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Fostering green investments and tackling climate-related financial risks: which role for macroprudential policies?

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Fostering green investments and tackling climate-related financial risks: which role for macroprudential policies?

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Abstract

While there is a growing debate among researchers and practitioners on the possible role of central banks and financial regulators in supporting a smooth transition to a low-carbon economy, the information on which macroprudential instruments could be used for reaching the "*green structural change*" is still quite limited. Moreover, the achievement of climate goals is still affected by the so-called "green finance gap". The paper addresses these issues by proposing a critical review of existing and novel *prudential approaches* to incentivizing the decarbonization of banks' balance sheets and align finance with sustainable growth and development objectives. The analysis carried out in the paper allows understanding under which conditions macroprudential policy could tackle climate change and promote green lending, while containing climate-related financial risks.

Keywords: Climate Change, Climate Finance Gap, Banking Regulation, Macroprudential Policy, Central Banking, Climate-finance risk.

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1 Introduction

There is now widespread recognition of climate change (Oreskes, 2004; Doran and Zimmerman, 2009; Cook et al., 2013). As pointed out by Rockström et al. (2009), three of nine interlinked planetary boundaries have already been overstepped and the ecosystem is heading toward a tipping point that poses an existential risk to society (Friedlingstein et al., 2014). To enhance a so-called green structural change, considerable investments are required in the sectors characterized by high capital costs, i.e., the building, industrial, transport and energy sectors (WEF, 2013), as shown in Figure 1. Additionally, considering green energy efficiency, it has been estimated that an eight-fold increase in annual investments is needed by 2035, while investments in the so-called low-carbon power generation (including renewable energy, nuclear energy, and carbon capture and storage) will need a three-fold increase, in order to be aligned with a green transition scenario (OECD/IEA, 2014).

The evidence for the "green finance gap", i.e. the lack of sufficient financial resources to be directed towards green investments (Buchner et al., 2017), is particularly relevant for the transition towards a low-carbon economy, because it represents a serious hindrance for the achievement of the climate goals as discussed during the COP-UNFCCC (Conference of the Parties to the United Nations Framework Convention on Climate Change) (COP, 2015, 2016) and for an adequate technological progress (D'Orazio and Valente, 2018) that could prevent a so-called *soft landing* (Schoenmaker and Van Tilburg, 2016). However, the required investments are difficult to be met under the current financial framework (Mazzucato, 2013; Mazzucato and Semieniuk, 2018). A growing body of evidence suggests that investment processes, accounting frameworks, and financial regulatory regimes contain an intrinsic "carbon bias" that creates barriers to aligning the finance sector with sustainable transition roadmaps (see Campiglio, 2016; Volz, 2017, among others). Moreover, at the current stance, the financial portfolios that are highly exposed to carbon-intensive "stranded" assets (Caldecott and McDaniels, 2014; Battiston et al., 2017) imply a potential threat for the *soft landing* scenario (Schoenmaker and Van Tilburg, 2016) and have implications for systemic risk (Gros et al., 2016). Some analysts have argued that macroprudential initiatives following the financial crisis, notably Basel III, seem to promote short-term "brown" investments at the expense of more long-term, climate-friendly investments (Gersbach and Rochet, 2012; Haldane, 2013; Thanassoulis, 2014), and the liquidity requirements in particular, might negatively affect banks' willingness to lend to green projects (Liebreich and McCrone, 2013; Narbel, 2013; Spencer and Stevenson, 2013; Caldecott and McDaniels, 2014). Additionally, it has been noted that although the nowadays financial regulatory framework made notable progress to detect, assess and contain systemic risks (BCBS, 2011), it still overlooks the possibility that systemic risk arises in case of a "green transition".

