions (IFIs) are listed alongside 96 countries within the region of their domicile. Each listing is color coded using shades of the 11 region colors on the outer circumference. Line segments in the plot center depict proceeds allocations, originating from points that directly touch country labels on the inner circumference (i.e. the domicile of issuing organizations) and ending at points slightly separated from country labels at line segment termini (i.e. the location of recipient projects or assets). Additionally, line segments are color coded according to the green categories of the projects or assets financed, as listed in the figure.

Prominent trends include (1) interregional allocations from IFIs to ‘Renewable Energy’; (2) allocations to a diverse array of green categories throughout the greater European Economic Area (EEA); (3) high-frequency allocations to ‘Clean Water and Wastewater Treatment’ in North America; and (4) comparatively greater allocations to BRICS (Brazil, Russia, India, China, and South Africa) countries among developing regions.

4.3.1. International finance institutions (IFIs)
Due to their regular advisory roles and expert knowledge of market policies and regulations, many of the development finance institutions among the IFIs of this study have led sustainable development investing in low-income countries (Clark et al 2018). Similarly, since the 2012 United Nations Conference on Sustainable Development in Rio de Janeiro, many supranational development banks have spearheaded the call to invest 2% of global GDP into greening ten key sectors of the economy (agriculture, buildings, energy supply, fisheries, forestry, energy efficiency, tourism, transport, waste management, and water). In line with this, each demonstrated steadfast commitments to GHG emission reductions, renewable energy capacity building, and other environmental policy targets. Of the overwhelming majority of green bond proceeds between 2008 and 2017 that were allocated to the ‘Renewable Energy’ category, IFIs provided the largest shares to both developed and developing countries. As referenced in many post-issuance reports, green bonds were valuable tools within IFI climate change and sustainable development finance initiatives.

For example, in accordance with its Strategic Framework for Development and Climate Change, (World Bank 2012) the World Bank has issued over $13 billion in green bonds since 2008 to raise funds for mitigating and adapting to climate change. In the scope of this study, the World Bank IBRD allocated over $6.3 billion to 15 renewable energy projects across 7 regions and 8 countries. Similarly, under its Climate Strategy, the European Investment Bank (EIB 2015) commits a minimum of 25% of its total investments to climate change mitigation and adaptation. Since 2007, it has issued over €15 billion in Climate Awareness Bonds (CABs) with nearly €5.2 billion in proceeds allocated 74 times to renewable energy projects across 5 regions and 24 countries. As with these cases, each of the other IFIs assessed in this study developed similar policy directives that drove their green bond allocations to renewable energy investments.

4.3.2. The European Economic Area (EEA)
With 63 binding and 68 non-binding European Union (EU) environmental targets established for the present through 2050 (Paleari et al 2013), regional frameworks such as the EU 20–20–20 targets steer Europe towards a 20% reduction in total greenhouse gas emissions, a 20% increase in energy efficiency by 2020, and a 20% share of renewables in total energy consumption (EEA 2018). They also establish precedent for the EU NDC of 40% domestic reductions of 1990-level emissions by 2030 (UNFCCC 2019b). Each of these policies, in addition to the recent adoption of the European Commission Action Plan on Financing
Sustainable Growth, demonstrate expanding NDC and SDG orientations throughout the region. Moreover, a number of local and national policies provided supportive backdrops for burgeoning green bond market activities.

Overall, the European Economic Area (EEA) received $25.2 billion over 729 green bond proceeds allocations, making it the largest recipient region. Of this, Sweden, Norway, and France received the largest shares, and the majority these went to the ‘Renewable Energy,’ ‘Green Building Infrastructure,’ and ‘Low-Carbon Transportation’ categories. In the case of Sweden, its National Strategy for Sustainable Regional Growth and Attractiveness 2015–2020 targets demographic development, climate, environment, energy, and social cohesion as the core challenges of its national development (Ministry of Enterprise and Innovation of Sweden 2016). Conducive to many of these pursuits, green bond issuers provided $5.1 billion through 246 allocations to ‘Green Building Infrastructure’ and ‘Renewable Energy.’ The Kommuninvest government agency was the largest financier of both categories, allocating $994 million over 83 instances to the former and $817 million over 36 instances to the latter.

