Economic Change and Restructuring
https://doi.org/10.1007/s10644-020-09266-9

Green bonds as an instrument to finance low carbon transition

Eftichios S. Sartzetakis[1]

Received: 19 June 2019 / Accepted: 23 January 2020

Abstract
The present paper examines the role that green bonds can play in financing the transition to low carbon economy. We first establish the need for central banks to respond to climate change challenges, and we present the main ways in which they can get involved. We explain why green bonds should be used as an instrument of choice for financing the low carbon transition, based first, on the theoretical argument of intergenerational burden sharing and second, on the practical need for large, long-term infrastructure investments. After defining green bonds, we present their main characteristics. We then summarize the main developments in the green bonds market during the last decade. We conclude by presenting existing challenges and barriers and ways to overcome them so that the green bonds market develops further.

Keywords Green bonds · Climate change · Low carbon transition

JEL Classification Q54 · G12 · G28

1 Introduction

In recent years, there is increasing recognition of the importance of the financial risks associated with climate change. The literature has identified three types of climate-related financial risk: Physical: risks that could arise from climate and weather-related events, such as floods and storms, which can damage productive capital or disrupt trade. Liability: risks that could arise from parties who have suffered loss or damage. Transitional: risks that could arise from the process of adjusting to a

The author gratefully acknowledges financial support from the Bank of Greece. He would also like to thank the journal's Guest Editor and two anonymous referees for their very helpful comments and suggestions.

✉ Eftichios S. Sartzetakis
esartz@uom.edu.gr

[1] Economics and Management of Sustainable Development (EMSD) Research Unit, Department of Economics, University of Macedonia, 156 Egnatia Street, Thessaloniki 54006, Greece

lower-carbon economy, such as changes in technology, policy, or investors' expectations. For example, moving away from fossil fuel would decrease the value of the related financial assets inflicting losses to all investors holding these assets, including pension funds and insurance companies (Bank of England 2015). If physical damages from climate change increase fast, a rapid transition away from fossil fuels will become inevitable and the subsequent fall in fossil fuel-related financial assets will be significant enough to pose a threat to the stability of the financial system.

Over the past few years central banks acknowledged the potential systemic risk that climate change and the transition away from fossil fuels could pose to the financial system. In his widely referenced speech in September 2015, Mark Carney, Governor of the Bank of England and Chairman of the G20's Financial Stability Board, acknowledged the potential threats of climate change to financial resilience and the need for coordinated action by the financial sector to facilitate the efficient transition to a lower-carbon economy. In his words, "with better information as a foundation, we can build a virtuous circle of better understanding of tomorrow's risks, better pricing for investors, better decisions by policymakers, and a smoother transition to a lower-carbon economy." (Carney 2015). Although, following Carney, a number of authors (for example Batten et al. 2016) and financial authorities recognized the above-mentioned threats (among others, European Systemic Risk Board 2016), the reaction has been yet very slow and hesitant, involving mainly suggestions and recommendations. These include first, the advice to firms to disclose information regarding their emissions (Task Force on Climate-related Financial Disclosures 2016). For this to be effective the development of a standardized method to disclose such information is required. The second recommendation concerns the development of specific stress-tests that will assess the risk climate change poses to the financial sector. Third, the use of lower reserve requirements for commercial banks and other institutions that have a higher share of green lending has been proposed (Campiglio 2016). Actually, Banque du Liban, the central bank of Lebanon is already implementing such a policy (Banque du Liban 2009, 2010). Fourth, there is an extensive discussion of the environmental effect of quantitative easing (large-scale asset purchases, mainly government bonds but also corporate bonds and equities via open market operations). This discussion leads to the argument that a significant portion of these purchases should be directed toward green bonds.

In what follows we will first discuss whether and how central banks should respond to climate change challenges, briefly going through the main proposals. Section 3 will focus on what we consider as the main two reasons for promoting the use of green bonds: the theoretical issue of intergenerational equity and the practical need of large infrastructure investments. Section 4 will present the main characteristics of green bonds, focusing on those that they pose challenges in further developing the market. Section 5 will summarize the historic development of the green bond market emphasizing its potential. The final Section will summarize the discussion and present some proposals for the further development of the green bond market.

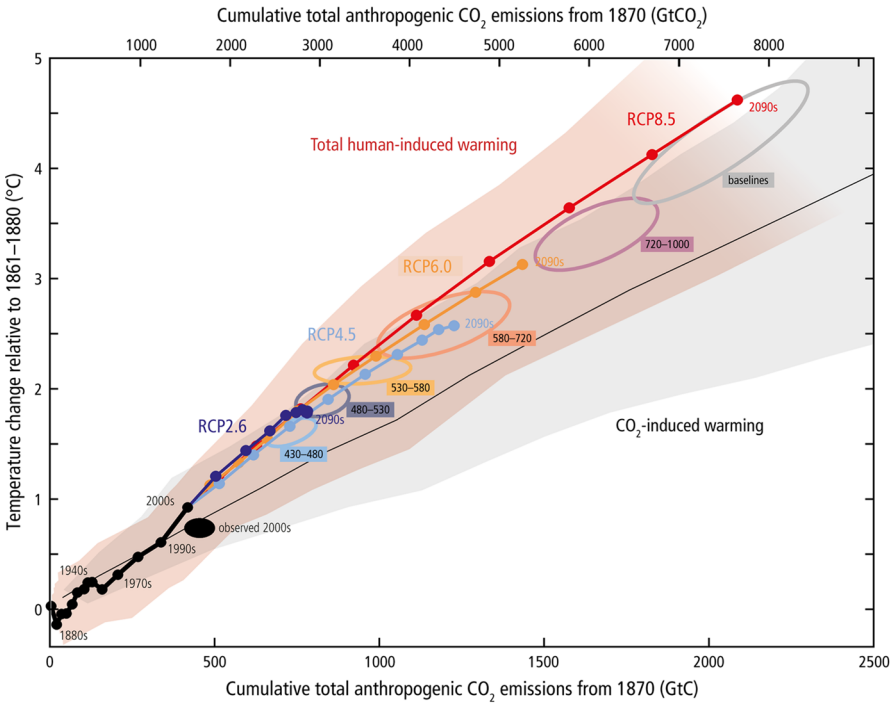

Fig. 1 Warming versus cumulative CO2 emissions. *Source*: IPCC (2014), Figure SPM.5 (b)

2 The role of central banks in responding to climate change challenges

There is almost unanimous international consensus that "warming of the climate system is unequivocal" and that "human influence on the climate system is clear" (IPCC 2014). Thus, decisive and speedy policy action to mitigate climate change is required. At the international level the coordination of actions is undertaken by the United Nations Framework Convention on Climate Change (UNFCCC) that established the target to limit the increase in average global temperatures to 2 °C, a target that was revised to 1.5 °C at the 21st Conference of the Parties (COP 21) in Paris in November 2015. In order to achieve limits of this range, a certain cap in the stock of greenhouse gases in the atmosphere should be placed. As illustrated in Fig. 1, in order to limit the "total human-induced warming to less than 2 °C relative to the period 1861–1880 with a probability of > 66% would require cumulative CO_2 emissions from all anthropogenic sources since 1870 to remain below about 2900 $GtCO_2$" (IPCC 2014, p. 10). This amount defines the so-called "carbon budget." Given the amount of CO_2 emitted up to now, it has been estimated that the remaining cumulative carbon budget, consistent with keeping global warming below 2 °C, is 1000 $GtCO_2$ (Gignac and Matthews 2015).

According to these data, strong action is required to curb CO_2 emissions. Following COP 21 in Paris, 165 countries have already submitted their pledges, known as the Nationally Determined Contributions (NDCs), to reduce their greenhouse gas (GHG) emissions (which can be accessed at UNFCC, NDC Registry, http://www4.unfccc.int/ndcregistry/Pages/All.aspx). Governments will attempt to fulfill these promises using fiscal policy instruments that include, apart from direct spending, market instruments such as taxation and carbon markets. However, recent literature shows that fiscal instrument might not be enough to fulfill these pledges and most importantly that much stronger action is needed relative to the Paris NDCs. Furthermore, it has been suggested that following 2030 "…challengingly deep and rapid mitigation" will likely be required (Millar et al. 2017). Even if it was possible to implement the necessary fiscal policies, their cost could hinder current economic growth raising issues of intergenerational equity. This argument was recently made by Sachs (2014) who suggested that the introduction of debt financing of current climate mitigation actions could be a more just solution. This is so since at least part of the payments of debt will be made by taxing future generations. Sachs (2014) was the first to present the intergenerational burden sharing solution through a formal, though simple, overlapping generations model. He demonstrated that such a combination of fiscal and financial instruments could yield a Pareto efficient solution to climate mitigation. In the next Section we will briefly present Sachs' work and the recent extensions by Flaherty et al. (2016), Andersen et al. (2016) and Orlov et al. (2018).