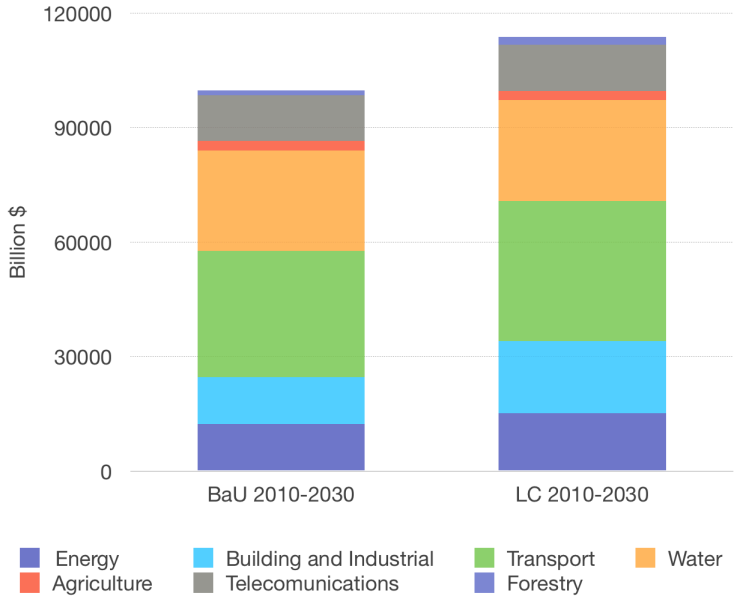

Figure 1: Annual estimated investments needed by sector in two different scenarios: Business-as-Usual (BaU) left bar, Low-carbon economy (LC) right bar. Data in billion US$2010 rates. The reported estimates show that to make the so-called low-carbon scenario effective, $14 trillion are needed over the period of 2010-2030; the annual average investment in green technologies in all the sectors considered in the study, should be on average $0.7 trillion.
Source: authors' elaboration based on data presented in WEF (2013). We refer the reader to the WEF (2013, Appendix 1) for more details on the methods used to gather and process the data.

Nowadays, climate-related financial risks are highly debated because of the possible effects of these risks for the financial system, and financial stability in general (see Carney, 2015; Dietz et al., 2016; Battiston et al., 2017; Monasterolo et al., 2017; Volz, 2017, among others). Three different types of risk have been identified (Carney, 2015). *Transition* risks are those that could arise from a sudden and disorderly transition to a low-carbon economy. *Physical* risks are "those risks that arise from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability of exposure of human and natural systems" (Batten et al., 2016). *Liability* risks stem from "parties who have suffered loss from the effects of climate change seeking compensation from those they hold responsible" (Carney, 2018, p.2). Nevertheless, central banks and regulators, with few exceptions (Batten et al., 2016; Carney, 2018; Dikau and Ryan-Collins, 2017; Campiglio et al., 2018), seem to overlook climate objectives in practice (Monnin, 2018). A possible explanation for this neglect is related to the models traditionally used by central banks, which "are not well suited to capturing the effects of climate change or the complexity of the economic transition" (Sevillano and Gonzalez, 2018, p.129). Indeed, only recently a

new generation of models has been developed to account for the effects of climate change on financial and economic stability (Balint et al., 2017; Fontana and Sawyer, 2016; Dafermos et al., 2017, 2018; Monasterolo and Raberto, 2018; Bovari et al., 2018; Lamperti et al., 2018).

Despite the rising awareness of the adverse impact of climate-related risk on financial stability (Carney, 2015; HLEG, 2018; DNB, 2017), there are no internationally agreed-upon regulatory schemes to withstand the potential losses they can cause to the financial sector. To tackle climate-related financial issues, the attention of researchers has been so far devoted mainly to the possible effects of the transition process on the financial sector (Carney, 2015; Covington and Thamotheram, 2015; Campiglio et al., 2017; Bovari et al., 2018) and *market-based measures* have been proposed to solve the issue (Stiglitz et al., 2017). However, carbon taxes, as well as policies based on subsidies, seem to reflect a lack of awareness of the financial risks related to climate change (World Bank, 2014, 2016; Campiglio, 2016), such as the loss of value of financial assets (Dietz et al., 2016), or the issue of stranded assets (Caldecott, 2017; Delis et al., 2018).

Taking into account the current policy framework and the climate-related financial risks, the paper takes a different perspective, and aims to investigate the possible effects of financial regulation, as well as the transition process towards a green economy. In our analysis, we focus in particular on the extent to which a prudential regulation, explicitly aimed at promoting a green economic transition, is a tool policymakers could and should use to foster green investments and mitigate climate-related financial risk (Carney, 2015; Gros et al., 2016; Draghi, 2017). We show these interlinkages in Figure 2.

A number of research works have been studying possible modifications of standard central banking to include instruments to support the green transition, considering for example green bonds or green quantitative easing (Batten et al., 2016; Matikainen et al., 2017; Volz, 2017; Campiglio et al., 2018). In our paper, instead, we shed light on the regulatory instruments that can be implemented within the existing regulatory framework. In particular, we focus on the following research questions: Is the current macroprudential regulatory framework "green enough" to enhance both a low-carbon transition and financial stability?; If not, how policymakers can make it "greener" and what are the possible (unintended) consequences the existing regulatory framework can have on the transition? We consider these questions of particularly relevance because, as pointed out by Carney (2015), the "green transformation" of the global economy may occur paired with high market volatility and disturbances in capital flows, causing systemic risks for the financial sector.

