The Tightening Links Between Financial Systems and the Low-Carbon Transition

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Abstract This chapter investigates the implications of the policy changes triggered by the Global Financial Crisis on the transition to a low-carbon society. The immediate effects have mostly been negative: national governments have retracted from public spending and fiscal support to clean technologies; new macroprudential regulation has discouraged banks from lending to low-carbon projects; monetary policies have perpetuated the high-carbon lock-in of the economic system. However, the

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transformed macroeconomic and institutional setting, together with the increased awareness of the links between financial dynamics and natural resources, has also created new space of opportunity for low-carbon investment and financing. New concepts and policy proposals have emerged, including the 'green growth' narrative, the idea of aligning macroprudential policy to climate objectives and the suggestion to use unconventional 'Quantitative Easing' monetary policies to support low-carbon investment.

Keywords Low-carbon transition • Climate-related risks • Environmental policy • Macroprudential regulation • Quantitative easing • Green growth

JEL Classification E44 • E58 • E62 • G20 • Q43 • Q58

1 Introduction[1]

Two main channels exist connecting financial systems to the transition to a sustainable economy.[2] First, the transition needs large-scale investment, and investment needs to be financed. At present, several obstacles are preventing financial resources to flow towards low-carbon sectors. Second, the low-carbon transition and the policies aimed at supporting it are likely to have strong economic and financial implications. Moving away from fossil fuels would lead to a drop in the valuation of fossil-dependent companies, which would in turn affect the investors holding their financial assets, with potential cascade effects throughout the financial system. Both issues are complex, dynamic and linked by non-linear feedbacks.

[1] Minor portions of this chapter are based on previous work by the authors, in particular: Campiglio (2016), Campiglio et al. (2017) and Godin et al. (2017).

[2] We will use the terms 'green', 'sustainable', 'low-carbon' and 'climate-friendly' in their broad sense and employ them as synonyms to refer to investment in all sectors involved in producing goods and services with a low environmental impact, or technologies that help to reduce the environmental impact of other sectors. A non-exhaustive list includes generation of electricity from renewable sources, energy efficiency in buildings, electric vehicles and low-carbon transportation, and waste and water management. While keeping a broad perspective, we will mainly focus on climate change, climate mitigation policies and renewable energy production.

Managing the complexity of the low-carbon transition is further complicated by the current macroeconomic context. The Global Financial Crisis (GFC) has thrown the international economic system in a state of enduring turmoil characterized by low investment levels, sluggish growth and poor confidence, thus worsening the outlook for low-carbon investment. The crisis also drastically changed the global policy and institutional setting, especially in high-income countries: while a large number of national governments have retracted from countercyclical policies in an attempt to maintain balanced budgets, central banks have pursued new and unconventional policy instruments, effectively becoming the main institutions to promote macroeconomic and financial stability.

This contribution will argue that the fallout of the GFC in terms of policy implementation has, on average, had a negative impact on the prospect of a low-carbon transition: governments have reduced spending and fiscal measures in support of renewable energy sectors; the new financial regulations have pushed investors away from low-carbon investment; the quantitative easing (QE) programmes launched by many central banks have perpetuated the existing high-carbon financial lock-in.

However, the new macroeconomic setting and the renovated roles of public institutions have also created new space of opportunity for low-carbon investment and financing, as well as raised the collective awareness on climate-related financial risks and the wider links between financial dynamics, the 'real' economy and natural resources. Several new crisis-shaped narratives and proposals have been put forward. In particular, we will critically discuss the concepts of green growth, climate-aligned macroprudential regulation and green QE.

The remainder of the chapter is structured as follows. Section 2 will present in more detail the two main finance–environment links mentioned above: the need for low-carbon finance and climate-related financial risks. Section 3 will study the environmental impact of GFC-induced policies, focusing in particular on fiscal policies, financial regulation and monetary policy. Section 4 will then discuss the new opportunities for environment-friendly policies that the current context offers. Finally, Sect. 5 discusses further research directions and concludes.

2 Finance and the Low-Carbon Transition

This section will present and discuss the main systemic links connecting financial systems to the low-carbon transition. Section 2.1 will study the channels through which financial resources could flow to low-carbon sectors and the obstacles that are currently blocking them. Section 2.2 will look at the potential financial repercussions of the transition and the policies put in place to support it.

2.1 The Need for Low-Carbon Finance

Before developing the discussion, it is useful to clarify the concept of 'low-carbon'—or 'climate'—finance, as the definition is often not consistent across the related literature. Figure 1 presents the distinct stages of the investment process. At the end of the chain, there is the physical realization of the investment. This can take a number of different forms, such as large renewable energy projects, climate adaptation

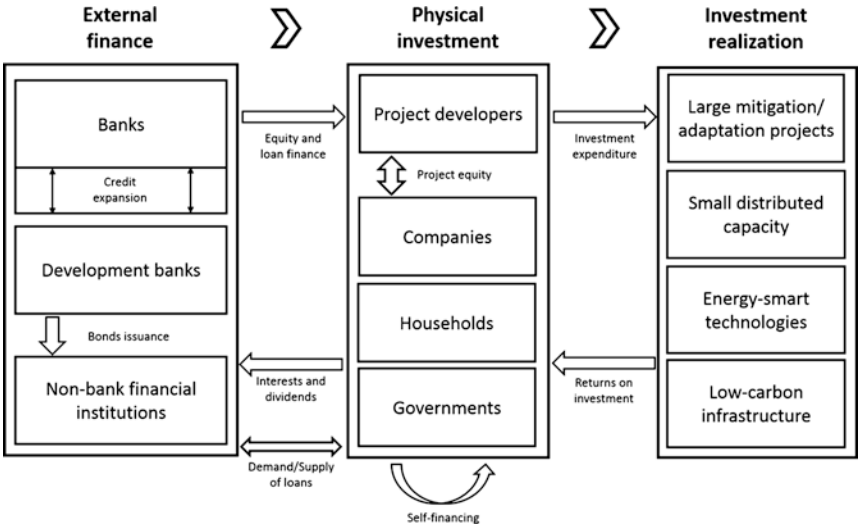

Fig. 1 A stylized representation of low-carbon investment financing

infrastructure, small renewable energy installations, new low-carbon technology, and others. Physical investment expenditure is usually carried out by private actors, such as households (in the case of small projects), project developers, utilities and other types of companies. However, these entities—as private firms more generally—usually require external finance in order to carry out the investment. For instance, in the case of renewable energy, a common funding structure is non-recourse project finance, through which a parent company—e.g. a utility company—creates a project company with the only purpose of executing and managing the project. A large proportion of funding will then actually come from a group of external investors—banks, most often—in the form of debt.

External finance (left column of Fig. 1) can come from a variety of sources: commercial banks, non-bank financial institutions (e.g. pension funds and other institutional investors), companies, public development banks or a combination thereof. Within the financial network, in turn, one can find internal chains of financing, which are however difficult to identify and categorize. For instance, the role of institutional investors in directly financing green investment is still marginal, but they might also be indirectly involved via the purchase of debt securities issued by development banks to finance lending to low-carbon companies. It is also important to recognize the special role of the private banking system in endogenously creating and allocating credit. To the contrary of what the standard view assumes—see for instance the climate investment financing chain represented in CCST (2015) —commercial banks do not have to wait for savers to make a deposit in order to be able to lend, but rather create new credit in the act of lending. They do so by expanding both sides of their balance sheet—new deposits as liability and new debt as asset—together with the balance sheet of the borrower—new deposits as assets and new debt as liability (Ryan-Collins et al. 2011; McLeay et al. 2014). Consequently, the amount of available external finance for low-carbon investment is also a function of the demand for credit by low-carbon companies.

It is useful to keep in mind this distinction when analysing the available data on current climate finance, as different data sources position

themselves at different stages of the chain. For instance, one of the most widely cited sources of data—the Bloomberg New Energy Finance (BNEF) database—aggregates 'asset finance' and 'small distributed capacity',[3] which refer to direct investment expenditure (right column of Fig. 1), together with public equity, which instead positions itself closer to the origins of external finance (a financial investor purchasing new equity of a listed low-carbon company). The 'Global Landscape of Climate Finance' report series published by the Climate Policy Initiative (CPI 2015) offers a more detailed disaggregation of financial flows, but there is a limit to how much one can disentangle the interactions among actors of the financial system.