The need for further and very rapid action to limit the increase in global temperature, avoiding physical and liability risks, as well as the need to control the resulting high transition risks in the financial markets, have prompted the discussion regarding the role that central banks could play in the transition to the low carbon economy. Central Banks' reaction up to now has been reluctant, based mainly on the neutrality of their role. Most of the advanced economies' Central Banks have been granted, since the 1990s, operational independence and their mandate has been focused mainly on price stability, that is, controlling inflation rate typically below 2%. However, Central Banks' mandate was not always limited to financial and price stability and, as public institutions, have supported in the past wider public objectives, including high employment, exchange rate stability, the control of government deficits and the support of strategic industrial sectors. Furthermore, responding to the last economic crisis, Central Banks have been involved in large-scale transactions of existing financial assets (mainly government but also private bonds), via Quantitative Easing (QE) programmes. These supposedly market-neutral interventions have been criticized extensively for showing an "unintended structural bias toward carbon-intensive industry." (Matikainen et al. 2017). Despite efforts to ensure sector neutrality, QE programmes exhibit biases toward high carbon assets, such as for example, loans to conventional technology car manufacturers. The criticism to the QE programmes, combined with the financial risks associated with climate change and the fact that the low carbon transition requires a vast amount of long-term investments, are the main reasons supporting the idea of extending the role of Central Banks in assisting the low carbon transition (see for example Campiglio et al. 2018). In some emerging and developing countries the Central Bank's

mandate is broader and closely connected to the government's objectives, which allows them to support social and environmental goals more directly. However, Central Banks in high-income countries are not expected to widen their mandate and there are a number of arguments that support this choice. Apart from the theoretical arguments against policy discretion laid out in a general context by Kydland and Prescott (1977) and with emphasis on Central Banks' credibility by Blinder (2000), one should also consider the costs that possible extra responsibilities will place on Central Banks and the extent to which institutions that are managed by non-elected officials should be given the power to decide over social and environmental issues.

Even in the case that Central Banks do not change their mandate, it is clear that the importance of the climate change problem will require their active involvement in assisting the low carbon transition. Central Banks can get involved in a number of different ways. In the medium to long term, the main goal should be the integration of environmental and social factors and especially climate-related criteria, into their investment strategy. Immediate results could be derived by directing more capital toward low carbon economy activities in the framework of the ongoing QE programmes. Actually, many experts and policymakers have already suggested a "green" QE-programme (for example see Murphy and Hines 2010). Another option is to support the development of the Green Bonds market. Furthermore, similar principles could be applied to Central Banks' collateral frameworks.

3 The case for green bonds

In this Section we will present two arguments, one theoretical and one practical, in support of the use of bonds in financing the transition to low carbon economy. The first argument is that green bonds, as debt financing instruments, could help spread the cost of the transition in a more just and efficient way across generations. To develop this argument we will briefly review the growing part of the literature initiated by Sachs' work in 2014. The second argument is the practical need for extremely large long-term investments to finance the transition. We will briefly present the investment requirements and explain why green bonds are the best vehicle to finance low carbon infrastructure.

3.1 Intergenerational equity

One of the arguments for using bonds to finance climate change mitigation, is that at least part of the necessary investment should be paid by future generations so as the current generation does not carry the entire burden of climate change mitigation. Debt financing has been historically used to finance large-scale projects such as infrastructure, stretching the repayment of the loans to a number of generations. Climate change is by definition an intergenerational problem, since greenhouse gasses are long-lived and their impacts will be felt long after the emissions are generated. The issues of intergenerational justice and equity have been raised in a number of works (see for example Page 2006) which though focus mainly on the fact that

climate change created an intergenerational externality via which the current generation imposes high costs on future generations. However, there is the other side of the coin, that is, the benefits of costly action to mitigate climate change taken by the current generation will be enjoyed by future generations. A number of interesting questions are raised. Should the current generation choose to slow current growth based on cheap fossil fuel energy, for example, by imposing heavy carbon taxes, so as to move to a low carbon economy, aiming at minimizing climate change damages to future generations? And if the answer is positive, can the current short-sighted political system (governments are elected every 4 years) provide the necessary policies? Can we find a way to distribute costs and benefits from mitigating climate change justly across generations?

Sachs (2014) was the first to consider these questions, using a simple theoretical overlapping generations (OLG) model. He assumes two-period-lived agents (generations) which work during the first period (in which they are called young) while retiring in the second during which they support their consumption needs by savings made during the first period. Disposable wage income during each generation's working period is equal to the market wage *w(t)* minus taxes *T(t)*. In what follows we will briefly present the two generation model, that is, $t=1,2$, which Sachs extends to many generations. The pre-tax level of wages received in the first period is negatively affected by greenhouse gas emission mitigation efforts *M(1)*, that is, $w(1) = W - \lambda M(1)$. GHG emissions in the first period, E, and mitigation efforts, *M(1)*, determine GHG concentrations, $G(2)$, in the second period,

$$G(2) = (1 - M(1))E.$$

The level of wages received in the second period (by the second generation's youth) decreases directly with the level of greenhouse gas concentrations, $w(2) = W - \theta G(2)$. Therefore, the disposable income of each young generation is,

$$Y(t) = w(t) - T(t).$$

First period mitigation efforts could be financed through taxing labor income in the first period or by debt that will be repaid by taxing labor income of future generations. Thus, a government that works for the benefit of all generations could use a combination of taxes and bonds applied to each generation, so as to achieve a balanced distribution of wealth across generations. Such a combination will consists of transfers—*T(1)* that will be financed by selling equal value bonds *B(2)* and be repaid by taxing youth in the second period, $T(2)=(1+r)B(2)$, where r is the bonds' interest rate. The government thus sets,

$$T(2)/(1 + r) = -T(1).$$

The first generation consumes *C1(1)* when young, which is less than *Y(1)* since they save at a rate s,[1] in order to finance consumption *C2(2)* when old. Therefore,

[1] The rate of savings is calculated so as to maximize utility in both periods.

$$C1(1) = (1 - s)Y(1).$$

Saving are in the form of bonds and claims to physical capital,

$$sY(1) = B(2) + K(2).$$

Assuming that both physical capital and bonds yield the same net rate of return r, consumption of the first generation when old is,

$$C2(2) = sY(1) = (1 + r)[B(2) + K(2)].$$

Production in first period relates only to labor, $Q(1) = w(1)L$, while in the second relates to capital also, $Q(2) = w(2)L + rK(2)$. Each generation's utility $U_i, i = 1, 2$, is written as a function of disposable income, $U_i = U_i(Y(t))$. Substituting we get, first and the second generation young's utility,

$$U_1 = U(W - \lambda M(1) - T(1)),$$

$$U_2 = U(W - \theta(1 - M(1)) + (1 + r)T(1)).$$

The government selects the effort of mitigation *M(1)*, so as to maximize social welfare which, taking a utilitarian approach and representing the social discount factor with δ, is the sum of the utilities in the two generations,

$$SW = U_1 + U_2/(1 + \delta).$$

It is clear that if δ is very high, there will be minimal mitigation effort, while if δ is close to zero, *M(1)* will be close to one. However, intergenerational transfers can be found that improve both generations' utility. In this simple two-period model, Sachs considers a transfer $T(1) = -\lambda M(1)$, that offsets the first generation's cost of mitigating emissions. With such a transfer, the second generation's disposable income is, $Y(2) = W - \theta(1 - M(1))E - \lambda M(1)(1 + r)$. If $\theta E/(1 + r) > \lambda$, then *Y(2)* is increasing in *M(1)*. Thus, if the present value of the benefits from one unit of mitigation exceeds its cost, then clearly $M(1) = 1$, that is, all emissions should be mitigated.