The contribution of the research carried out in the paper is twofold. First, a critical review of existing and novel *prudential approaches* to align finance with sustainable growth and development objectives, as well as incentivize the "decarbonization" of banks' balance sheets, is presented. Second, by reviewing official central banks documents, it provides an

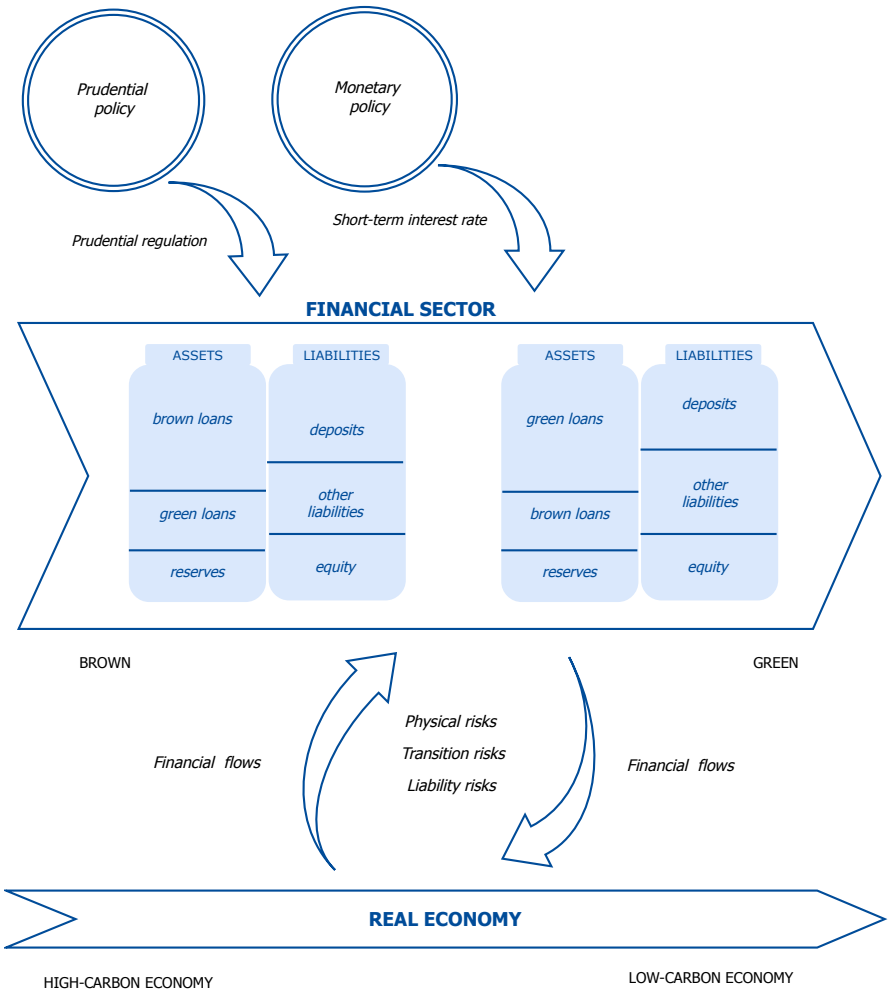

Figure 2: The interaction between the real and financial sectors, accounting for monetary and macroprudential policies interventions, in case of the low-carbon transition process.

up-to-date mapping of green prudential regulations and tools at the OECD and European level.

The remainder of the paper is organized as follows. Section 2 introduces the topic of financial regulation aimed at tackling climate change, by presenting the state-of-the-art in the existing regulatory framework. Section 3 discusses possible extensions of existing prudential regulations explicitly aimed at affecting credit allocation, fostering green investments, and tackle climate-related financial risks. A review of the available green macroprudential tools is presented, along with an analysis of their pros&cons. Finally, Section 4 concludes.

2 Financial regulation and climate change

Financial stability has been particularly relevant in the last decades, when policymakers from emerging to advanced economies have been working to implement macroprudential policy tools (see Kahou and Lehar, 2017; Galati and Moessner, 2017, for recent reviews on macroprudential policies)[1]. The introduction of financial regulation as a new "policy mandate" for central bankers has been accelerated by the 2007-2008 financial crisis. By echoing the *Financial Stability Hypothesis* (Minsky, 1992), the financial crisis raised the awareness that it is important to catch the early-warning signals of crises and address, already in "normal times", the potential risks that could affect the financial system. One of the key lessons of the financial crisis has been indeed that "*[. . .] stability is destabilizing*" (Minsky, 1982, p.101) and that price stability can coincide with the build-up of excessive financial risk.