Once the limitations of current climate finance data have been clarified, what is the available evidence on the current state of climate-friendly investment? FS-UNEP and BNEF (2016) show that the overall amount of investment in renewable energy capacity[4] has been strongly expanding in recent years, moving from 46.6 billion USD in 2004 to 285.9 billion in 2015. As can be observed in Fig. 2, however, this trend has not been free from impediments. There has been a brief stall in 2008–2009, mainly the result of the financial crisis, from which the sector recovered relatively easily. There has then been a more serious crisis in the 2011–2013 period, during which new investment dropped from 278.5 to 234.1 billion USD. This has mainly been the result of a change in the strategy of many governments concerning the support to the industry, itself a consequence of the Eurozone crisis and the austerity programmes implemented. Finally, despite 2014 and 2015 having been good years, preliminary data from BNEF (2017) seems to indicate that 2016 has seen another decline in investment.

This has been due to both the sharp decline in the cost of renewable capital, especially in solar technology, and the slowing down of the Asian markets, that still have to properly put to use the large new capacity built in past years. A similar picture is offered by CPI (2015), which, looking

[3] Asset finance refers to 'all money invested in renewable energy generation projects'; solar project with less than 1 MW are estimated separately and referred to as small distributed capacity (FS-UNEP and BNEF 2016, p. 10).

[4] FS-UNEP and BNEF (2016) data include investments in solar, wind, biomass and waste-to-energy, hydropower projects of less than 50 MW, biofuels, geothermal, wave and tidal energies.

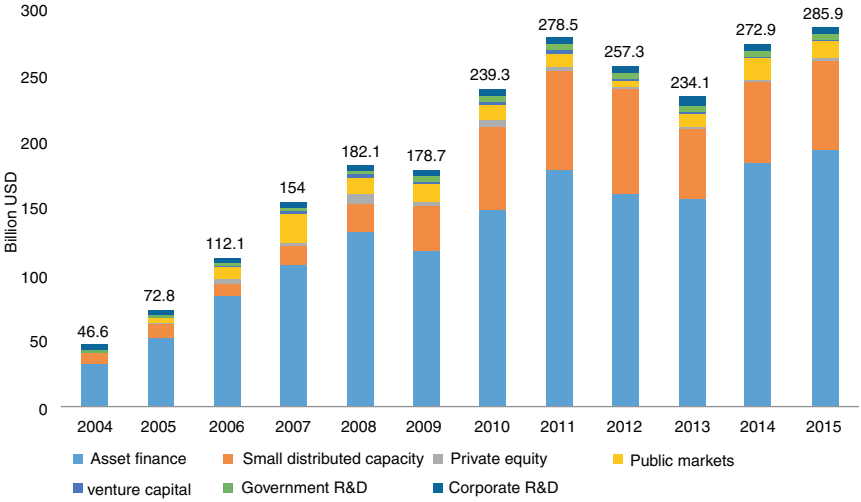

Fig. 2 New global investment in renewable energy (FS-UNEP and BNEF 2016)

at a wider universe of climate-friendly investments,[5] reports a decline in the 2011–2013 period, followed by a strong increase in 2014 to 392 billion USD.

Despite the upward trend, several estimates concur in considering current values of climate investment insufficient to steer the global economic system onto a path compatible with the 2°C degrees commitment on temperature increase agreed in Paris in 2015 (UNFCCC 2016). IEA (2015a), for instance, calculates that decarbonizing the global economic system would entail annual additional investment in the power, transportation, industry and building sectors of around 1.2 trillion USD, moving from a 2016–50 total of 318.4 trillion USD in their 6 Degrees Scenario to a total of 358.8 in their 2 Degrees Scenario. UNEP (2011) estimates the annual additional investment needed to achieve a green economy in the range of 1–2.6 trillion USD over the 2010–50 period. IPPC (2014c) reviews a number of available studies to find a median value of additional annual investment in renewable energy just below

[5] These include renewable energy, energy efficiency, sustainable transport, water and waste management, climate adaptation projects and others (CPI 2015).

100 billion USD in the 2010–29 period, and closer to 200 billion over 2030–49. Concurrently, annual investment in end-use energy efficiency in transport, building and industry would have to increase by more than 300 (2010–29) and 700 billion USD (2030–49). Investments of similar scale would also be needed in nuclear energy and fossil plants with carbon capture and storage (CCS) technology. A portion of these required additional investments could originate from the lower projected investment in fossil fuel extraction and fossil power plants without CCS. Other calculations reported by Campiglio (2016) and Olbrisch et al. (2011) provide estimates in the same range.

As argued in Bowen et al. (2014), large surges in investment levels are far from unprecedented, especially in low- and middle-income countries. At the moment, however, there does not seem to be a strong driving force that could naturally fill the green investment gap. So, where will the financial resources come from, and how will they be mobilized? A first broad dichotomy one can identify is between money coming from public institutions—such as the government, public development banks and the central bank—and financial resources coming from private actors—project developers, institutional and other types of investors, commercial banks.

Private sources represent by far the largest proportion of finance flowing to green sectors. According to CPI (2015) private finance amounted to 243 billion USD in 2014, more than 60% of total climate finance. However, if one considers that most of the remaining part (130 billion USD) comes from development banks, which raise a large proportion of their finance by issuing and selling bonds on private capital markets, the percentage of private finance on the total is probably much higher. Private actors are also the source from which the large majority of finance will have to come from in the future if the low-carbon transition is to become a large-scale process. Even in the event of abundant low-carbon government spending—not the case at the moment—it needs to be in the interest of households and firms to invest in low-carbon technologies for the transition to be system-wide.

There are different instruments and channels to match companies or project developers in search of external finance and private financial

investors looking for investment opportunities. These can be aggregated in two main categories: debt and equity. Most project-level debt comes from commercial banks, with bonds only representing a minor proportion of overall private debt finance, as well as a small portion of the wider universe of 'green bonds'. The amount of debt finance coming from public development banks is also relevant. The other option for a project or a company to be financed is through equity money. This could be the case of a utility company financing a project via own resources, or an institutional investor purchasing the new equity of a project or a company—publicly listed or not—or a venture capitalist financing the very early stages of the technology development. In order to attract the interest of larger investors, a number of yieldcos have emerged in recent years, publicly traded companies that own parts of renewable energy projects already in their operational stage. These are expected to generate stable cash flows in the long run, which are then mostly distributed to investors in the form of dividends (FS-UNEP and BNEF 2016).

However, despite the plenitude of options, most banks and financial investors are still strongly reluctant to finance the low-carbon sector. One of the main reasons for this is the high degree of perceived risk associated with renewable energy and other low-carbon activities (Frisari et al. 2013). Clean technologies are still relatively new and they have not proved themselves reliable and profitable yet. Most of them are perceived as heavily dependent on public support, as confirmed by the drop of investment experienced in 2012–13 after many national governments cut their fiscal support. Policy uncertainty is probably the single most relevant factor negatively affecting the development of the sector. The market is still relatively illiquid, thus raising exit strategy risks. There are risks related to financing and refinancing. In emerging economies, these risks are exacerbated and some additional ones are present, related to the political and social situation, the reliability of domestic financial markets, the legal framework and the characteristics of the labour market. Renewable energy projects are also usually characterized by other unattractive features such as very high initial capital costs, which also makes them more dependent on external financing and vulnerable to financing costs (Schmidt 2014).