In an overlapping generations model, using most of the assumptions of the above two-period model, Sachs finds such combinations of policies that allocate the cost of climate change mitigation across generations in a Pareto efficient way. That is, sets of policies that while leaving the current generation with unchanged disposable income, it improves the second generation's welfare by avoiding climate change damages. Shifting the cost of climate mitigation to future generations is justified based on the willingness of future generations to avoid much higher costs of climate change in the absence of climate mitigation in the first period.

Andersen et al. (2016) extended Sachs' simple OLG model by introducing the following three elements: first, capital in the production function, making thus interest rates endogenous,

$$y_{t+j} = H(S_{t+j})A(K_{t+j}L_{t+j}) = H(S_{t+j})AK_{t+j}^{\alpha}L_{t+j}^{1-\alpha},$$

where y is output, L is labor, K is capital, S_{t+j} is the stock of the pollutant at time $t+j$ and $H(S)$ is the damage function; second, a description of how the stock of pollution is generated, linking it to the use of capital,

$$S_{t+j+1} = (1-\epsilon)S_{t+j} + (1-\mu)G\left(K_{t+j}\right),$$

where ε is the is the speed at which pollution is absorbed by the environment, and $(1-\mu)G\left(K_{t+j}\right)$ is the pollution function; and third, a simple description of damages as function of the stock of pollution, that is, $H(S_{t+j})$. They assume that agents in each generation care about their consumption level during their retirement, while their utility decreases from working during the first period. There is no intergenerational altruism and environmental quality does not enter agents' utility function. The government, that is assumed infinitely lived, can undertake, at any point of time, costly abatement activities, which it can finance either by taxation or by public borrowing. Using this still simple, but richer than Sachs' model, they arrive at qualitatively similar to Sachs' results. In particular they find that the government can use a combination of taxes and bonds that ensures that no generation is made worse off, while some are made better off and the debt is paid off in finite time. Combining the two environmental policies (taxes and bonds) reduces pollution relative to the business as usual scenario and no generation's utility is decreasing while some generations' utility increases.

Flaherty et al. (2016) introduce a growth model, extending Sachs' discrete time model to a continuous time model which embeds the stages of the overlapping generations model into a continuous time. Abatement activities are carried out through private agents and are financed by the issuance of green bonds. While abatement reduces climate change impacts, sovereign debt increases. Future generations pay back the bonds through an income tax. The continuous time model is calibrated and the results show that through this policy, the current generation is unaffected, while abatement activities improve the environmental well-being of future generations. Gevorkyan et al. (2016) extends the analysis of Flaherty et al. (2016) by considering both a carbon tax and green bonds as funding sources to mitigation and adaptation activities. Using the Flaherty et al. (2016) continuous time growth model, they show that using a combination of taxes and bond financing, is superior to other policy choices. They also show that, as in the case of Flaherty et al. (2016), bonds are repaid and the debt is sustainable within a finite time horizon.

Orlov et al. (2018) improve further the modeling framework by introducing an explicit representation of the carbon cycle which is captured using the DICE model's representation of the effect of carbon stock on three reservoirs for carbon—the atmosphere, the upper ocean, and the lower ocean. Production, damages from climate change and the effect of abatement are modeled in a similar way to Flaherty et al. (2016). Furthermore they consider social welfare maximization instead of just proving the existence of Pareto improvements through the use of green bonds. That is, the government chooses the level of GHG abatement that maximizes social welfare, which is assumed to take the following form,

$$W(t) = \sum_{s=1}^{t} (1+\rho)^{-5(s-1)} L(s) \frac{c^{1-\alpha}(s)}{1-\alpha}.$$

The authors run five different scenarios of the DICE model that incorporates the use of bonds whose repayment value increases by a constant interest rate which is different from the endogenously determined return on capital. A scenario i is a Pareto improvement in social welfare relative to another scenario j if $W_i(t) \geq W_j(t)$ for all $t = 1, \ldots, T-1$, and $W_i(T) > W_j(T)$. They arrive at similar results as all the above-mentioned papers; namely, that the use of green bonds to finance climate change mitigation efforts leads to social welfare maximization. Green bonds smooth out distortionary taxation and the speed of the transition to low carbon economy depends crucially on the level of the interest rate.

The complexity of the problem at hand necessitates a number of assumptions both in the theoretical modeling and for the numerical solutions. All theoretical papers (Sachs 2014; Andersen et al. 2016; Flaherty et al. 2016; Gevorkyan et al. 2016) do not model explicitly the carbon cycle. Furthermore, the two papers using OLG models (Sachs 2014; Andersen et al. 2016) do not examine the social optimum but rather Pareto improvements in exogenously defined changes. Also Flaherty et al. (2016) does not consider how the exogenously determined bond issuance and repayment periods affect the social welfare function. Finally, Orlov et al. (2018), the only study that integrates a climate model using the DICE model, make a number of simplifying assumptions including a constant across time interest rate and that the effects of climate change are the same for all regions.

3.2 The need for investment to support the low carbon transition

It is evident that the transition to a low carbon economy requires large investments in low carbon and climate-resilient options in critical sectors such as energy and transport. Although there is growing interest from private investors, it would be impossible to mobilize the necessary amounts from either bank lending or private sources of debt and equity capital. Given that the largest portion of the necessary investment is needed for infrastructure projects, which are characterized by high up-front capital costs that can only be recovered over a long period, it is clear that the use of bonds in financing these projects will have to bear most of the weight.

There are many studies attempting to estimate the necessary investment in infrastructure,[2] consistent with the goal of maintaining an upper limit of 2 °C or lower to average global temperatures. The Global Commission on the Economy and Climate (GCEC) (2014, 2015, 2016) reports estimate total basic infrastructure spending between 2015 and 2030 at around $89 trillion. This estimate includes investments in energy efficiency and primary energy of around $30 trillion, in addition to basic elements of the conventional definition of core infrastructure that includes

[2] Bhattacharya et al. (2016), provide a review of some of these studies, in Sect. 3.3 which are summarized in Table 2.

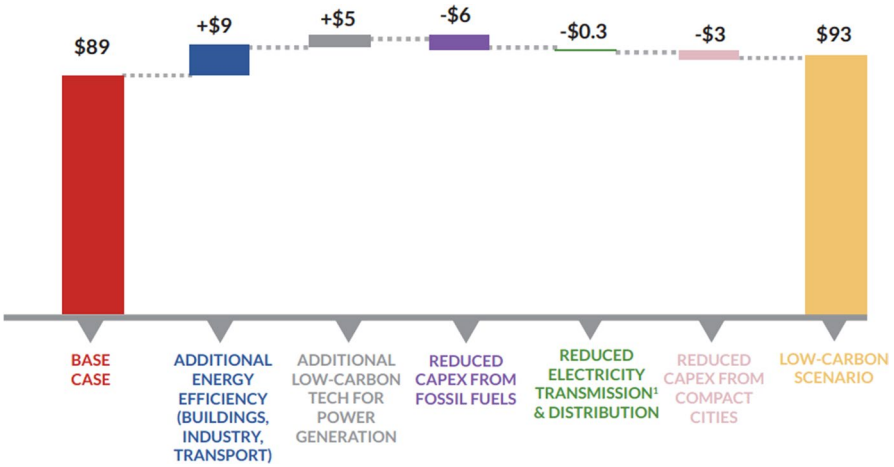

Fig. 2 Global Investment requirements, 2015–2030, US$ trillion, constant 2010 USD. *Source*: GCEC (2014)

power, transport, water and waste, and telecommunications, estimated to be around $59 trillion. Bhattacharya et al. (2016) increase the estimate for core infrastructure, mainly in emerging markets and developing countries, by about $20 trillion to $80 trillion (or around $5–$6 trillion on average per year). Regardless of the final estimate, it is clear that the global need for infrastructure investment in the next 15 years will be extremely high. The interesting part of the GCEC (2014) report is that the additional investment required to support the shift to low carbon economy is only about $4 trillion over the next 15 years, or $0.27 trillion per year on average. As illustrated in Fig. 2, this is because the higher costs of energy efficiency and low carbon energy (estimated to be about $14 trillion) are largely offset by savings from lower investment in fossil fuels, electricity transmission and distribution, and from a shift to more compact cities (estimated to about $10 trillion). Although a number of other studies increase this estimate, for example Bhattacharya et al. (2016) estimate the additional investment needs to about $15 trillion, or $1 trillion per year, it still remains a small fraction of total core investment needs.