In addressing the concerns raised by the financial crisis, the regulators decided to improve the existing international financial framework by going beyond the so-called Basel II approach, which was concerned with the safety and soundness of individual financial institutions[2]. The post-crisis "new normal", instead, has been featured by a macroprudential framework, namely Basel III, that explicitly tackles systemic risks thereby limiting the incidence of disruptions in the provision of key financial services that can have serious consequences for the real economy. However, under the existing Basel III accord, climate-related financial risks are narrowly defined, and regulatory capital and liquidity regulations[3] (under Pillar 1) do not explicitly require banks to assess the impact of climate-related risks (CRRs) on bank's exposures (BCBS, 2016; ESRB, 2016a). Moreover, it reinforces short-termism[4] in financial markets (Haldane, 2011), hence creating obsta-

[1] There exist different policy frameworks and types of mandates for central banks, depending on whether monetary policy and macroprudential policy are conducted "under the same roof", whether financial stability is considered as a secondary objective for monetary policy, or if the two are considered to be conducted independently by two different authorities/institutions (see Smets et al., 2014, for a theoretical discussion about these issues). In particular, in the last decade, the matter on whether monetary policy should include financial stability objectives has been highly debated (see Angelini et al., 2012; Mishkin, 2017, among others) and it has been documented that the pervasiveness of the interaction among the "two spheres" changes especially in time of crises (Smets et al., 2014).

[2] With term "Basel", we refer to the so-called Basel Accords, which are banking regulation agreements related to capital, market and operational risks, issued by the Basel Committee on Banking Supervision (Switzerland) (see Borio, 2003, 2014, among others). By now, there are three accords published, each one improving upon the previous; namely, Basel I, Basel II, Basel III. In the paper, we refer mostly to Basel II and III. For a comparison between the two frameworks, we refer the reader to Table 3 reported in the Appendix A.

[3] Capital requirements are set by regulatory agencies, such as the Bank for International Settlements, for banks and other depository institutions to determine how much liquidity is required to be held for a certain level of assets. These requirements are set to ensure that banks and depository institutions are not holding investments that increase the risk of default and ensure that they have enough capital to operate and allow for deposit withdrawals. The objective of liquidity requirements is to promote the short- and long-term resilience of the liquidity risk profile of banks imposing to hold an adequate level of liquid assets against their liabilities.2

[4] In the paper, we adopt the following definitions: a short-term financial instrument is one that has 1

cles for capital mobilization aimed at green investment projects (King, 2013; Spencer and Stevenson, 2013; Bhattacharya et al., 2015), which require long-term "patient" financial capitals that are, by definition, riskier than short-term assets (Dore, 2008; Mazzucato, 2013).

GREEN BASEL III		
Pillar I **Enhanced capital & liquidity requirements**	**Pillar II** **Enhanced supervisory review**	**Pillar III** **Enhanced risk disclosure & market discipline**
- *Liquidity coverage ratio* (LCR) - *Net Stable Funding Ratio* (NSFR) - *Leverage ratio* - *Capital conservation buffers* - *Countercyclical capital buffers* - Enhanced loss absorption clause - Securitization - Trading risk - Counterparty credit risk	- Internal capital adequacy assessment process (ICAAP) - Supervisory review Evaluation process - Stress tests - *Climate-related stress tests*	- Regulatory capital components - Regulatory capital ratios - Securitisation exposures - Enhanced disclosure * *(qualitative disclosure)* * *(quantitative disclosure)*

Table 1: The *enhanced* Basel III framework considering climate-related financial risk concerns. Instruments discussed in the paper are in italics.

The decision about whether to incorporate a "green objective" in the mandate of central banks and/or regulatory authorities, depending on the country and related institutional frameworks, has been highly debated in recent years (Schotten et al., 2016; DNB, 2017; HLEG, 2018). In our view, considering the negative externalities deriving from climate-related financial risks, regulatory authorities can suggest measures that could allow banks to increase long term lending, without harming the financial system's stability. If one adopts this perspective, macroprudential policy enriched with the "greened" tools, should be concerned with financial stability and a climate-related objective, hence reaching also the objective of aligning finance with sustainable growth and development. Bearing these caveats in mind, we suggest the implementation of a set of regulatory tools that we present and discuss in Section 3. As showed in Table 1, we focus mostly on lender-based measures[5] that are already defined under Pillar I[6], by emphasizing the "green potential" they entail. Indeed, we point out that the existing capital requirements could make banks more hesitant towards green lending, and liquidity requirements could penalize long-term loans (Blundell-Wignall and Atkinson, 2010; Allen et al., 2012; Angelini et al., 2015). It is thus important to change their impact in order to achieve the above-discussed objectives.

Regarding Pillar II, we maintain that it should be extended to include CRRs, and that

to 3 years of maturity; a long-term asset is one that is characterized by more than 7 years of maturity.