In light of these risks, returns on green investments should be very high in order to attract investors. However, this does not seem to be the case at the moment. Ceres (2014) compares target and actual returns for a range of different asset classes. While project bonds seem to offer a return broadly in line with the ones offered in other sectors, low-carbon equity—both private and public—has performed worse than general benchmark indices. FS-UNEP and BNEF (2016) report values of all-in cost of project debt between 2.5% and 4.5% in high-income economies, which appear to be higher than the current average return on debt but possibly not high enough to attract large amounts of finance to the sector. Volatility of returns is another issue: the yieldco model mentioned above seemed to offer relatively high and stable dividend flows to investors for a while, but during 2015, their share prices plummeted and it is not clear what the future development of this asset class might be. Therefore, despite a significant expansion of 'ethical', 'sustainable and responsible' and 'impact' investment in recent years (Eurosif 2016; GIIN 2016), the large bulk of profit-driven financial investors is still to be attracted to low-carbon sectors.

The main proposed policy instrument to achieve this is the modification of the system of prices. Since most environmental goods and services do not have a price, they are usually excluded from the computation of private costs and benefits. This creates a market failure, in that the market price system is unable to take into account the 'social' costs deriving from pollution and natural resource degradation. This market failure calls for the government to intervene by modifying prices. For instance, the implementation a 'carbon price' has been repeatedly proposed (World Bank 2016). Two main ways exist to do this. The first is to introduce a tax on the carbon content of goods and services. The second is to create a cap-and-trade system of emissions allowances, such as the European Union Emissions Trading Scheme (EU ETS). In this case, policy-makers fix the quantity of allowable emissions while the price is freely determined by the market. Other price-modifying options include phasing out subsidies to fossil fuels and introducing feed-in tariffs in support of renewable energy. A comprehensive price system, capable of internalizing environmental externalities in economic decisions, should put households, firms

and financial institutions in the position of wanting to participate to low-carbon sectors.

However, two categories of complications affect this policy strategy. First, a carbon price may never be implemented. Proposals of carbon taxes or carbon markets are likely to encounter strong political and social resistance on the grounds that they will harm business and increase energy bills. Even if these policies are introduced, they may not last, or incur in major execution problems as in the case of the EU ETS. The uncertainty around the long-term policy commitment is a major obstacle for green investment as, even in the presence of the 'right' prices, firms may decide to wait to internalize them. Second, as argued in Campiglio (2016), even a stable and credible carbon price may not be sufficient to steer the required amount of economic resources to green investment. This is due to the existence of an additional market failure, related to the process of creation and allocation of credit that, under circumstances of deep macroeconomic stress, may lead investors not to react as expected to price signals and banks not to lend even in the presence of potential profitable investments.

2.2 Climate-Related Financial Risks

After having discussed the financial requirements of the transition to a low-carbon economy, we now turn to investigating the possible financial implications of climate change and mitigation policies.

Two main types of climate-related financial risks can be identified. The first is represented by the possible damages and undesired modifications to the production and consumption process brought by man-induced environmental changes. Examples of disruptive phenomena produced by climatic change include extreme weather events, coastal flooding, heavy precipitations and droughts (IPCC 2014a). These can have large impacts on the assets of households and businesses as well as on the balance sheets of their insurance companies and the commercial banks they have borrowed from (Batten et al. 2016). Dietz et al. (2016) estimate the average global value at risk due to climate damages between 2015 and 2100 in a

business-as-usual scenario to be 1.77%, but reaching 16.86% at the 99th percentile, which is equivalent to approximately 24.2 trillion USD of lost financial assets.

The second broad area of climate-related risks is represented by the potential disruption brought by the low-carbon transition itself and the implementation of policies aimed at supporting it. There are several layers of complexity here. First, the commitment of the international community to keep the increase of global temperatures below 2°C (UNFCCC 2016) will require a large portion of existing reserves of oil, gas and coal to remain in the ground, thus becoming 'stranded'. Meinshausen et al. (2009) calculate that less than half of all economically recoverable fossil reserves should be used up to 2050 to achieve at least a 50% probability of not exceeding 2°C. Carbon Tracker Initiative (2013) estimate in 762 gigatonnes the amount of CO_2 embodied in the reserves of 200 listed companies and calculate that, in order to remain below the 2°C threshold with an 80% probability, only about a fourth of these can be burnt. McGlade and Ekins (2015) estimate that around 80% of coal reserves, half of gas reserves and a third of oil reserves will have to remain unexploited. Writing off these assets from balance sheets will deeply impact fossil companies, which are among the largest businesses of the world. The FT Global 500 list of listed companies by market capitalization sees two of them (Exxon Mobil and PetroChina) in its top ten (FT 2015). In 2011, before the recent large drop in oil prices, the oil and gas producers in the top ten were five (Exxon Mobil, PetroChina, Petrobras, Royal Dutch Shell and Chevron). If one takes into account the numerous large unlisted oil companies—among which there is what is considered to be the largest company in the world, Saudi Aramco—it appears clear how stranded physical assets might produce wide systemic implications.

Second, a very large part of the economic system is at present inextricably linked to the use of fossil fuels and other polluting materials. For instance, the production of electric power, which in turn is a crucial input factor in most production processes, is still predominantly based on fossil fuels. IEA (2016) reports that in 2014 around two thirds of global electricity generation has been coming from coal (40.8%), natural gas (21.6%) and oil (4.3%). The transportation sector, which accounts

for approximately 23% of global energy-related CO_2 emissions (IPCC 2014b), is mainly centred around the combustion of oil-based products in automobiles, heavy-duty vehicles, airplanes and ships. Heating of buildings and industrial processes also usually requires substantial amounts of fossil fuel inputs. All these productive sectors could be negatively affected by a low-carbon transition, as they would have to overhaul their production technology and process, while possibly having to write off a relevant portion of their high-carbon physical capital assets.

Third, and possibly more importantly, the stranding of physical assets—both natural resources and productive capital—is likely to lead to a sharp reduction in the valuation of the companies owning them and the market price of the financial assets they have issued. This, in turn, will adversely affect the wealth of all the investors holding the devalued financial assets in their portfolios, and all the investors holding the financial assets of the latter investors and so on, with potential systemic ramifications and cascade effects throughout the whole financial network. Battiston et al. (2017) run a network-based climate stress test on the EU and US financial system to find that direct and indirect exposures to climate-relevant sectors represent a large portion of investors' equity holdings portfolios—in particular for pension funds.

The financial risks attached to the low-carbon transition have increasingly attracted the attention of central banks and other institutions responsible for financial stability—e.g. Bank of England (Carney 2015), Netherlands Central Bank (Schotten et al. 2016), Bank of Italy (Signorini 2017), Bank of France (Villeroy de Galhau 2015), Bank of Canada (Lane 2017), the Swedish Financial Supervisory Authority (Bowen and Dietz 2016), the European Systemic Risk Board (ESRB 2016) and the G20 group (GFSG 2016) —some of which have started developing methodologies to stress test their financial systems for climate-related shocks.

It is unclear whether the financial industry has also begun to acknowledge the existence of climate financial risks. The Efficient Market Hypothesis (Fama 1970) would imply that asset prices fully reflect the information available to rational profit-maximizing financial actors. If this were the case, climate-related financial risks may have already been internalized in the current price system and the absence of a decline in

asset values would suggest that financial actors simply do not believe that a firm carbon budget will be implemented.[6]

However, the picture might be more complex than this. There is a large number of concurrent reasons for which individuals operating in the financial industry may overlook and under-price climate transition risks (Silver 2017; Weber 2017). Following widespread convictions and social norms in the financial industry, they may perceive low-carbon investment just as a relatively unprofitable niche market. Their educational background may have given them limited knowledge of climate and energy issues, possibly causing them to overlook or only partially understand related news and empirical evidence, whose validity they may not be able to assess. Perhaps more importantly, the structure of incentives that investment professionals face tends to steer them away from low-carbon assets. The performance of asset managers is evaluated looking at how their short-term risk-adjusted returns compare with those offered by their peers, which drives them to hover around an established index. Deciding to drop stranded-to-be assets—usually very relevant in indices and relatively risk-free in terms of historical volatility—from their portfolios may be interpreted as excessively risky, with possibly lower returns in the short term. Asset managers will thus tend to prefer sticking to the accepted behavioural norms of their social group, externalizing longer-term transition risks to asset owners (Thomä and Chenet 2017).