The main challenge in this very crucial period of time that an immense renewal/addition to basic infrastructure is expected to be built, is to ensure that investment capital is reallocated from high to low carbon options. The problem is that low carbon investments, although they provide large social benefits, they involve, at least at the initial stages of the market's development, low returns, higher risks and depend heavily on policies and regulations. Thus, the necessary low carbon infrastructure investments cannot be provided by private markets without the public sector's intervention. Although bank and corporate financing has been and will continue to be an important source, it is clear that it cannot meet the very high needs for the transition, which as discussed above range between $0.27 and $1 trillion. Bond markets could play a crucial role in filing the gap and raise the necessary financing for low carbon development. OECD (2017) provides a number of reasons why bonds are the best

vehicle for both the public and the private sector to finance low carbon infrastructure. In summary: they provide an additional source of green financing to cover the immense needs in green investments; they enable more long-term financing of green projects that is otherwise difficult to attain; they promote the development of bond issuers' green strategies including improvements in their environmental risk management processes; they promote higher transparency, thus making issuers' environmental reputation an important issue; they have the potential to offer a cost advantage, that is differentiated pricing for green versus regular bonds; and they provide institutional investors, such as pension funds, insurance companies and sovereign wealth funds, new financial instruments to achieve their investment targets.

Therefore, apart from an increase in public infrastructure investment directly financed from national budgets, the necessary infrastructure could be financed by sub-national and local governments or through Public–Private Partnerships. Finance could also be provided by National Development Banks (NDBs), Multilateral Development Banks (MDB) such as the World Bank, the Inter-American Development Bank (IADB) and the European Investment Bank (EIB), or trough private finance, including pension funds, insurance companies and investment funds. Green Bonds is the most prominent financial instrument to increase the flow of private capital into low carbon, and in general environmentally friendly, infrastructure.

4 Green bonds: definition and basic elements

Green bonds, like any other bond, are fixed income securities for raising capital to finance low carbon investments, or in general environmentally friendly investments. Although OECD focused initially the discussion of green investments mainly on low carbon and climate-resilient investments (Corfee-Morlot et al. 2012), it later broadened the scope and provided, in 2016, a comprehensive definition for green bonds.

"Green bonds are debt instruments used to finance green projects that deliver environmental benefits. A green bond is differentiated from a regular bond by its commitment to use the funds raised to finance or refinance "green" projects, assets or business activities. Green bonds can be issued by either public or private actors up front to raise capital for projects or for refinancing purposes, freeing up capital and leading to increased lending." (OECD et al. 2016)

A green bond is differentiated from a regular bond by just its label, which adds an extra characteristic on top of the standard financial ones, such as maturity, coupon, price, and credit quality of the issuer. Although it seems simple, defining this characteristic and developing the necessary measurements to evaluate which investments belong to this category, it has proven to be quite a challenging task. While the necessary apparatus exists to help investors in assessing the standard financial characteristics, the same does not yet hold true for green bonds. Potential investors need to evaluate the purpose of bond issuing and to that extent they need information regarding, among others, the projects selected to be financed, the allocation of the proceeds and the mechanisms to monitor and report the projects' development through time. Although the market for green bonds exhibits high growth in the last few years, as it will be illustrated in the next Section, it requires the development

of a rigorous framework to ensure transparency and communication of information regarding the selection of projects and the effective monitoring of green bonds proceeds, in order to reach its enormous potential. Building such a framework is necessary to facilitate interactions between the issuers and investors and to maintain the credibility of the market for green bonds. We will return to this point in the Epilogue.

4.1 Green bond principles

Responding to the challenge of developing a common framework, the International Capital Market Association (ICMA), an association of 530 participants on both sides of the capital market, located in over 60 countries worldwide, among which the World Bank, issued in 2014 the first set of voluntary guidelines for green bonds. Since then, these guidelines, known as the Green Bond Principles (GBP), have been continuously developing. Although other guidelines for green bonds have also been developed in the last couple of years by different issuing authorities, such as those by the People's Bank of China (PBoC), China's central bank and capital market regulators from ASEAN countries (ACMF; 2018), GBP have achieved broad market acceptance and recognition by policy makers and regulators. Actually both the above referred efforts are based on GBP and although there are some differences, they mainly provide more specific guidance on how they are to be applied regionally. Apart from issuing authorities, similar actions are developing at the country level, such as the guidelines developed by the Japanese Ministry of the Environment (Government of Japan; 2017) and more recently the initiative of the European Commission.[3]The GBP build a framework for the provision of information regarding all stages throughout the bond's life, including the bond's launching, its evaluation by investors, and the monitoring of the proceeds' use. The 2017 guidelines develop along four core components: the use of proceeds, the process of project evaluation and selection, the management of proceeds and the reporting (ICMA 2017).

4.1.1 Use of proceeds

The most important component of green bonds is the subject of the projects financed by the proceeds. All guidelines provide a list of what they consider as green projects. The main categories include renewable energy and energy efficiency, pollution prevention and control, sustainable land use, biodiversity conservation, clean transportation and also climate adaptation. It is important that the environmental benefits of green projects are clearly presented by the issuer and if possible quantified as well, so that they can be verified by independent evaluators. The following is ICMA's list of green bonds' indicative categories:

[3] Recognizing the importance of sustainable finance, the European Commission, in 2018, set up a technical expert group on sustainable finance (TEG). One of TEG's main goals is to develop an EU green bond standard. TEG began work in July 2018 and has already provided two reports the most recent one on January 2019 (European Commission 2019).

- Renewable energy (including production, transmission, appliances and products);
- Energy efficiency (such as in new and refurbished buildings, energy storage, district heating, smart grids, appliances and products);
- Pollution prevention and control (including waste water treatment, greenhouse gas control, soil remediation, recycling and waste to energy, value added products from waste and remanufacturing, and associated environmental monitoring analysis);
- Sustainable management of living natural resources (including sustainable agriculture, fishery, aquaculture, forestry and climate smart farm inputs such as biological crop protection or drip-irrigation);
- Terrestrial and aquatic biodiversity conservation, (including the protection of coastal, marine and watershed environments);
- Clean transportation (such as electric, hybrid, public, rail, non-motorized, multimodal transportation, infrastructure for clean energy vehicles and reduction in harmful emissions);
- Sustainable water management (including sustainable infrastructure for clean and/or drinking water, sustainable urban drainage systems and river training and other forms of flooding mitigation);
- Climate change adaptation (including information support systems, such as climate observation and early warning systems);
- Eco-efficient products, production technologies and processes (such as development and introduction of environmentally friendlier, eco-labeled or certified products, resource efficient packaging and distribution).

The Green Bond Guidelines issued in 2017 by the Japanese Ministry of the Environment, adopt the same green projects categories (MOEJ 2017). The Japanese Guidelines also require the issuer to provide information regarding any incidental negative impacts on the environment that the project might have in addition to the intended benefits, and they provide a list of such negative impacts for each category of eligible projects. People's Bank of China has endorsed a list of green projects developed by the China Society for Finance and Banking in 2015 and is known as the China Green Bond Endorsed Project Catalogue (the Catalogue) (Dai et al. 2016). Although most of projects' categories included in the Catalogue are similar to the ICMA's categories listed above, there are some important differences. The critical one is that the Catalogue includes fossil fuel projects, public transport projects that use fossil fuels, while it excludes supply chain of green products or facilities.

4.1.2 Process for project evaluation and selection

The second component refers to the provision of information regarding the process for project evaluation and selection. The issuer of a green bond should provide investors with information about the following. First, the environmental objectives that she intends to achieve, for example climate change prevention. Second, the criteria for the evaluation and selection of green projects, including the category, among the above specified ones, in which the project belongs and the potential negative

environmental effects. For example, a renewable energy project that reduces CO_2 emissions could meet the objective of climate change prevention, if their negative impacts are not significant. Third, the process through which it is deemed that the proposed projects can provide environmental benefits that achieve the stated objective and meet the criteria for the use of proceeds. It is also recommended that the issuer provides information regarding the entities, internal departments or external consultants, that set the criteria, specify the process and evaluate the projects' eligibility. It is clear that as the market develops, apart from the above information released by the green bond issuer, its overall environmental reputation will play a crucial role in attracting investors. Therefore, the above three steps should be designed and followed carefully in order to build a positive profile in the market for green bonds.