[5]While the restriction on lenders influence the supply side of credit, measures like the release of loan-to-value (LTVs), loan-to-income (LTIs), and debt-to-income (DTIs) influences the demand for credit (Duca et al., 2018). Generally, the application LTV and DTI caps set a limit on the amount of lending to a particular customer based on the value of the asset is obtained (e.g., mortgage) or impose restrictions depending on the income of borrowers. In this way, they boost the resilience of the banking sector directly by dropping the probability of default and loans' loss-given-default. These measures could be used in the green transition to limit lending to targeted companies or sectors which are primarily involved carbon-intensive activities.

[6]The term "Pillar" refers to the areas of focus of the Basel's accords.

the identification of early warning risk indicators is fundamental in the macroprudential policy setting process. In this respect, climate-related stress tests (CRSTs) are of vital importance to assess the extent to which financial institutions are exposed to carbon-intensive assets (Kelly and Reynolds, 2016; Thoma and Chenet, 2016; Battiston et al., 2017; Monasterolo et al., 2017). A CRST aims at evaluating the resilience of the financial system to adverse climate shocks. It does so by analyzing the possible impact of hypothetical climate-related shock scenarios on the stability of individual financial institutions and the financial system in its complexity. Despite raising awareness about the CRRs and exposures, developing a robust stress test is a very important first step to calibrate and evaluate green macroprudential tools. Indeed, information filtered from the stress tests could be used to define minimum capital standards, risk weights, credit caps and floors for a particular type of asset (see Section 3). Regarding Pillar III, we claim that disclosure requirements, both quantitative and qualitative, should be included so that investors can fully learn the risks to which specific banking institutions are exposed. Similar proposals regarding the enhancement of Pillars II and III have been discussed by the European Systemic Risk Board (ESRB)[7], according to which, in the short-term, disclosure should be enhanced to include CRRs in regular stress tests, while carbon stress tests are more appropriate for the medium/long-term (ESRB, 2016b). An analogous view has been expressed by the EBF (2018); it emphasizes, however, also the crucial importance of the establishment of a common taxonomy and disclosure framework before any modification of the existing regulation. We deem the last point of particular importance as the extent to which a financial asset can be considered "green" plays a crucial role in the definition of a bank's portfolio. To the best of our knowledge, there is no commonly defined taxonomy nor an agreed-upon disclosure framework, as advocated by the Financial Stability Board-Task Force on Climate-related Financial Disclosures (TCFD, 2017). However, some progresses in this direction have been made in the past months. For example, in May 2018, the EU Commission set up a Technical Working Group on Sustainable Finance, whose main tasks are to assist the Commission in the development of (1) an EU taxonomy of environmentally sustainable economic activities; (2) an EU Green Bond Standard; (3) a category of "low carbon" indices for use by asset and portfolio managers as a benchmark for a low carbon investment strategy; (4) metrics allowing improving disclosure on climate-related information. Although an appropriate and widely agreed-upon metric of "greenness" is difficult to achieve, for the sake of clarity of the analysis carried out in the paper, we suggest a possible definition of the "green" attribute to be attached to any financial asset that meets the requirement; we use the following definition throughout the paper. In our view, a green asset is one related to the financing of a green investment,

[7]For discussions about "green-related" measures under Pillar II and III, we refer the reader to ESRB (2016b); Battiston et al. (2017); Monasterolo et al. (2017); Stolbova et al. (2018); EBF (2018), and the references therein.

which is in turn defined as a project aimed at energy efficiency, renewable energy development, sustainable water management, clean transport systems development, sustainable agriculture, pollution prevention, climate change adaptation. In this context, any social aspect, although important, is not considered for this definition of "green". Alternative measures of "green" could be the environmental risk classification computed by Moody's (2018), a low value resulting from a CRSTs, or a labelling scheme as the one developed for green bonds (see Ehlers and Packer, 2017). Regarding the definition of brown, as pointed out by UN-Environment and World Bank (2017), "[a]lthough a formal definition of brown assets does not exist, existing initiatives associate them with the financing of emission-incentive activities (for example, oil and gas)" (UN-Environment and World Bank, 2017, p.42). In our paper, we share this interpretation. However, as emphasized by HLEG (2018), additional research is needed to enhance the development of a common defined taxonomy of "green", "brown" and "neutral" assets[8].