A large stream of literature has now extensively argued that investment professionals, as all human beings, suffer from limited rationality and behavioural biases (Simon 1959; Kahneman and Tversky 1979; Hirshleifer 2001). Confronted with problems more complex than what they can master, individuals act following simpler 'rules of thumb' that may lead them to systematic errors. Status quo bias may lead individuals to disproportionally prefer the current state of things (Samuelson and Zeckhauser 1988). Additionally, confirmation bias may bring them to disregard new information not in line with their pre-existing system of beliefs or to interpret it in a way to support it.

[6] Stock prices of a large number of companies operating in fossil fuel sectors have indeed been declining in recent years. However, this trend seems to have been driven mainly by the large drop in fossil fuel prices since 2014, which in turn has been determined by a mix of stagnating demand, abundant supply and geopolitical reasons (Baumeister and Kilian 2016).

In a world of limited information, bounded rationality and radical uncertainty, asset prices may not fully reflect risks. Shiller (2015) argues that an 'irrational exuberance' of the financial system may lead to the overvaluation of financial assets. In the case of climate investment, we may be in the presence of a case of 'irrational apathy' (Critchlow 2015), for which a combination of behavioural biases leads the financial system to disregard climate transition risks and overprice financial assets issued by fossil or fossil-dependent industries. This 'carbon bubble', once markets internalize the perspective of a low-carbon transition (assuming this will actually take place), may have deep macroeconomic and financial implications.

3 The Environmental Implications of the GFC

This section will discuss how the new global policy context that emerged from the GFC has affected the prospects of a low-carbon transition. We will focus on public spending and fiscal policies (Sect. 3.1), macroprudential regulation (Sect. 3.2) and monetary policies (Sect. 3.3).

3.1 Public Finance and Austerity

The GFC had deep and diversified implications on public spending and policies, which in turn had relevant repercussions on the transition to sustainability. We can broadly distinguish two phases. The immediate reaction of many national governments to the financial crisis has been the design and implementation of counter-cyclical 'stimulus' packages—comprised of a mix of tax reliefs, public spending and loan guarantees—aimed at supporting employment, encouraging private spending and investment, and protecting the most vulnerable segments of the population. Simultaneously, a large international movement of opinion formed around the proposal of using the occasion to address the climatic challenge, by directing the stimulus packages towards the development of sustainable infrastructure and clean technologies. This 'Green New Deal' would have supported the economic recovery by fostering the expansion

of productive activities linked to sustainability, such as renewable energy production, modernization of buildings, the expansion of the railway system and other forms of low-carbon mobility, the development of a 'smart' electric grid and sustainable agriculture (GNDG 2008; UNEP 2009).

Indeed, most of the national stimulus packages did incorporate climate-friendly measures, although to a varying degree. Barbier (2010) calculates the green component of the global post-crisis fiscal stimulus effort at around 463 billion USD, worth approximately 15% of the overall stimulus package and 0.7% of the GDP of the countries involved. China and South Korea stood out in this ranking with a green component of 95% and 33% of the total fiscal stimulus, respectively. For both countries, the green stimulus was equivalent to approximately 3% of their GDP. Values were much lower in the EU and the United States, with green fiscal stimulus representing 0.2% and 0.7% of GDP, respectively. Although the methodology behind these calculations was contested for its crude categorization of 'green' policies (Tienhaara 2014) and some doubts have emerged on the actual effectiveness of these measures (Sonnenschein and Mundaca 2016), during this 'Keynesian moment' the idea of using public fiscal power to simultaneously address the economic and the environmental crises was largely fashionable in high-income countries.

Soon after, however, the economic narrative quickly and drastically changed. The high public deficit and debt levels, combined with low growth and sluggish employment, led a number of countries to a sovereign debt crisis, particularly pronounced in the Eurozone 'periphery' countries—Greece, Italy, Spain, Portugal and Ireland. This shifted the focus of policy-makers and international markets to strategies aimed at balancing the public budget, which led to the Fiscal Stability Treaty of the EU (EU 2012) as well as to the introduction of passages mentioning budget balance in some national constitutions—e.g. Italy and Germany.[7]

Austerity strategies can have a range of different implications on the low-carbon transition, depending on which specific policies are enacted to achieve a balanced budget. A reduction of public spending, especially if directed towards infrastructure investment, is likely to have negative

[7] The balanced budget principle was introduced in Article 81 of the Italian Constitution by Constitutional Law 2012/1, and in Article 109 of the Basic Law of Germany in 2009.

effects, as investment requirements for low-carbon technologies—e.g. a wide network of battery charging stations for electric vehicles—are much higher than those for high-carbon ones, mostly already in place and only requiring maintenance. A reduction of fiscal support can produce both positive and negative impacts, depending on which activities and sectors are deprived of public assistance: a cut in subsidies for fossil fuel consumption would accelerate the low-carbon transition; a reduction in feed-in tariffs supporting renewable energy production would hinder it. An increase in the tax burden aimed at expanding government revenues may also have diverse effects depending on the details of the policy implemented. Potentially, applying an environmental tax could be a win-win choice, as it would help fiscal consolidation while reorienting choices of households and firms towards low-carbon sectors.

Unfortunately, the actual impact of post-GFC fiscal policies have mostly been negative. The reluctance of governments to embark on large-scale expenditure programmes has negatively impacted the prospect of low-carbon infrastructure development. A wide number of countries reduced the feed-in tariffs previously introduced to support clean power production. This has also been the result of an unexpectedly quick uptake of these technologies in some countries like Italy and Germany, which accelerated the cut of the subsidies. In some cases—e.g. Spain, Romania—the measures have been retroactive (FS-UNEP and BNEF 2016). In the meantime, despite some promising exceptions, there has not been a generalized increase in environmental taxation (Bruvoll et al. 2013). The lack of public support, in combination with a paralysed credit system, led to a consistent decline in renewable energy investment for two consecutive years (see Fig. 2).

Concurrently, as argued by Geels (2013) and Scruggs and Benegal (2012), the public discourse has to some degree shifted away from climate change, sustainability and the low-carbon transition. The financial crisis and economic recession quickly occupied the main stage in the media and the public opinion attention, downgrading climate mitigation to an expensive luxury to be postponed to better times. This was also reflected in the reduced ambition of energy and environmental national strategies in many countries, reinforcing the narrative contraposing environmental action and economic prosperity.

3.2 The Environmental Implications of Macroprudential Regulation

The bursting of the subprime mortgage bubble in the United States and the financial and property-related bubbles in a range of European countries, together with the subsequent systemic economic crisis, put the financial system under the spotlight of public opinion, media and regulators. The banking system was blamed for having created massive quantities of new credit in absence of the appropriate underlying conditions. The financial system more widely was accused of having hidden these unsustainable amounts of debt using multiple layers of obscure financial instruments, while generating enormous personal profits. It became clear that gradual financial deregulation over the past decades had played a crucial role in creating the conditions for the crisis to take place.

The main post-crisis regulatory effort at the international level has been the 'Basel III' Accord, a voluntary supervisory framework formulated by the Basel Committee on Banking Supervision (BCBS). Basel III is supposed to have positive effects on both individual banking institutions, who would be more resilient to negative shocks (microprudential regulation), and the banking system as a whole, who would be less prone to systemic shocks and traumatic cascade effects (macroprudential regulation). The latter objective motivates the introduction of additional regulation for 'systemically important banks' (FSB 2016). Basel III intervenes in two main areas: (i) it raises the quality and quantity of banks' capital base and improves the coverage of risk; (ii) it increases the liquidity requirements (BCBS 2010).

Capital requirements mainly consist of a set of ratios comparing the capital base of a bank—e.g. its Tier 1 capital made of equity and retained earning—to a risk-weighted valuation of its assets. All these measures will be gradually introduced until full implementation by 2019. The rationale behind them is to avoid excessive leverage, that is, to put a limit to the ability of commercial banks in expanding their credit.