4.1.3 Management of proceeds

The proceeds of the green bonds should be managed and tracked in an appropriate manner through a formal, internal to the issuer, process which should also be transparent. Green bond proceeds should be credited to a sub-account that is financially separate from other business accounts, so all transactions can be easily identified. The proceeds should be allocated to the projects as early as possible and in the event that some are left unallocated, in which case the reasons should be explained, the temporary placement of the balance should be made known to investors. To enhance transparency, the use of external auditors it is highly recommended.

4.1.4 Reporting

The final component concerns the information provided by the issuer after the issuance of a green bond regarding the status and the use of the proceeds. The disclosure of information on the use of the proceeds should be made publicly, for example, on the issuer's website, and should be updated as often as possible, at least annually, in order to enhance transparency. In most guidelines, the suggested content of disclosed information includes the following items:

- A list of the projects and the amount of the proceeds that has been allocated to each one;
- Account of unallocated proceeds and how they are managed;
- Brief description and updated information of each project's progress;
- Each project's expected environmental benefits.

The most important of the above items is the provision of information on the projects' environmental impact. The issuer should specify and use qualitative performance indicators that are consistent with the projects' objectives and criteria set in the "process for project evaluation and selection" stage. For increased transparency quantitative indicators should also be specified, when possible, and information should be disclosed regarding the methodology and data collection processes used to develop the indicators. Continuing using the example of a renewable energy

project with the objective to prevent climate change and criteria the amount of CO_2 emissions reduction, the indicators that could be specified are, the net reduction of CO_2 emissions after the implementation of the project, or the increase in the renewable energy share in total energy consumption after the project's implementation. Furthermore, information should be provided regarding the methodology of calculating the environmental benefits. In the case of CO_2 emissions reduction from a solar power generation project, the issuer should specify the formula by which the reductions are calculated, the period the calculations are concerning, detailed data on energy generation, the electricity-related CO_2 emissions coefficient, etc. In case that provision of information using quantitative indicators is difficult internally, the issuer could use external certifications. Actually, there are some sectors for which impact reporting is relatively easy, such as in the example of solar power, while for some other ones, such as the built environment and forest management, the provision of quantitative data is relatively more difficult. In such cases the use of external certification is recommended, such as those concerning the environmental impact of buildings (among which the Leadership in Energy and Environmental Design (LEED®) in USA; the Building Research Establishment Environmental Assessment Methodology (BREEAM) in UK, the Comprehensive Assessment System for Built Environment Efficiency (CASBEE), in Japan; the Haute Qualite Environnementale (HQETM), in France; and the Deutsche Gesellschaft for Nachhaltiges Bauen (DGNB), in Germany); sustainable use of forest resources (such as the Japanese Forest Stewardship Council (FSC) endorsed by WWF); sustainable fisheries (such as the Marine Stewardship Council (MSC) certification and the Aquaculture Stewardship Council (ASC)), etc.

As the market for green bonds expands and the number of green bond issuers increases, many investors and market stakeholders find impact reporting very important. Despite its obvious and increasing importance, only a minority of issuers provide some form of environmental impact reporting. Boulle et al. (2017) examined a data set consisting of 146 issuers and 191 bonds of a total amount of $66 billions, issued up to 1 April 2016, and found that the majority (in particular 74%) of bonds provided some post-issuance reporting. However, from the bonds which provided some form of reporting, only a minority of 38% included information on environmental impact. The trend though is promising, since impact reporting is increasing steadily, from just over 25% in 2013 to just below 45% in the beginning of 2017.

While impact reporting is increasingly used, there is no consistency in the quantitative indicators and the data used. There is wide variation in methodology, content and format. For the example of CO2 emissions reduction used above, some issuers use net savings while some others intensity as an indicator. Some use annual data, while some others biannual or even monthly. It is clear that as the market develops further and the demand for impact reporting is increasing, some type of benchmarking is required in order to allow comparability and enhance transparency. In this direction, an informal working group of eleven International Financial Institutions,[4]with the assistance of ICMA, developed in 2015 a harmonized

[4] African Development Bank (AfDB), Agence Francaise de Developpement (AFD), Asian Development Bank (ADB), European Bank for Reconstruction and Development (EBRD), European Investment Bank (EIB), Inter-American Development Bank (IDB), International Bank for Reconstruction and Develop-

framework for impact reporting of green projects (IFI 2015). It should be noted that the level of reporting should be reflecting the size of the issuer, since small issuers might have limited resources to produce a detailed impact report.

4.1.5 External review

To increase transparency and develop trust in the green bond market, issuers could use external review to provide an objective assessment of the project's alignment with the above stated components of the GBP. An external review is particularly important in cases that the issuer does not have the capacity and/or the expertise to provide the required information, or in cases of projects that generate negative environmental impacts, so as to certify the existence of large net environmental benefits. External reviews can be used for the entire process or specific parts of it before or after the issuance of the bond. Furthermore, there are several types of reviews, such as consultant review, verification, certification, and rating (ICMA 2017).

External reviews should be made public and they should clearly specify which aspects of the bond they have reviewed and the type of criteria they used. Given that the required expertise varies from environmental evaluation and certification to financial and accounting audits, an issuer could use more than one external reviewer. The reviewers' report should provide information on their relevant expertise.

5 The green bonds market

The market for bonds with a green label has grown rapidly in recent years. It was initiated with the European Investment Bank's "Climate Awareness Bond (CAB)" issued in 2007, which is widely seen as the first bond with a green label. Subsequently a number of Multilateral Development Banks, including the World Bank, the Asian Development Bank, and the African Development Bank, issued bonds for projects that had environmental objectives. Green bonds can be categorized, according to the issuer and in the case of private bonds according to its financial characteristics, in the following seven types: Sovereign bond: issued by a national government; Local government bond: issued by a municipal government, region or city; Supranational, sub-sovereign and agency (SSA) bond: issued by international financial institutions (IFIs) such as the World Bank and the European Investment Bank, sub-sovereign national development banks, such as the German KfW, and agency bonds issued by export–import banks; Corporate bond: issued by a corporate entity and classified based on the "use of proceeds" claim; Project bond: a bond backed by single or multiple projects for which the investor has direct exposure to the risk of the project; Asset-backed security (ABS): a bond collateralized by one or

Footnote 4 (continued)
ment (IBRD), International Finance Corporation (IFC), Kreditanstalt fur Wiederaufbau (KfW), Nederlandse Financierings-Maatschappijvoor Ontwikkelingslanden (FMO), and Nordic Investment Bank (NIB).

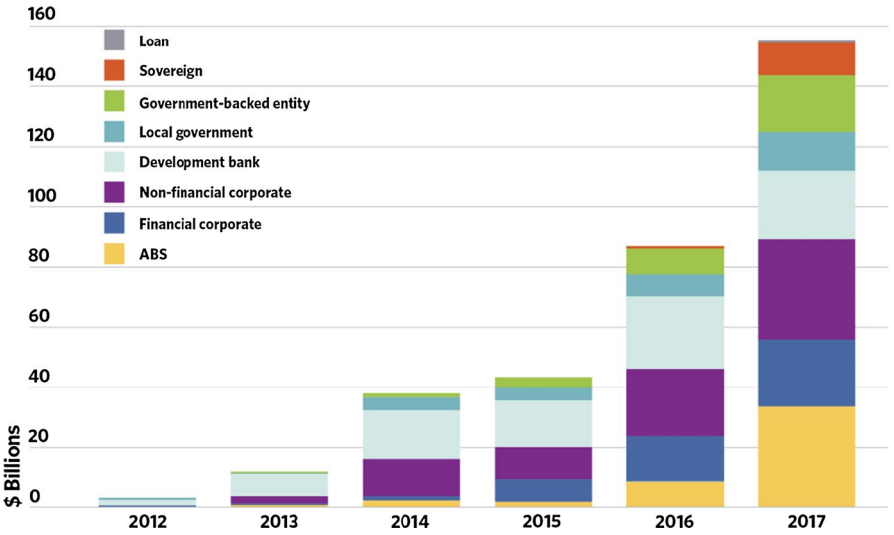

Fig. 3 Growth in the labeled green bond market. Where, ABS stands for Asset-Backed Securities. *Source*: CBI (2018)

more specific projects, usually providing recourse only to the assets, except in the case of covered bonds; and Loan: corporate bond issued by a financial institution to raise capital specifically to provide loans to green activities (OECD 2017). For the first few years after the EIB's issuance of CAB, the market was dominated by bonds issued by the SSA. As Fig. 3 illustrates, it was in 2013 that the first corporate issuers entered the market, followed by local governments in 2014.