As the first country to form a cabinet-level ministry for environmental regulations in 1972, Norway is a climate and sustainable development forerunner with extensive eco-friendly legal precedents. As of June, 2017, its Law on Climate Goals expanded the Norwegian commitment to the EU NDCs to include an 80% to 95% reduction in 1990-level greenhouse gas emissions by 2050 (Ministry of Climate and Environment of Norway 2017). Of the $2.5 billion in proceeds allocated to Norway over 117 instances, ‘Renewable Energy’ and ‘Green Building Infrastructure’ received the largest shares. Among prominent issuers, the Bergenshalvøens Kommunale Kraftselskap (BKK) state-backed power company provided $588 million over 53 instances to ‘Renewable Energy’ while the Kommunalbanken Norway (KBN) government agency contributed more than $471 million through 24 allocations to ‘Green Building Infrastructure.’

France obtained $3.2 billion in proceeds over 163 allocations. Of this, ‘Green Building Infrastructure’ and ‘Low-Carbon Transportation,’ both received $1.2 billion, with 73 and 52 respective allocations to each. The largest allocator was the Île-de-France regional government, which applied over $1.6 billion across multiple green categories in accordance with its SDG-aligned regional development plan. Additionally, the City of Paris disbursed over $261 million to 7 domestic tram, cycle path, and electric vehicle projects in accordance with its Paris Climate Action Plan (City of Paris, Green Parks and Environment, Urban Ecology Agency 2018). The Plan calls for (1) a 75% reduction of greenhouse gas emissions compared to 2004 levels by 2050, (2) a 25% reduction of greenhouse gas emissions compared to 2004 levels by 2020, (3) a 25% reduction in energy consumption compared to 2004 levels by 2020, (4) a 25% portion of the total energy mix made
up of renewable energy or energy, and (5) adapting Paris to climate change and resource scarcity.

4.3.3. North America

North America received $13 billion in green bond proceeds through 634 allocations, making it the second largest recipient region. Canada’s NDC commitments include a 30% reduction of GHG emissions (UNFCCC 2019b), and its Pan-Canadian Framework on Clean Growth and Climate Change promotes carbon pollution pricing, climate change resilience and clean technology innovation investments, and GHG emissions reductions to under 523 megatonnes (Mt) by 2030 (Government of Canada 2016). The United States tells a different story. On the one hand, the recent repeal of many federal environmental policies (e.g. the Climate Action Plan, the Clean Water Rule, and the Clean Power Plan) and planned withdrawal from the Paris Agreement (and its 26%–28% emissions reduction NDC) (UNFCCC 2019b) mark a distinct shift away from previous climate-related commitments. On the other hand, many state government members of the United States Climate Alliance vow to pursue Paris objectives through statewide policy coordination, and growing support for the Green New Deal stimulus program stands to realign US economic planning, industrial policy, and infrastructure investments with SDGs and existing US NDCs.

Of the total allocations to the region, $11 billion was disbursed 614 times to the US figure 3 highlights the $1.5 billion in provided via 536 allocations to ‘Clean Water and Wastewater Treatment.’ Major allocators included the New York State Environmental Facilities Corporation and the State of Connecticut Department of Energy and Environmental Protection. From 2014 to 2016, the former committed $780 million through 286 allocations to its Clean Water and Drinking Water State Revolving Fund (CW and DW SRF) projects, while from 2015 to 2017, the latter committed $461 million through 202 allocations to its own CW SRF projects. In both cases, SRFs provided market-rate or below market-rate financing for public health-related water projects that adhere to the Environmental Protection Agency’s Clean Water Act. Over the long run, the green impacts of the wastewater treatment, pump station, waterline, sewer, lake restoration, and drinking water projects funded with these proceeds will likely indicate progress towards SDG 6 (‘Clean water and sanitation’) and other sustainability objectives.