Liquidity regulation complement capital adequacy requirements by introducing two further fundamental ratios that banks need to respect: the liquidity coverage ratio (LCR) and the net stable funding ratio (NSFR). The LCR ensures that banks hold an amount of 'high-quality liquid assets' sufficient to cover their liquidity needs during a prolonged

(30 days) funding stress scenario (BCBS 2013). High-quality liquid assets are central bank reserves, cash or other assets that can be easily converted into cash on capital markets with little or no loss of value, such as sovereign bonds. These are then compared to 'total net cash outflows', that is, the expected net outflows over 30 days of funding stress. The required ratio is scheduled to gradually increase, reaching 100% in 2019. The NSFR requires banks to respect at least a 1:1 proportion between 'available amount of stable funding' and 'required amount of stable funding' (BCBS 2014) with the rationale of avoiding a maturity mismatch between assets and liabilities. The required amount of stable funding is calculated looking at the liquidity profile of the assets of the bank. Long-term (over 1-year maturity) assets are expected to be matched by liabilities of similar maturity and not short-term wholesale funding. The NSFR will become a minimum standard in 2018.

A number of analysts have argued that the new Basel III regulation, and the liquidity requirement ratios in particular, might negatively affect banks' willingness to lend to low-carbon projects (Liebreich and McCrone 2013; Narbel 2013; Spencer and Stevenson 2013; Caldecott and McDaniels 2014). The main channel through which commercial banks lend to large-scale renewable energy projects is non-recourse project finance, which in 2015 represented 52% of total 'asset finance', which in turn represented around 70% of total investment in the sector (FS-UNEP and BNEF 2016). However, holding these types of assets will worsen the capital and liquidity requirements that banks are supposed to respect under Basel III.

First, a higher degree of risk is associated with bank credit for long-maturity project finance, thus expanding the denominator of the risk-weighted capital requirements and worsening the ratio. At the same time, however, S&P Global (2016) estimates that in the 1998–2012 period, the average annual default rate of rated project finance debt was lower than the one for corporate issuers, while the loan recovery ratio was higher, thus indicating an overall creditworthiness of the asset class. Second, project finance debt certainly does not qualify as a 'high-quality liquid asset', as required to satisfy the LCR. Third, loans to renewable energy projects tend to exhibit longer tenors compared to plants fuelled by gas or coal. This is due to the higher capital costs of clean technologies (Lazard 2016) and

their different cost profile, characterized by very high upfront costs followed by much lower variable costs (Nelson and Shrimali 2014). Longer-term assets will require banks to maintain more stable sources of funding for a longer period, which comes at a cost. This may lead banks to reduce the tenor of the loan, thus making a refinancing necessary at some point in the future. This will tend to increase the perceived risk of the project.

In general, the implementation of Basel III is regarded by some as likely to produce a reallocation of investments towards liquid, shorter-term and less risky assets, while renewable energy projects are on average illiquid, long-term investments characterized by a range of technological, financial and policy uncertainties. Caldecott and McDaniels (2014) report how already European banks appear to have sold at discount prices over 11 billion USD of project finance loans to US and Japanese banks in 2012, and that more similar transactions are expected. In the meantime, tenors on project finance loans have moved from 10–15 to 5–10 years.

At the same time, however, other analyses seem to indicate that, among the criteria that a bank uses to decide whether to approve lending, the associated regulatory capital may play only a marginal role. CISL (2014), for instance, runs qualitative interviews with practitioners from a set of emerging economies and concludes that Basel III's capital and liquidity requirements would be insignificant in affecting banks' decision on whether to lend to low-carbon projects, and on what interest rate to apply. This would be consistent with the evidence that compliance of banking institutions with both capital and liquidity requirements seems to be already quite high (Cohen 2013; Gobat et al. 2014).

3.3 Quantitative Easing and High-Carbon Lock-In

The most relevant process of policy change triggered by the GFC has probably been the expansion of the range of action of central banking institutions, especially in high-income countries. After having limited their sphere of competence to the setting of interest rates for decades, the post-crisis economic stagnation and the apparent inability of national governments to implement long-term fiscal recovery programmes have led a large number of central banks to put in place 'unconventional' policy measures.

The first reaction to the crisis has been to cut the reference interest rates to levels close to or lower than zero (BIS 2013). Given the weak effects of such a move in a macroeconomic context that would have probably needed interest rates well below zero to regain confidence, they launched substantial QE programmes of purchase of financial assets. Depending on the country, these may include public sector (sovereign or supranational) bonds, asset-backed securities, covered bonds, corporate bonds, or equities. These purchases are counterbalanced in central banks' balance sheets by the simultaneous creation of a proportional amount of central bank reserves[8] that are put at the disposal of commercial banks. In other words, the central bank autonomously expands its own balance sheet by employing newly created money to purchase financial assets from banks and other financial institutions on the secondary market, with the aim of reducing financing costs, encouraging bank lending, stimulating private spending, achieving a stable rate of inflation around a pre-announced target and reviving economic growth. In the EU, QE has also been aimed at calming the financial turmoil around sovereign debt titles experienced by several Eurozone periphery countries in the 2010–2012 period. The US QE programme also served the purpose of cleaning up financial markets from corporate mortgage-backed assets and other 'toxic' financial assets (Fawley and Neely 2013).

More recently, some central banks have expanded the range of assets eligible for purchase to debt securities issued by private companies. The European Central Bank (ECB), in addition to its ongoing purchases of covered bonds and asset-backed securities, began buying corporate bonds in June 2016 under its Corporate Sector Purchase Programme (CSPP) (ECB 2016a). As of the end of March 2017, the ECB had already accumulated €75 billion worth of corporate bonds. In September 2016 the Bank of England launched its Corporate Bond Purchase Scheme (CBPS), with the aim of purchasing "a portfolio of up to £10bn of sterling bonds representative of issuance by firms making a material contribution to the UK economy, in order to impart broad economic stimulus" (BoE 2017a).

[8] Central bank reserves are accounts that commercial banks hold at the central bank and use to settle interbank transactions.

In theory, QE is meant to act as a lever operating on the economy as a whole, leading to asset price increases across the board. This would decrease the cost of borrowing and encourage additional debt issuance, thus increasing investment and the rate of inflation, and contributing to overall economic growth. In practice, however, a large amount of research on the topic seems to support the proposition that QE may have unintended sectoral effects due to frictions in the market and a lack of substitutability between assets (Krishnamurthy and Vissing-Jorgensen 2011; IMF 2013; Rogers 2014; Nassr et al. 2016). Thus, despite their 'neutrality' intentions, both the ECB and the Bank of England may create unintended market distortions through their purchase strategies due to imperfections in the transmission channel, with relatively more benefit for the assets being purchased relative to other assets. Even allocating purchases according to the makeup of the market, or the economy, is a decision to maintain the status quo—and so one could argue is not truly 'neutral' in that it reinforces existing market distortions compared to the socially optimal distribution of capital.

It is unclear what the implications of QE on the low-carbon transition might be in the case of purchase of sovereign bonds (the allocation of raised finance depends on government budget strategies), covered bonds and asset-backed securities (too little information on these purchase programmes is disclosed). A more detailed assessment can be performed on the purchase of corporate bonds, for which more information is available. Campiglio et al. (2017), for instance, study whether QE programmes may have had unintended negative consequences for low-carbon sectors, focusing in particular on the CSPP programme of the ECB and the CBPS programme of the Bank of England. The analysis suggests that, as the schemes currently stand, the purchases are allocated to high-carbon sectors in disproportionately large amounts relative to the sector's contribution to the European economy.

4 Opportunities from New Policy Settings

In Sect. 3, we have argued that the changes in the global policy setting triggered by the GFC mostly had negative effects on the prospect of a low-carbon transition. Public investment in sustainable infrastructure

and fiscal policies in support of renewable energy investment have been cut as part of the austerity strategy; new financial regulation has penalized low-carbon assets because of their illiquid and higher riskiness features; the recently adopted unconventional policies have perpetuated the high-carbon financial lock-in.