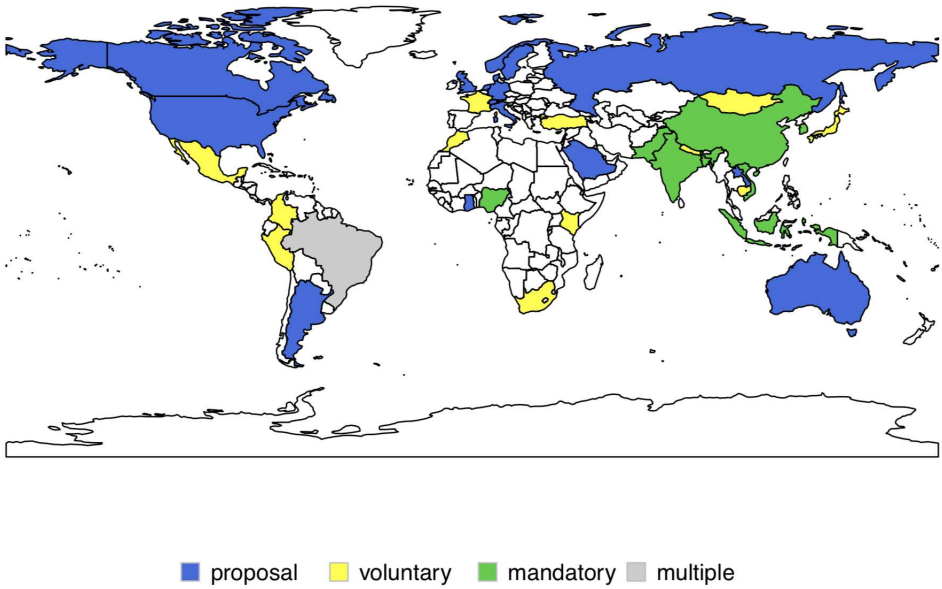

Figure 3: The diffusion of green prudential requirements; year: 2018 (last update: October). Source: Authors' elaboration based on the "Green Macroprudential Index" computed according to the data contained in (D'Orazio and Popoyan, 2018).

Before looking at the prudential tools in details, we consider countries' experiences in the development and adoption of green regulations. Figure 3 offers an overview (as of March 2018) of the state-of-the-art climate-related regulations. We distinguish among four categories: countries that adopted a mandatory regulation (described in green), countries that developed a voluntary regulation (described in yellow), countries that have both mandatory and voluntary regulations (described in grey), and finally countries which are

[8] An interesting implementation of these concepts has been proposed by Kemp-Benedict (2018) in a theoretical model that studies the interactions between investments and macro dynamics.

discussing the possibility to introduce such regulations (described in blue). From this analysis, several interesting conclusions can be drawn. First, a clearly defined cluster of emerging economies located in the East Asia region (namely; China, India, Pakistan, Bangladesh, Vietnam, Indonesia) appears as the leader of the adopters of mandatory regulations. Other examples are Nigeria and Brazil, for which we report the adoption of both mandatory and voluntary regulations. Second, European countries, as well as other high-income countries emerge instead as the "laggards", because, except from France[9], the adoption of a climate-related perspective in the financial regulation is still a topic of discussion at the policy level (HLEG, 2018). In line with previous existing analyses (Alexander, 2014; Dikau and Ryan-Collins, 2017), it is therefore evident that low income countries and emerging economies are the most engaged in pursuing policies aimed at greening the banking sector. The rationale behind this evidence is twofold. First, central banks in emerging and low-income countries have a larger spectrum of goals (and functions) than their high-income countries counterparts. Indeed, policy objectives usually explicitly include output growth, exchange rate stability and macroprudential supervision (Hahm et al., 2012; Ghosh et al., 2016; Chen et al., 2017). Second, low-income countries are more exposed to climate change; therefore they have to craft a response that needs to be more timely and effective in the very short run.

3 *Green* macroprudential tools: challenges and implications

In this section, we analyze the ongoing debate and discuss possible novel tools aimed at supporting the low-carbon transition while keeping the financial system "safe and sound". Additionally, we propose a classification of macroprudential tools (see Claessens, 2014; Cerutti et al., 2017, for more insights of the classification approaches of macroprudential instruments), as shown in Table 2. Furthermore, we discuss the challenges and implications deriving from their possible enforcement; we summarize the results of our analysis in Table 6 while additional details on the countries' implementation, policy's objective/s and juridical frameworks are available in (D'Orazio and Popoyan, 2018). We additionally provide an overview of the diffusion of specific prudential instruments in Figure 4. From the inspection of this figure, we notice that no capital instruments have been implemented yet. The most diffused instrument are mostly lending limits, which are mandatory in Bangladesh, India, Nigeria, Brazil, Laos, South Korea, Vietnam and are in the policy agenda discussion in Denmark, Ecuador, Japan, Kenya. Regarding measures related to Pillar II, we observe that climate-related stress tests have been so far implemented only in China, and are under discussion in France and the Netherlands. Finally, risk disclosure

[9] In 2013, the country set up an "Action plan for EU strategy" put forward by the Ministry of Ecology in order to embed social responsibility and responsible finance in the private and public sector as well as in the financial sector.

and risk assessment defined under Pillar III, are gathering a lot of interest in countries such as Colombia, Indonesia, Pakistan, Peru, South Africa, Switzerland, Turkey. For a more detailed overview on the European and Asian areas, we point the reader to Appendix B and C, respectively.