A key catalyst for the market's development was the introduction, in January of 2014 by the International Capital Market Association (ICMA), of the Green Bond Principles, examined in detail above, which are the basis for many of the existing green labels (see ICMA 2017 for the current version). Since then, the market for labeled green bonds[5] has expanded dramatically almost doubling after each subsequent year: from $11 billion in 2013 to more than triple, $37 billion, in 2014; in 2015 the market experienced a plateau, with aggregate issuance just over $40 billion; in 2016 it surpassed $85 billion (more than 100% growth), and in 2017 reached $155.5 billion (an 83% growth), as Fig. 3 illustrates. Although expectations were high for 2018, since the first half was very strong, issuance of labeled green bond during the year reached $167.6 billion, exhibiting a significantly lower than the previous year's growth of just 3% (CBI; 2019). All reports project that green bond issuance for 2019 will exceed $180 billion potentially reaching as high as $210 billion.

There are two main positive trends in the green bonds market: geographic and project type diversity. Although the market is still dominated by few countries,

[5] The Climate Bonds Initiative (https://www.climatebonds.net/), the source of the data presented in this Section, uses the term "labeled green bonds" to denote bonds that the issuer has label them as "green".

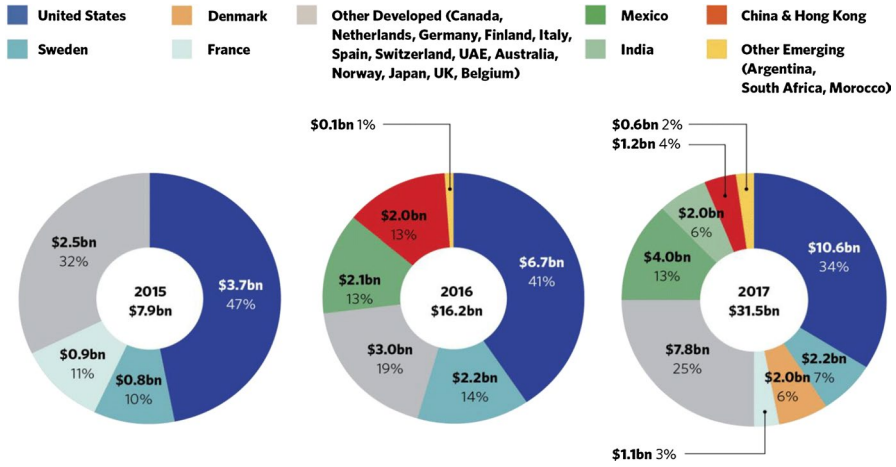

Fig. 4 Geographic distribution of green bond issuance. *Source*: CBI (2018)

predominantly by the USA, there is fast increase in geographic diversity as shown in Fig. 4. In 2017, USA, China and France accounted for 56% of issuance, with the US Agency Fannie Mae issuing a $24 billion green Mortgage Backed Security (MBS), and the French government issuing a sovereign green bond of $10.7 billion. In total, 239 issuers, from 37 countries, came to market of which 146 (60%) for the first time in 2017. Some of the new entrants came from ten countries, including Argentina and Switzerland, which never before had participated in the market.

Apart from geographic diversity, there is increasing diversity in the type of projects financed. Although renewable energy projects still attract the main part of the proceeds, their share declines (from 38% in 2016 to 33% in 2017). Low carbon buildings and energy efficiency accounted for 29% of 2017 use of proceeds, showing a substantial increase. Furthermore, allocations to low carbon transport almost doubled in volume, since a number of new rail and urban metro projects were initiated. Although the trend to finance an increasingly diverse range of projects continues, waste, land use, and adaptation themes continue to attract the smallest share of the total finance, in part due to a lack of clear definitions on which project types would qualify.

A third positive characteristic of the green bond market is the increasing participation of the public sector. Apart from the first issuance of a substantial sovereign bond by the French government noted above and the issuance of a €4.5 billion sovereign bond from the Kingdom of Belgium, the largest single deal during 2018, there is an increase in issuance from local governments and government-backed entities.

Despite its fast growth, the market for green bonds remains still a relatively small part of the total bonds market. The global outstanding bonds market was valued at approximately $97 trillion in 2014, while in the same year the new bond issuance amounted to $19 trillion (OECD; 2017). New green bond issuance in 2014 was

Fig. 5 Low carbon investment needs, new bond issuance and green bond issuance. *Source*: OECD (2017)

below, while in 2015 just above $40 billion, constituting a miniscule fraction, just 0.21%, of the newly issued bonds.[6]

Similar estimates are presented in other studies as well, with the G20 Green Finance Study Group (2016) providing an estimate below 1% and Ehlers and Packer (2017) an estimate of less than 1.6% of global debt issuance in 2016. Figure 5 illustrates the very small share of green bonds in the total newly issued bonds. The figure also presents the estimated investment needs, consistent with a 2 °C emissions pathway, in the renewable energy, energy efficiency and low emissions vehicles sectors to 2035 as estimated in IEA's 2014 World Energy Investment Outlook (IEA 2014).

As stated in footnote 2, the above discussion on the evolution of the green bond market was based on CBI's data on labeled green bonds. This categorization includes green bonds certified by CBI (a very small percentage), bonds labeled by other independent reviewers and self-labeled green bonds. However, there are bonds that, although unlabeled by their issuers, they are clearly financing green/climate assets that help enable a low carbon economy. These bonds are defined by the CBI as climate-aligned bonds and if they were accounted for, the total size of the green bonds market increases considerably. For example, CBI (2017) reports $895 billion in "climate-aligned bonds" outstanding by the middle of 2017, which includes bonds financing low carbon and climate-resilient assets or projects, of which $234

[6] Similar estimates are presented also in G20 Green Finance Study Group (2016).

billion in labeled green bonds. Thus, if more issuers label properly their bonds, the labeled green bond market could become more substantial.

5.1 Market performance

The green bond market has already been identified as "— the most developed segment of thematic, impact oriented bonds" (SBN 2018). The drivers of the green bond's market growth could be classified into financial motives, that include expected lower risks and better financial performance due, for example, to the increased transparency offered by green bonds, and to non-pecuniary motives, that is, investors' environmentally friendly preferences lead them to increase their investments in green bonds.[7]These characteristics could explain the fact that the "green" label is currently the most developed segment of thematic bonds.

From the point of view of the supply, it is clear that issuing a green bond is more expensive relative to conventional bonds, given the costs of possible certification, regular reporting, holding separate accounts for the proceeds, etc.Hachenberg and Schiereck (2018) review the literature and report that the additional costs are "… estimated to be between 0.3 and 0.6 basis points for a $500 million issue, depending on the level of work." (p. 374). From the point of view of the demand, an interesting question that arises is whether the "green" label provides a "price premium," that is, whether investors are willing to accept a lower yield spread for a green relative to a conventional bond with the same characteristics. If they do, then this premium should influence the bond's price. A number of recent studies compare the yield of a green bond to that of a conventional counterfactual and find that green bonds allow issuers to borrow at a lower price. An early study by Barclays (2015), finds a difference of 17 basis points in spreads (option adjusted spread) between green and conventional bonds as of mid-2015. The study uses a large sample (the Global Credit Index universe) to ran a regression on spreads using a variable for green bonds and some common risk factors. The study also shows that the gap in spreads increases progressively from the beginning of 2014 up to the mid-2015. Ehlers and Packer (2017) use a cross-section of twenty-one green bonds issued between 2014 and 2017, to compare their credit spreads to those of conventional bonds issued by the same organization at the closest possible date. Their results show a mean difference of around 18 basis points in spreads. Baker et al. (2018), find also that green bonds are priced at a premium, using a sample that includes 2083 green U.S. municipal bonds issued between 2010 and 2016 and 19 green U.S. corporate bonds issued between 2014 and 2016. The spread gap is estimated at roughly 6 basis points and this premium doubles or even triples for bonds that are not only self-labeled as green (and confirmed by Bloomberg) but also externally certified as green by a third party, according to industry guidelines, and publicly registered with the Climate Bonds Initiative (CBI). Zerbib (2019) uses data from the secondary market for the period July 2013 to December 2017 for a sample of 110 green bonds and finds a much more

[7] Zerbib (2019) offers a very informative review of the relevant literature.

moderate green premium of 2 basis points. Fatica et al. (2019) also find that green bonds carry a green premium which is heterogeneous across types of non-governmental issuers. They also confirm Baker et al. (2018)'s result showing that certified corporate green bonds sell for a larger premium relative to those that they are not externally certified. Bachelet et al. (2019) also find that there is differentiation in the value of green premiums, which they attribute to the bond issuer's reputation or green third-party verifications. For institutional issuers reputation is enough, while private issuers need to certify the "greenness" of the bond to achieve the premium. These results point out the importance of external certification to reduce informational asymmetries and avoid suspicion of green (bond)-washing. The literature on the issue of the existence and magnitude of a green premium is growing fast recently and includes also Hachenberg and Schiereck (2018), Gianfrate and Peri (2019) and Tang and Zhang (2019).