At the same time, however, this same context has generated new concepts and policy proposals to be experimented in the pursuit of a sustainable economy. The increased awareness around the repercussion of financial dynamics on socioeconomic systems has led to a renovated interested in understanding and addressing the links between finance and the environment. We will argue that these new ideas could not have been developed without the financial crisis taking place, or at least not at the same speed. We will in particular focus on three of them: the green growth paradigm (Sect. 4.1), climate-aligned macroprudential regulation (Sect. 4.2) and green QE (Sect. 4.3).

4.1 The Green Growth Paradigm

The economic context created by the GFC has been the perfect *milieu* for the quick development of the 'green growth' concept. For a long time the main keyword in international environmental policy-making and research has been 'Sustainable Development' (SD), famously defined in the Brundtland Report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). As argued in Jacobs (2012), the discourse around sustainable development, while successful in bringing resources and the environment to the attention of the international public opinion, was putting forward a narrative that focused excessively on the sacrifices to be made in the name of sustainability. The effort towards environmental protection was mainly presented as a necessary drag on economic prosperity, and thus inherently unattractive to policy-makers.

This narrative could not survive intact the trauma of the financial crisis, after which the public discourse quickly shifted away from the environment and towards more pressing economic and financial issues (Geels 2013). This represented the ideal trampoline for the emerging green growth narrative to become mainstream since it delivers a powerful,

attractive message at times of crisis: economic prosperity and environmental sustainability are not only compatible; they are mutually reinforcing. In times of protracted 'secular' stagnation (Teulings and Baldwin 2014), investing resources in low-carbon sectors could be just what is needed to simultaneously achieve a sustainable society and a prosperous economy (Bowen 2014).

The first incarnation of the green growth paradigm has been the push for incorporating green elements in the post-crisis stimulus packages, already discussed in Sect. 3.1. The concept survived the radical turn of many countries to austerity strategies and quickly established its roots in all major international development institutions (OECD 2011; UNEP 2011; World Bank 2012). The core policy tenet of green growth is to correct the market failure related to the absence of environmental goods from the price system, which leads households, firms and financial investors not to value them at their 'true' social cost. This can be achieved in three main ways: (1) the introduction of an additional price on the polluting content of goods and services (e.g. a carbon tax to disincentive the production and consumption of carbon-intensive goods); (2) the implementation of subsidies in support of renewable energy production and other forms of clean technologies (e.g. feed-in tariffs); (3) the elimination of public subsidies currently supporting the consumption of fossil fuels. A carbon price in turn can be introduced either through an additional tax or through the creation of a market of emission permits (World Bank 2016). The combination of these fiscal measures should be able to radically modify the structure of incentives faced by consumers, producers and investors, steering them away from high-carbon technologies and processes (NCE 2014).

Raising a carbon tax is broadly in line with budget consolidation and strategies aimed at limiting public deficit, as it would ensure fiscal revenues for the government, possibly very large ones. In 2014 environmental taxation in OECD countries represented on average 5% of the overall amount of fiscal revenues, equivalent to 1.56% of GDP (OECD 2015). Values ranged from the 0.06% of GDP in Mexico to 4.11% in Denmark. Carbon pricing is expected to sensibly expand environmentally related fiscal revenues. Bowen et al. (2014), for instance, use two Integrated Assessment Models (IAMs) to estimate 2°C-compatible car-

bon tax revenues in the order of 2–6% of global GDP by 2030. Carbon fiscal revenues within each region would be sufficient to finance total investment in energy supply. Similar considerations apply to the auction of emission permits, although these are often distributed for free to firms participating in the schemes, thus providing no benefit to public budgets. Another often-cited measure that could help consolidation objectives, but similarly controversial for its distributional effects, is the phasing out of subsidies to fossil fuel consumption. IEA (2015b) estimates global subsidies to fossil fuels in 2014 at 493 billion USD, while Coady et al. (2015) calculate overall energy subsidy costs—including local air pollution, climate change and other externalities—at around 5.3 trillion USD in 2015, equivalent to 6.5% of global GDP. Saving money from direct fossil fuel subsidies and indirect health and pollution costs produced by fossil consumption would certainly improve public fiscal position, while improving the prospects of a low-carbon transition.

However, higher taxation and reduced public subsidies, while possibly positive for public budget balances, may have negative economic and social implications. For instance, imposing a 2°C-compatible carbon tax could seriously affect business and consumers, increasing the price of energy and forcing them to quickly transition to clean technologies while not prepared to do so. Eliminating fossil fuel subsidies, on the other hand, could have negative repercussions on the lower-income parts of the population, which benefit from the subsidies in terms of improved access to energy. As a consequence, these measures have often been opposed and in certain occasions they had to be retracted due to protests and social unrest (OECD 2013). However, governments could relatively easily solve this issues by implementing complementary fiscal policies aimed at using carbon tax revenues to decrease taxation on labour or investment spending, or to increase public transfers to households negatively affected by the phasing out of fossil fuel subsidies, thus obtaining a *double dividend* (Goulder 1995).

While attractive, the idea has received numerous critiques. Some have criticized it as a mere continuation of business as usual, as it does not propose a reform of those fundamental features of the current economic system that have led to the financial and environmental crises in the first place (Lander 2011). Others have raised doubts on the actual likelihood

of an absolute decoupling between economic growth and environmental degradation (Antal and Van Den Bergh 2016; Ward et al. 2016). What is relevant for the purpose of this work is, however, that the GFC has strongly accelerated the development and diffusion of the Green Growth paradigm, and this in turn has been instrumental to keep sustainability at the centre of policy-making and media attention despite the concurrent economic crisis.

4.2 Climate-Aligned Financial Regulation

As discussed in Sect. 3.2, the international financial regulation framework designed after the GFC could be steering bank lending away from low-carbon activities due to their illiquidity, long-term investment perspective and high perceived risk. However, the existence of a possible threat to financial stability coming from climate change has increasingly been recognized and studied (see Sect. 2.2). This has led some commentators to propose including environmental considerations into macroprudential regulation, so to avoid undesired side effects on low-carbon investment while simultaneously protecting the financial system from climate-related risks.

Rozenberg et al. (2013), for instance, argue for the introduction of differentiated reserve ratio requirements directed in favour of green sectors. Reserve ratio requirements relate the amount of reserves that banks possess—either in the form of cash kept in their vaults or as deposits held at the central bank—to the stock of their clients' deposits. The reserve ratio is a form of liquidity requirement and gives an indication of how resilient a bank would be to an unexpected withdrawal of funds from its clients' deposits. Differentiating reserve requirements means to impose different reserve requirements, depending on the destination sector of lending. In the case of *green* differentiated reserve requirements, the reserve ratio that banks have to satisfy would be lower than average for loans directed towards low-carbon sectors. Given that banks obtain their profits from lending, and that a lower reserve ratio expands the potential amount of credit that a bank can create, this policy should give an incentive to banks to direct a larger amount of lending towards green investment.

A similar scheme—called 'National Energy Efficiency and Renewable Energy Action' (NEEREA)—has recently been implemented in Lebanon (Banque du Liban 2010; PWMSP 2011). The scheme aims at providing cheap credit to the private sector for projects related to renewable energy production and energy efficiency in buildings. If the commercial bank decides to accept the loan request, the firm presents a technical study of the project, which is assessed by the Lebanese Center for Energy Conservation (LCEC), an agency affiliated to the Lebanese Ministry of Energy and Water. If the project is approved, the Lebanese Central Bank provides its support by reducing the bank's obligatory reserve requirements by an amount equal to 100–150% of the loan.

Campiglio (2016) analyses this policy proposal in light of central banking operational frameworks. In many high-income countries, reserve ratios are in fact not likely to be effective as a constraint on bank lending behaviour, for at least two reasons. First, availability of reserves is currently far from being a problem for banks since central banks have inundated the interbank market with new liquidity through the QE programmes. Additionally, and most importantly, in most modern banking systems, central bank reserves are not capable of acting as a strong constraint, even in non-extraordinary circumstances. This is due to the fact that most central banks in high-income in recent decades have preferred to use the reference interest rate—that is, the price of reserves—rather than the quantity of reserves as their main policy instrument.