Intermediate Objective	*Category*	*Instrument*
Limit misaligned incentives, canalize credit to green sectors	Reserves Reserves of exposure	• Differentiated reserve requirement
Mitigate and prevent excessive credit growth and leverage	Capital Capital Capital	• CAR with GSF • Countrecylical capital buffer • Sectoral leverage ratio
Limit the concentration of certain exposures	Lending limits Lending limits	• Max(min) credit ceiling (floor) • Large exposures limit
Mitigate and prevent market illiquidity and maturity mismatch	Liquidity Liquidity	• Liquidity coverage ratio • Net stable funding ratio

Table 2: Classification of "green" macroprudential instruments.

Capital requirement. Recently, the so-called "green supporting factors" (GSF) have been advocated to overcome the green finance gap. Among the supporters, there are the European Commission (Dombrovskis, 2017), the High-Level Expert Group on Sustainable Finance (HLEG, 2018), and the European Bank Association (EBA, 2018). They emphasize the need to adjust banks capital requirements with green finance goals by introducing a GSF, that is deemed useful to incentivize lending to green sectors, thus promoting green investments. Opponents, however, express their skepticism considering the experience with the GSF prototype, i.e., the small and medium enterprise supporting factor (EBA, 2016), and hence the possible negative impact of GSF on bank stability (Matikainen, 2017; Finance Watch, 2018).

The proposed mechanism is meant to affect banks' ability to create credit and implies adjusting the minimum capital adequacy requirement (CAR); i.e., the ratio required by the regulator of a bank's capital over its risk-weighted assets. Although the effectiveness of (standard) CAR was highly debated in academic literature (Gauthier et al., 2012; Gersbach and Rochet, 2017), its potential to affect the lending capacity of financial institutions is largely supported by evidence (Aiyar et al., 2014; Budnik and Kleibl, 2018).

In the combined implementation of minimum capital requirement and GSF, banks could calibrate the risk-weighted capital ratios so that low-carbon activities would exert a lower pressure on their balance sheet and, therefore incentivize them to finance climate-related projects. The *de-risking* of green assets is particularly relevant in a credit risk measurement mechanism of risk-weighted assets, considering that, due to their longer pay-back period, green projects are usually assigned higher (compared to brown assets) risks weights. Considering the above-mentioned, the factor is applied on the denominator

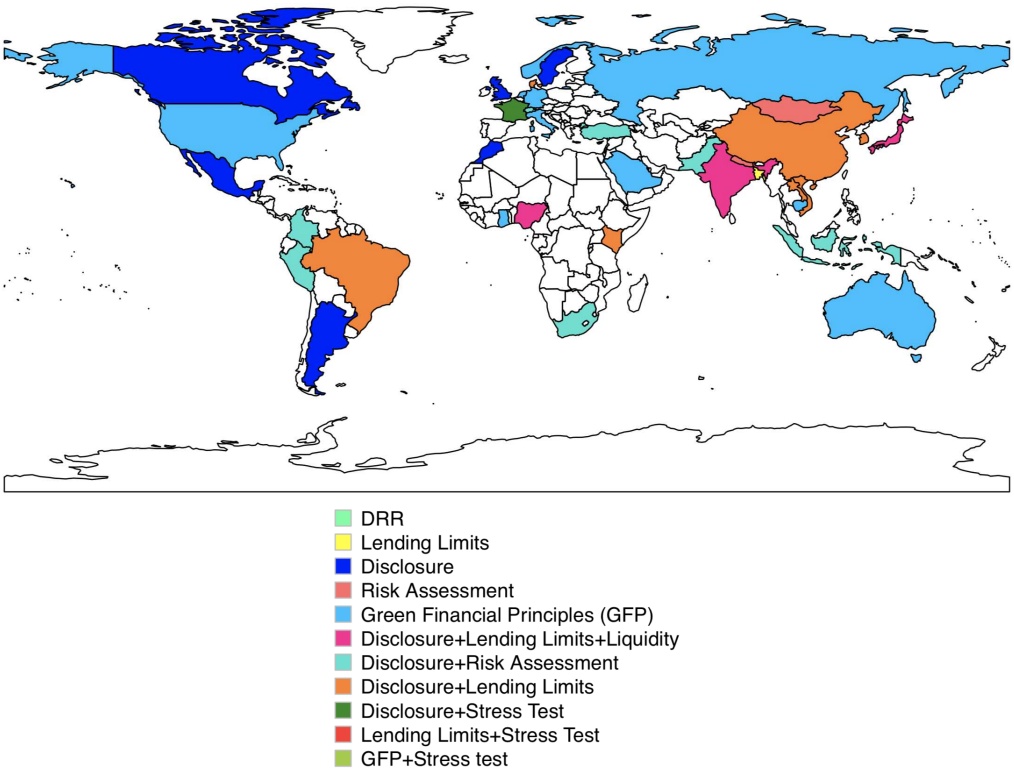

Figure 4: The diffusion of green macroprudential instruments. Source: Authors' elaboration based on the "Green Macroprudential Index" computed according to the data contained in (D'Orazio and Popoyan, 2018).