5.2 Market challenges

Although the market for green bonds is growing and there is evidence for continuously improving performance, there is both vast potential, given the global stock of manageable assets which in 2016 is estimated at $160 trillion (FSB 2018), and great need for investment to support the low carbon transition. However, in order to achieve the potential and cover the needs for the climate transition, a number of challenges facing the green bonds' market should be addressed. Bridging the informational gap between issuers and investors is probably the most important challenge. Providing clear green criteria and monitoring process will reduce both issuers' additional costs of certifying and contiguously communicating information regarding the green character of the proceeds' investments, and will provide investors with the required assurance of the green character of their investment. To a certain extent large issuers bear these costs using their reputation to reassure investors. However, to expand the market, there is clear need to reduce reputational risks and also involve smaller issuers. In order to move toward this direction, widely accepted, ideally universal, rules and standardization should be developed, defining green products and processes. This development should be achieved at these early stages in the development of the market so as to avoid "greenwashing" accusations that will harm the market. The development of the Green Bond Principles extensively discussed in Sect. 4.1 is a solid movement toward this direction.

Apart from the above, a number of additional challenges have been identified in the literature. A number of studies, including G20 (2016) and OECD (2017) have identified a number of challenges most of which relate to the above referred lack of "labeling." Some additional challenges listed include: lack of supply of labeled green bonds; difficulties for international investors to access local markets; and lack of domestic green investors. G20 (2016) offers various suggestions and policy recommendations to address these challenges.

6 Epilogue

Despite the fast growth of the green bond market demonstrated in Sect. 5, it is clear that it is still far from reaching the level of necessary investments detailed in Sect. 3.2. On the other hand though, there is plenty of room for further development, since the market for green bonds still remains a very small fragment of the global debt, as discussed in Sect. 5, even when unlabeled green bonds are considered. Thus, it is clear that there is huge potential for the green bond market and hope that the necessary finance will be provided for the low carbon transition.

In order to reach its potential, providing a viable instrument for substantial financial support for the transition to the low carbon economy, the green bonds market needs to address a number of challenges and barriers that currently faces. One important challenge is to widen the scope of low carbon investments that have access to the green bonds market. A significant part of low carbon investments relate to energy efficiency in buildings and other activities that are conducted by relatively small individual entities, which do not access directly the bond market. The way in which small and medium firms can gain access to the bond market could be through asset-backed securities. From the demand side of the market the main challenge is to improve the attractiveness of green bonds so as to increase the market's size. This, at least in the current state, cannot happen through financial incentives. Labeled green bonds do not carry, as of yet, a significant price premium in the primary market and the label does not improve investors' perception of the bond's credit quality. Therefore, the market's expansion could be based on public policies that reduce the risk of low carbon activities and by `mainstreaming' climate issues into financial institutions. Such policies could range from providing public institutions with mandates for green bonds, to setting green requirements into central bank collateral frameworks and instituting green quantitative easing.

The most important challenge though, is to bridge demand and supply in the green bonds market. That is, it is extremely important to further develop international guidelines and standards, so as to incentivize investing in green bonds, overcoming the lack of historic data and the risks of greenwashing. The benefits of using these international standards should be widely communicated so as to improve awareness and increase participation. Furthermore, external reviews and third-party certification should be promoted in order to improve the green bonds market's transparency and credibility. However, since for the further expansion of the green bonds market it is important that small and medium size entities participate in the market, significant consideration should be placed in reducing costs of green bonds standardization, reporting and reviewing.

References

Andersen TM, Bhattacharya J, Liu P (2016) Resolving intergenerational conflict over the environment under the Pareto criterion. CESifo Working Paper Series No. 6053, CESifo Group Munich

ASEAN Capital Markets Forum (ACMF) (2018) ASEAN green bond standards. http://www.theacmf.org/initiatives/sustainable-finance/asean-green-bond-standards. Accessed 3 Feb 2020

Bachelet MJ, Becchetti L, Manfredonia S (2019) The green bonds premium puzzle: the role of issuer characteristics and third-party verification. Sustainability, 2019, 11, 1098. https://www.mdpi.com/2071-1050/11/4/1098/pdf. Accessed 3 Feb 2020

Baker MP, Bergstresser DB, Serafeim G, Wurgler JA (2018) Financing the response to climate change: the pricing and ownership of U.S. green bonds. NBER Working Paper No. w25194. Available at SSRN: https://ssrn.com/abstract=3275327 or http://dx.doi.org/10.2139/ssrn.3275327. Accessed 3 Feb 2020

Bank of England (2015) The impact of climate change on the UK insurance sector. Prudential Regulation Authority, September 2015. http://www.bankofengland.co.uk/pra/Documents/supervision/activities/pradefra0915.pdf. Accessed 3 Feb 2020

Banque du Liban (2009) BDL environmental loans. presentation by Banque Du Liban Financing Unit. https://pdfslide.net/documents/bdl-environmental-loans.html. Accessed 3 Feb 2020

Banque du Liban (2010) Intermediate circular on reserve requirements. Intermediate Circular No. 236, Banque du Liban, Beirut. http://www.bdl.gov.lb/circulars/intermediary/5/37/0/Intermediate-Circulars.html. Accessed 3 Feb 2020

Barclays (2015) The cost of being green. US Credit Focus, September 2015. https://www.environmental-finance.com/assets/files/US_Credit_Focus_The_Cost_of_Being_Green.pdf. Accessed 3 Feb 2020

Batten S, Sowerbutts R, Tanaka M (2016) Let's talk about the weather: the impact of climate change on central banks. Bank of England, London, Staff Working Paper No. 603. http://www.bankofengland.co.uk/research/Pages/workingpapers/2016/swp603.aspx. Accessed 3 Feb 2020

Bhattacharya A, Meltzer J, Oppenheim J, Qureshi MZ, Stern N (2016) Delivering on sustainable infrastructure for better development and better climate. Brookings Institution, Washington, DC. https://www.brookings.edu/research/delivering-on-sustainable-infrastructure-for-better-development-and-better-climate. Accessed 3 Feb 2020

Blinder A (2000) Central-bank credibility: why do we care? How do we build it? Am Econ Rev 90(5):1421–1431

Boulle B, Frandon-Martinez C, Meng AX (2017) Post-issuance reporting in the green bond market. Published by the Climate Bonds Initiative. https://www.climatebonds.net/green-bonds-use-proceeds-trends-and-best-practice-report. Accessed 3 Feb 2020

Campiglio E (2016) Beyond carbon pricing. the role of banking and monetary policy in financing the transition to a low-carbon economy. Ecol Econ 121:220–230

Campiglio E, Dafermos Y, Monnin P, Ryan-Collins J, Schotten G, Tanaka M (2018) Finance and climate change: what role for central banks and financial regulators? Nat Clim Change (Perspect) 8:462–468

Carney M (2015) Breaking the tragedy of the horizon—climate change and financial stability. Speech at Lloyd's of London, 29 September 2015. https://www.bankofengland.co.uk/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability. Accessed 3 Feb 2020

CBI (2017) Bonds and climate change: the state of the market 2017. Climate change initiative. https://www.climatebonds.net/files/files/CBI-SotM_2017-Bonds%26ClimateChange.pdf. Accessed 3 Feb 2020