The manipulation of the reference interest rate helps the central bank to have a better control on the interbank lending rate, which is the interest rate at which banks lend to one another. However, this leaves the determination of the quantity of reserves out of the control of central banks: if the objective is to keep the price of money in the interbank market around a certain range then central banks have to satisfy any demand of reserves coming from the banking market. Denying new reserves to banks in moments of liquidity stress would automatically put pressure on the price of reserves on the interbank market, putting the interest rate out of the control of the central bank. Therefore, in high-income economies where central banks give themselves as a priority the stability of the interbank rate, reserve requirements cannot act as a constraint.

Things might work differently in emerging economies, where central banks are willing to let the interbank rate fluctuate more, in exchange of a stronger control on the quantity of reserves. This is supported by the evidence that, while high-income countries have abolished or gradually reduced reserve requirements to very low levels (Gray 2011), many emerging economies have often used reserve requirements and a wide range of other macroprudential tools in recent years (Lim et al. 2011; Cerutti et al. 2017). A non-exhaustive list of policy tools includes liquidity and capital requirements, caps on the loan-to-value ratio, caps on debt-to-income ratio, ceilings on credit growth, restrictions on profit distribution, and many others. The People's Bank of China is also using 'dynamic' differentiated reserve requirements, for which required reserve ratios are different across banking institutions depending on their size, their financial conditions—for instance, their capital adequacy ratio—and the sector they operate in (Ma et al. 2013).

Another option could be to focus on capital adequacy ratios and incorporate environmental, social and governance (ESG) criteria into asset risk assessment for risk-weighted capital requirements. In particular, introducing considerations linked to climate and carbon emissions would reflect the increasing concern around climate-related risks to financial stability. As discussed in Sect. 3.2, loans to low-carbon infrastructure projects would now appear as unfavourably risky on banks' balance sheets, thus possibly leading them to drop these assets in favour of more liquid, standardized assets, which are, however, unlikely to provide a comparable protection against climate damages. Differentiating capital requirements depending on the type of lending that banks provide, or attributing lower risk weights to low-carbon assets, could correct this high-carbon bias and fruitfully manage to direct larger flows of new credit creation towards them.

These policies may appear very far from the usual central banking practice in high-income countries. However, the vast majority of advanced economies have implemented some form of macroprudential policy at some point in the past. Elliott et al. (2013) review the long history of macroprudential instruments employed by the United States throughout the last century to promote or curb credit growth, often with specific sectors in mind (housing, for instance). These included underwriting

standards, reserve requirements, deposit rate ceilings, credit growth limits, supervisory pressures and other policies, which have helped public authorities in their attempt of moulding the shape of the American economic system.

The use of macroprudential policy to encourage additional green investment would, however, mean diverting the policy tool from its primary objective of addressing systemic financial risk. While this has been done before, for example with preferential regulatory treatment for loans to small and medium enterprises (SMEs) in the EU, it would be predicated on such assets being provably of lower risk—either due to being 'future-proofed' against transition risk or if backed in some way by government support; for example, the way the European Investment Fund has been supporting financing to small businesses, such as loan guarantees (EBA 2016). Otherwise, there could be the risk of encouraging excessive investment in green projects, which then fail to provide investor returns, and thus creating an undesirable trade-off between financial stability and environmental sustainability (CISL 2014). Caution should be used in implementing these measures and a process of monitoring put in place, so as to promptly correct the strategy in case the formation of a 'green bubble' is detected.

4.3 The Role of Central Banks: A Green QE?

As already discussed, the GFC has triggered an unprecedented expansion of central banks' range of action in high-income countries. Far from limiting themselves to setting the reference interest rates, they have embarked on ambitious QE programmes of financial asset purchases. QE programmes involve two main aspects. First, a certain amount of financial assets is purchased. Sovereign bonds represent the large majority of holdings, but as shown in Sect. 3.3, private assets are also being bought. Second, new liquidity—that is, central bank reserves—is created and put at the disposal of commercial banks, in the hope that these will in turn increase lending to the real economy. However, lending conditions took a long time to recover and, despite recent improvements, they are still far from the pre-crisis situation (BoE 2016; ECB 2017). Additionally,

there is no evidence that whatever credit is created by commercial banks is flowing to low-carbon sectors. Therefore, neither of the two aspects of QE seems to be helping societies in facing the urgent and systemic challenge of climate change and the transition to a sustainable economy. To the contrary, the analysis performed in Campiglio et al. (2017) suggests that, if anything, current QE schemes may be perpetuating society's high-carbon lock-in.

This has led some to propose reoriented QE programmes so to support low-carbon sectors more directly through the purchase of 'green' assets linked to climate-friendly investment—a 'Green Quantitative Easing' (Murphy and Hines 2010; Werner 2012; Anderson 2015). As part of their ongoing programmes of financial asset purchases, central banks could buy on the secondary markets assets that are linked to the realization of low-carbon projects. 'Green bonds'—debt securities whose proceeds are earmarked for specific environment-friendly uses—represent one example of such assets in rapid expansion (CBI 2016). Green bonds can be issued by private firms, governments, public development banks and other actors.

Purchasing green bonds issued by development banks would probably be the most effective and least controversial way of implementing a green QE. Public development banks are financial institutions devoted to supporting the process of national or regional economic development, often providing credit to activities that commercial banks are unwilling to finance, or on more favourable terms. Both national and multilateral banks[9] have become one of the most prominent actors in climate finance (CPI 2015; FS-UNEP and BNEF 2016). They also appear to be instrumental in delivering finance to the riskiest renewable energy projects (Mazzucato and Semieniuk 2016). As part of its Public Sector Purchase Programme (PSPP), the ECB is already purchasing debt securities emitted by 'supranational' entities, which include both international/regional institutions located in the euro area—European Investment

[9] National development banks include, to cite some of the largest, the China Development Bank (CDB), the German Kreditanstalt fur Wiederaufbau (KfW) and the Brazilian Banco Nacional do Desenvolvimento (BNDES). MDBs include the European Investment Bank (EIB), the International Bank for Reconstruction and Development (IBRD), the International Finance Corporation (IFC), the Asian Development Bank (ADB) and others.

Bank, Nordic Investment Bank and others—and national agencies and development banks—KfW in Germany, Caisse des Dépôts in France and many others.[10] As of the end of March 2017, the holdings of supranational assets amounted to 162 billion EUR, out of a 1481 billion total of PSPP holdings.

Therefore, it is possible that the ECB could already be implementing an indirect and unplanned form of Green QE through the purchase of, for instance, EIB's bonds whose proceedings are then used to finance low-carbon projects. This could be made explicit and expanded (Anderson 2015). The President of the ECB, Mario Draghi, confirmed that, while not allowed to buy EIB bonds on the primary market, the ECB could certainly buy green bonds issued by the EIB on the secondary market, provided they comply with the ECB rating standards (EU Parliament 2015).

However, the execution of such a suggestion using bond purchases would be currently constrained. First, EIB loans are limited to 50% of a project's financing, meaning that an increase in lending by the EIB would need to be matched by additional funding from private banks or EU grants. Second, many development banks are constrained in their lending by predetermined leverage ratios. The banks of the World Bank group and other multilateral development banks (MDBs), for instance, usually cannot lend more than 100% of their total subscribed capital (plus reserves and retained earnings). In the case of the EIB, mainly lending to high-income European countries, the value is 250%. However, all of them sit very comfortably below this statutory ceiling. Just considering actual paid-in capital,[11] the equity/loan ratio of MDBs tend to be much higher than their private counterparts (Humphrey 2015). Their traditionally conservative capital management, together with the difficulties experienced in raising further capital from subscribing states, limits the amount of lending available. Third, public development banks lack one

[10] The complete list of eligible supranational entities can be found at this link: https://www.ecb.europa.eu/mopo/implement/omt/html/pspp.en.html.

[11] There are two types of capital base in MDBs: (i) paid-in capital (plus reserves and retained earnings) and (ii) 'callable' capital, guaranteed by governments in times of crisis. The share of paid-in capital has been gradually shrinking in all MDBs (Humphrey 2015); governments prefer to offer callable capital, as it doesn't involve any actual budgetary disbursement.

of the most crucial characteristics of banks: the ability to autonomously expand their own balance sheets. The power of creating credit through the act of lending is in fact forbidden to development banks, which have to limit their lending to the amount of finance they raise on the secondary markets through the issuance of bonds.