4.3.4. Developing regions

The final major trend relates to the $17.3 billion in proceeds provided over 426 instances to the developing regions of the Balkan Peninsula, the Commonwealth of Independent States (CIS), multiple segments of Africa and Asia, and Latin America and the Caribbean (LAC). BRICS countries received comparatively higher shares of proceeds than their regional counterparts. This includes (1) $640 million over 9 allocations to Brazil, (2) $297 million over 5 allocations to Russia, (3) $2.7 billion over 52 allocations to India, (4) $2.9 billion over 44 allocations to China, and (5) $359 million over 10 allocations to South Africa. Each with NDCs that aim to make non-fossil fuel based energy account for at least 40% of their national energy mixes by 2030, Brazil and India were the only two developing nations in this study that received allocations from domestic institutions. Of these, BRF S.A. of Brazil should be noted for providing some of the most thorough post-issuance reporting out of all the non-IFI institutions examined in this study (including estimates of sustainable forest management, waste reductions, and water recycling).

The $2.9 billion provided through 44 disbursements to China represents the most diverse proceeds allocations among all of the developing nations. Specifically, over $1 billion was allocated 16 times to ‘Low-Carbon Transportation,’ over $800 million was allocated 14 times to ‘Renewable Energy,’ and the remaining $1.2 billion was allocated to ‘Clean Water and Wastewater Treatment,’ ‘Ecosystem and Resource Management,’ ‘Energy Efficiency,’ and ‘Waste Management and Recycling’ categories. The majority of these funds flowed from the World Bank IBRD and aligned with China’s NDCs, which aim for a (1) 60% to 65% reduction of 2005-level CO2 emissions by 2030, (2) a 25% increase in non-fossil fuel based energy consumption, and (3) a 4.5 billion cubic meter (m3) increase in forest stock (UNFCCC 2019b). Multiple regulatory developments seemed to encourage the expansion of the Chinese green bond market, including the (1) the joint issuance of the Guidelines for Establishing the Green Financial System by seven ministerial agencies (including the People’s Bank of China and the Chinese Ministry of Finance); (2) the establishment of pilot green finance zones in five provinces; and (3) the inclusion of green development in the Belt and Road Initiative (Hong Kong Exchanges and Clearing Limited HKEX 2018).

4.4. Environmental impact estimates

There is an intricate overlap among many SDG and Paris NDC targets. Just as SDG 7 (‘Affordable and clean energy’) calls for substantial increases in global energy efficiency and renewable energy, NDCs for over 60 countries commit their signatory countries to renewable energy capacity and generation increases through the 2020s. Similarly, while SDG 15 (‘Life on land’) calls for the protection of terrestrial ecosystems, biodiversity, and land productivity, the NDCs of Belarus, Georgia, Burkina Faso, Chile, Lebanon, Vietnam, Bhutan, and Honduras each commit them...
to protecting or restoring forests and otherwise developing land in a sustainable manner (United Nations UN 2015, UNFCCC 2019b). Though many green bond issuers are SDG and NDC-conscious (or operate under the sovereignty of governments that are), to what were green bond allocations in line with SDG or NDC outcomes?

Overall, more than $58 billion in proceeds was allocated 1,851 times by the 53 institutions included in this study (see table S2). Of this, 74% of the total allocation volume ($43 billion) and 56% of the total number of allocations (1041) of this study were reported alongside the estimated environmental impacts of proceeds-recipient projects. Though these estimates are not explicitly additional, they are nevertheless informative and are summarized in table 1. About half (29) of the institutions in the study sample clearly articulated such green impact estimates. GHG emission reductions were the most consistently reported, and less consistently reported impacts (e.g. waste reduction and wastewater treatments volumes, etc) were excluded from table 1 due to general sparseness of data. Total annual GHG emission reduction estimates surpassed 108 million tCO2e. Green bond proceeds-recipient projects and assets were also estimated to provide net increases in renewable energy capacity, annual renewable energy generation, and annual energy savings of over 1.5 million megawatts (MW), over 57 million megawatt hours (MWh), and over 737 million MWh, respectively.