CBI (2018) Green bond highlights 2017. Climate bonds initiative: January 2018. https://www.climatebonds.net/files/reports/cbi-green-bonds-highlights-2017.pdf. Accessed 3 Feb 2020

CBI (2019) Green bonds: the state of the market 2018. https://www.climatebonds.net/resources/reports/green-bonds-state-market-2018. Accessed 3 Feb 2020

Corfee-Morlot J, Marchal V, Kauffmann C, Kennedy C, Stewart F, Kaminker C, Ang G (2012) Towards a green investment policy framework: the case of low-carbon, climate resilient infrastructure. OECD report. http://www.oecd.org/env/cc/Towards%20a%20Green%20Investment%20Policy%20Framework_consultation%20draft%2018-06-2012.pdf. Accessed 3 Feb 2020

Dai W, Kidney S, Sonerud B (2016) Roadmap for China: green bond guidelines for the next stage of market growth. Climate Bonds Initiative and International Institute for Sustainable Development (IISD). https://www.climatebonds.net/files/files/CBI-IISD-Paper1-Final-01C_A4.pdf. Accessed 3 Feb 2020

Ehlers T, Packer F (2017) Green bond finance and certification. BIS Quarterly Review, Bank for International Settlements, September 2017. https://www.bis.org/publ/qtrpdf/r_qt1709.pdf. Accessed 3 Feb 2020

European Commission (2019) Report on climate-related disclosures. Technical Expert Group on Sustainable Finance. https://ec.europa.eu/info/publications/190110-sustainable-finance-teg-report-climate-related-disclosures_en. Accessed 3 Feb 2020

European Systemic Risk Board (2016) Too late, too sudden—transition to a low-carbon economy and systemic risk. European Systemic Risk Board, Frankfurt am Main. https://www.esrb.europa.eu/pub/pdf/asc/Reports_ASC_6_1602.pdf. Accessed 3 Feb 2020

Fatica S, Panzica R, Rancan M (2019) The pricing of green bonds. European Commission—Joint Research Centre, paper presented at the EC conference on promoting sustainable finance, Brussels, 8 Jan 2019. https://ec.europa.eu/jrc/sites/jrcsh/files/presentation_serena_fatica.pdf. Accessed 3 Feb 2020

Flaherty M, Gevorkyan A, Radpour S, Semmler W (2016) Financing climate policies through climate bonds—a three stage model and empirics. Res Int Bus Finance 42:468–479

FSB (2018) Global shadow banking monitoring report 2017. Financial stability board. https://www.fsb.org/wp-content/uploads/P050318-1.pdf. Accessed 3 Feb 2020

G20 Green Finance Study Group (2016) G20 green finance synthesis report. http://unepinquiry.org/wp-content/uploads/2016/09/Synthesis_Report_Full_EN.pdf. Accessed 3 Feb 2020

GCEC (2014) Better growth, better climate: the new climate economy synthesis report. The Global Commission on the Economy and Climate, New Climate Economy, Washington, DC. https://newclimateeconomy.report/2014/. Accessed 3 Feb 2020

GCEC (2015) Seizing the global opportunity: partnership for better growth and a better climate. The 2015 New Climate Economy Report. The Global Commission on the Economy and Climate, New Climate Economy, Washington, DC. http://static.newclimateeconomy.report/wp-content/uploads/2014/08/BetterGrowth-BetterClimate_NCE_Synthesis-Report_web.pdf. Accessed 3 Feb 2020

GCEC (2016) The sustainable infrastructure imperative: financing for better growth and development. The 2016 New Climate Economy Report. The Global Commission on the Economy and Climate, New Climate Economy, Washington, DC. https://newclimateeconomy.report/2016/. Accessed 3 Feb 2020

Gevorkyan A, Flaherty M, Heine D, Mazzucato M, Radpour S, Semmler W (2016) Financing climate policies through carbon taxation and climate bonds—theory and empirics. https://www.santannapisa.it/sites/default/files/climate_bonds_papersemmleretaloct26_0.pdf. Accessed 3 Feb 2020

Gianfrate G, Peri M (2019) The green advantage: exploring the convenience of issuing green bonds. J Clean Prod 219:127–135

Gignac R, Matthews HD (2015) Allocating a 2 °C cumulative carbon budget to countries. Environ Res Lett 10(7), article id. 075004. http://iopscience.iop.org/article/10.1088/1748-9326/10/7/075004/pdf. Accessed 3 Feb 2020

Government of Japan (2017) Green bond guidelines, 2017. Ministry of the Environment. https://www.env.go.jp/en/policy/economy/gb/guidelines.html. Accessed 3 Feb 2020

Hachenberg B, Schiereck D (2018) Are green bonds priced differently from conventional bonds? J Asset Manag 19(6):371–383

ICMA (2017) The green bond principles 2017. International Capital Market Association. https://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/green-social-and-sustainability-bonds/green-bond-principles-gbp/. Accessed 3 Feb 2020

IEA (2014) World energy investment outlook. International Energy Agency. https://www.iea.org/publications/freepublications/publication/WEIO2014.pdf. Accessed 3 Feb 2020

IFI (2015) Green bonds: working towards a harmonized framework for impact reporting. Working group of eleven International Financial Institutions. http://www.eib.org/attachments/press/20151202-0530-finalrevised-proposal.pdf. Accessed 3 Feb 2020

IPCC (2014) Climate change 2014. Synthesis report. Fifth assessment report of the intergovernmental panel on climate change. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf. Accessed 3 Feb 2020

Kydland FE, Prescott EC (1977) Rules rather than discretion: the inconsistency of optimal plans. J Polit Econ 85(3):473–492

Matikainen S, Campiglio E, Zenghelis D (2017) The climate impact of quantitative easing. Policy paper, Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2017/05/ClimateImpactQuantEasing_Matikainen-etal-1.pdf. Accessed 3 Feb 2020

Millar RJ, Fuglestvedt JS, Friedlingstein P, Rogelj J, Grubb MJ, Matthews HD, Skeie RB, Forster PM, Frame DJ, Allen MR (2017) Emission budgets and pathways consistent with limiting warming to 1.5 °C. Nat Geosci 10:741–747

MOEJ (2017) Green bond guidelines, 2017. Ministry of the Environment, Government of Japan. https://www.env.go.jp/en/policy/economy/gb/guidelines.html. Accessed 3 Feb 2020

Murphy P, Hines C (2010) Green quantitative easing: paying for the economy we need. Finance for the future, Norfolk. http://openaccess.city.ac.uk/16569/. Accessed 3 Feb 2020

OECD et al (2016) Green bonds: country experiences, barriers and options. OECD/ICMA/CBI/China GFC. http://unepinquiry.org/wp-content/uploads/2016/09/6_Green_Bonds_Country_Experiences_Barriers_and_Options.pdf. Accessed 3 Feb 2020

OECD (2017) Mobilising bond markets for a low-carbon transition, green finance and investment. OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264272323-en. Accessed 3 Feb 2020

Orlov S, Rovenskaya E, Puaschunder J, Semmler W (2018) Green bonds, transition to a low-carbon economy, and intergenerational fairness: evidence from an extended DICE model. IIASA Working Paper. IIASA, Laxenburg, Austria: WP-18-001

Page EA (2006) Climate change, justice and future generations. Edward Elgar, Cheltenham

Sachs JD (2014) Climate change and intergenerational well-being. In: Bernard L, Semmler W (eds) The Oxford Handbook of the macroeconomics of global warming. Oxford University Press, Oxford, pp 248–259

Sustainable Banking Network (SBN) (2018) Creating green bond markets—insights, innovations, and tools from emerging markets. Prepared by IFC and the Climate Bonds Initiative (CBI) for the SBN Green Bond Working Group. https://www.climatebonds.net/resources/reports/creating-green-bond-markets-insights-innovations-and-tools-emerging-markets. Accessed 3 Feb 2020

Tang DY, Zhang Y (2019) Do shareholders benefit from green bonds? J Corp Finance. https://doi.org/10.1016/j.jcorpfin.2018.12.001

Task Force on Climate-Related Financial Disclosures (2016) Recommendations of the task force on climate-related financial disclosures. https://www.fsb-tcfd.org/publications/recommendations-report/. Accessed 3 Feb 2020

Zerbib OD (2019) The effect of pro-environmental preferences on bond prices: Evidence from green bonds. J Bank Finance 98:39–60