Disregarding the fact that it is in fact already happening, arguing for central banks to purchase public development banks' bonds would still probably be considered by some as an excessive intrusion of central banks into what should be the responsibility of elected governments. However, as unconventional this proposal may appear, it is not unprecedented. At the end of World War II, the Canadian Central Bank created an Industrial Development Bank (IDB) aimed at supporting the small and medium enterprise sector. The IDB—which in its 31 years of operations lent money to approximately 50,000 businesses—was entirely financed by the Central Bank, which purchased the whole amount of bonds issued by the IDB through the creation of new reserves (Ryan-Collins et al. 2013). More recently, far from aiming for neutrality, the Federal Reserve deliberately targeted mortgage-backed securities in order to "provide support to mortgage and housing markets" (New York Fed 2010) and thereby increase bank lending to households. Targeted longer-term refinancing operations (TLTROs) conducted by the ECB have had the aim of increasing lending to the real economy, and it explicitly excluded financial corporation and loans to households for house purchase (ECB 2016b). The Bank of England's Funding for Lending Scheme has targeted household lending (until November 2013) and lending to small and medium enterprises (BoE 2017b). The Central Bank of Bangladesh has set up a refinancing facility expressly targeted to projects in the field of renewable energy (Barkawi and Monnin 2015).

Central banks could also use their collateral framework to support assets issued by low-carbon firms or linked to low-carbon projects. As part of their standard monetary policy frameworks, central banks lend liquidity to banks only against adequate collateral (Nyborg 2017). The rules regarding the type of assets that are eligible as collateral at the central bank have a clear impact on banks' asset preferences, and low-carbon project assets tend not to be eligible. A 'haircut' is then applied to the market value used as collateral, which usually depends on their rating and

maturity. In this context, including ESG consideration could decrease the haircut applied to low-carbon sustainable assets, so that banks would have a relatively higher willingness to hold them and use them as collateral at the central bank.

Different central banking frameworks adopt different strategies. The People's Bank of China (PBC), for instance, exerts a sort of soft pressure—called 'window guidance'—on the banking system, for instance by holding monthly meetings with commercial banks to make sure that the allocation of credit across sectors follows the Central Bank's strategic plans. The Chinese window guidance framework has focused extensively on low-carbon sectors, which are considered one of the most important priorities for the country's development (Xian and Liping 2015). PBC (2013), for instance, states that "financial institutions were guided to intensify support …. to sectors crucial for economic and social development such as …. energy conservation and emissions reduction" and that "credit support to industries with high energy consumption and high emissions and industries with an overcapacity needs to be controlled" (p. 15). The China Banking Regulatory Commission (CBRC) also published a document presenting the 'Green Credit Guidelines', in which it is stated that "banking institutions shall promote green credit from a strategic height, increase the support to green, low-carbon and recycling economy, fend off environmental and social risks, and improve their own environmental and social performance" (CBRC 2012).

5 Conclusions and Further Research

Transitioning to a sustainable economic system will have multiple and diverse implications for the financial system. For the transition to ever take place, physical and financial investments must be reallocated towards productive activities that help decarbonizing the economy. The market drivers of the transition—e.g. the rapid decrease in the cost of renewable energy technologies—will play a crucial role in raising the interest of firms and financial investors but they will probably need to be complemented by public policies in order to respect the 2°C threshold

in temperatures increase. Both market and policy drivers, while pushing financial resources in the direction of green investment, may have undesired negative effects on financial stability triggered by the process of writing off carbon-intensive assets. The responsibility of public institutions—governments, central banks, financial regulators—is thus to achieve the fine balance that will deliver a quick but smooth transition.

In this context, this chapter has tried to investigate what have been the implications of the GFC on the prospect of a low-carbon transition, and in particular on the policies aimed at supporting it. We have argued that the immediate effects, while not strong enough to halt neither the expansion of green sectors nor the related policy effort, have mostly been negative. National governments, after an initial fiscal stimulus incorporating green components, have retracted from public spending and fiscal instruments in favour of clean technologies due to the adoption of balanced budget strategies and a stronger focus on growth and employment issues. The international financial regulation framework introduced with the Basel III Accord has worsened the incentives for banks to lend to renewable energy projects. Unconventional monetary policies launched by many central banks as a reaction to the crisis appear to have perpetuated the lock-in of the economic and financial system into high-carbon sectors.

However, the profound change of the global policy and institutional setting has also created space for new concepts and proposals. Sluggish growth and low employment levels have favoured the development of the green growth narrative, which argues for the introduction of carbon pricing and other instruments aimed at decarbonizing the economy while letting it expand. The concept is likely to be more appealing than 'sustainable development' to both policy-makers and market forces, although it still has to prove itself as a realistic strategy. The process of regulation of the financial system, combined with the possible bias against low-carbon investment, has led to the proposal of using macroprudential policy in order to incentivise bank lending to green sectors. Finally, given the unprecedented level of intervention of central banks, it has been suggested that QE programmes could be reoriented so to purchase assets that help supporting the low-carbon sectors, possibly including public development banks in the process.

A comprehensive and coordinated set of policies will have to be designed and implemented in order to address in an integrated manner the issues raised by climate change and the low-carbon transition. However, policy-makers currently lack the appropriate assessment tools. Despite the relevance of the topic, models connecting macroeconomic, financial and climatic issues in an integrated way are still rare.

The standard modelling frameworks in both climate economics and macroeconomic/monetary economics—IAMs and Dynamic Stochastic General Equilibrium (DSGE) models, respectively—do not currently appear up to the task of investigating the complexity around climate–finance interactions. Among other relevant shortcomings (Farmer et al. 2015), IAMs offer an excessively simplistic supply-side treatment of the economic system, usually depicted as an aggregate sector driven by exogenous trends and the intertemporal maximization of consumption by a representative agent, with no representation of financial variables and institutions. DSGE models, on the other hand, usually abstract from the biophysical basis of the economy, and the rare exceptions (Golosov et al. 2014; Annicchiarico and Di Dio 2016) do not provide an explicit representation of the banking and financial sector. They are also incapable of producing endogenous climate-related financial dynamics; that is, they rely on some kind of 'shock' to perturb the system populated by forward-looking optimizing representative agents and then smoothly move from one equilibrium to another. More, in general, DSGE models have come under heavy criticism for their inability to properly represent banking, credit and financial variables—as highlighted by their powerlessness in the wake of the financial crisis—and their links with the wider macro dynamics (Romer 2016).

More promising results can be expected by two non-neoclassical methods: agent-based models (ABMs) and stock-flow consistent (SFC) models. ABMs simulate the economy as complex evolving systems populated by a large number of agents and institutions interacting among each other according to distinct behavioural rules, not necessarily rational or forward-looking. SFC models usually represent the economic system as a set of interacting aggregate sectors, with a particular focus on the real and financial transactions linking them. Compared to ABMs, the degree of disaggregation in SFC models tends to be lower, but the physical and

financial interactions between sectors are better specified and the policy implications of results of easier interpretation. The insights into macro-financial booms and busts offered by these methodological approaches led policy-makers to start developing research around them—see, for instance, the work by the Bank of England (Burgess et al. 2016; Turrell 2016).

While traditionally applied to macroeconomic problems, the two approaches share a set of features that makes them particularly attractive for modelling climate-related risks. They are both able to move away from the simplistic assumptions of both IAMs and DSGE models to provide a more systemic and realistic description of socioeconomic systems, with a particular focus on balance sheet interactions between agents or sectors. They are indicated for studying non-linear behaviours, amplification effects, path dependencies and emerging properties, and they are not forced to rely on equilibriums. Thus, while still young (Balint et al. 2016; Dafermos et al. 2017; Godin et al. 2017), this stream of literature could soon shed more light on the dynamic interactions between financial and environmental systems, the relevance of which was so clearly highlighted by the GFC and its aftermath.

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