The results in table 1 provide reveal key insights. First, it is clear that IFIs provided the bulk of environmentally impactful green bond finance. The two main factors underlying this are that these institutions have 1) each implemented initiatives that leverage green bonds within their greater financing schemes (e.g. the initiatives outlined in sections 4.3.1); and 2) jointly contributed to establishing a harmonized framework for green bond post-issuance reporting (International Capital Market Association ICMA 2015) and greenhouse gas accounting (UNFCCC 2015b). Next, although there was a lack data and reporting for impacts related to broad array of SDG and NDC targets, available GHG emission reduction and clean energy-related impact estimates highlight demonstrable (though not necessarily additional) contributions to overarching SDG and NDC policy targets. Expanding green bond market activities also allude to greater support of these policy objectives in years to come. Furthermore, the fact the majority of total reported allocations (e.g. those included in table 1) generated unique impact information is a positive signal to potential environmentally-friendly investors. In many ways, green bonds did in fact ‘act as a feedback loop giving a degree of credibility to statements and promises that countries will achieve ‘such and such emissions reductions by such and such a date’ (Mathews et al 2010).

5. Conclusions

This paper investigated the extent to which green bond proceeds were allocated to projects and assets aligned with SDG and NDC-related environmental outcomes. It is evident that green bond markets are expanding, and renewable energy and other projects that address high-priority GHG emissions reduction targets received greater proportions of green bond proceeds. While many IFIs provided detailed, consistent, up-to-date post-issuance assessments, other institutions often failed to publish reports that articulate environmental impact estimates of proceeds-recipient projects and assets. This not only obfuscates the marginal impact of proceeds on progress towards policy targets in key countries (especially BRICS economies with high climate and sustainable development investment needs), but also may lead to information gaps that undermine or fail to bolster investor confidence.

Importantly, many post-issuance reports also do not clearly identify the additivity of green bond impacts. This renders it difficult to derive the connections between SDG and NDC-oriented environmental outcomes and green bond finance vehicles. In order to address this issue and more effectively aid investors, financiers, and policymakers in environmental finance decision-making, future reporting should, as a rule of thumb, provide explicit, accurate, and transparent information regarding additional versus non-additional environmental impacts.

Moreover, current reporting often does not track a wider array of sustainability and climate metrics. While energy and greenhouse gas-related measurements are more routinely provided, those pertaining to water and wastewater systems, waste management and recycling, ecosystem preservation, sustainable forest management, and other aspects pertinent to multiple SDGs and climate change adaptation objectives of the Paris Agreement are lacking. At a time when explicit adaptation criteria are needed to measure country-level progress and guide international discourse (Magnan and Ribera 2016), forthcoming reporting should include a broader spectrum of impact criteria. This would lay the groundwork for the universal environmental standards crucial to investors in assessing the green risks of their investment portfolios (Clapp et al 2015). Improved impact reporting thus would make green investment opportunities more identifiable, thereby expanding the transnational, green-conscience investor bases needed to achieve the SDGs by 2030 (Vörösmarty et al 2018).

Finally, recent reporting suggests that current proceeds allocation trends are insufficient for addressing the pressing, global investment challenges of the 21st century. For example, investing $26 billion to renewable energy over nine-year time periods (as occurred with green bonds in the scope of this study) would stop short of the $53 trillion by 2035 energy investment directive of the International Energy Agency IEA.
(2014). In the meantime, should global GDP continue to grow at up to 3.9% per year (as it did in 2018), the environmental benefits generated by recent green bond investments would provide only minor contributions to what would be needed to curb the effects of the roughly 37 gigatonnes (Gt) of CO2 emissions estimated to result from such growth (Jackson et al 2018). This shortfall is exacerbated by recent projections that by 2020, overcome ‘damage and loss’ costs of climate change could reach $50 billion per year (Money for Climate 2017). Thus, it is clear that a drastic scaling up in green bond financing, in conjunction with substantially greater applications of other environmental finance mechanisms, will be required to address a potentially broadening scope of SDG and Paris Agreement investments. Nevertheless, the rate at which green bond proceeds allocations are growing suggests that they are gaining prominence within the broader context of environmental finance and still stand as viable financing instruments for advancing the outcomes of both agendas.

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