of banks' minimum CAR as follows:

$$CAR^t_{green} = \frac{E_t}{RWA_t} = \frac{E_t}{\alpha_b L^b_t + (\alpha_g - \alpha_{GSF}) L^g_t} \geq \beta, \tag{1}$$

where E_t is the bank's capital, RWA_t is bank's risk-weighted assets, $\alpha_b L^b_t$ and $\alpha_g L^g_t$ are respectively the brown and the green risk-weighted loans portfolios, and β is the CAR set by the regulator. α_{GSF} is a mark-down on a green loan risk-weight; it affects the capital requirement imposed on banks by altering the risk-weight of the asset depending on whether it is identified to be green or brown (HLEG, 2018; EBF, 2018), according to the criteria discussed in Section 2. From this definition it follows that if the bank is identified to be "brown", then $\alpha_{GSF} = 0$, otherwise $\alpha_{GSF} > 0$ and $\alpha_{GSF} < \alpha_g$.

According to us, the policy direction is right; however, the way it is approached can undermine its effectiveness and have destabilizing effects for the banking sector. First, the introduction of a GSF in the current stance implies looser regulatory CAR for green assets, which underestimates possible real financial risks associated to them (Schoenmaker and Van Tilburg, 2016; Matikainen et al., 2017; Van Lerven and Ryan-Collins, 2018). In our view, a CAR-GSF cannot be efficiently implemented until a more risk-sensitive approach is adopted. As discussed in Section 2, this will be based on the establishment of a common taxonomy and disclosure standards for green assets, as well as mechanisms to transform climate exposures (measured by carbon intensity) into credit risk and a creditworthiness indicator. Additionally, acknowledging that if we consider carbon-intensive assets as highly risky does not automatically imply that green assets are safer, the implementation of a GFS should be conceived together with the set up of a targeted loan-loss reserve which could be able to absorb the risk that cannot be backed-up by regulatory capital. Second, as pointed out by 2DII (2018), the GSF would have an overall limited effect if compared to the small and medium enterprise supporting factor, even under an expanded application of the factor. According to the report, the total capital savings related to the introduction of the GSF would be of 2-4 € billion, or 5-8 € billion under an expanded definition. These amounts are however lower than the estimated 12 € billion for the small and medium enterprise supporting factor (EBA, 2016).

Considering the arguments mentioned above, a stronger case in favor of a "*brown-penalizing factor*" (BPF) emerges, as highlighted by 2DII (2018) and Villeroy de Galhau (2018). While the GSF would lower the capital requirement for green credit with no proved evidence that green assets are actually less risky (Moody's, 2018), the BPF would require banks to hold more prudential capital for carbon-intensive assets (add-on factor). Worth mentioning that a sustainability taxonomy would still be first required before the application of BPF. Furthermore, adopting this perspective, it implies that banks would become more risk-sensitive regarding brown assets and they would hold more loss-absorbing capital to withstand a possible carbon bubble or a probable repricing of stranded assets.

According to us, by adopting this definition of green capital requirement, policymakers would be more likely to avoid risk underestimation, consequently providing a more robust, and less risky, regulatory capital framework for the banking sector.

Differentiated reserve requirements (DRR). Among the instruments that could be implemented to aligning low-carbon transition and financial stability objectives, differentiated "green" reserve requirements are drawing particular attention (Rozenberg et al., 2013; Campiglio, 2016; Volz, 2017).

Reserve requirements are a central bank regulation employed by most central banks; it sets the minimum amount of reserves that must be held by a commercial bank as a counterpart to customer deposits and notes. They are used, in addition to their open-market operations, to control money supply.

DRR explicitly target financial institutions actively involved in the green transition by easing the reserve requirement (RR). The level of DRR depends on the composition on the bank's portfolio and may be reduced in proportion of the bank's lending to green sectors, thus subsidizing green credit. In contrast to the existing *harmonized RRs*, the *green RR* would allow banks to hold fewer reserves against a "green" loan portfolio. By directly affecting the bank's money-creating ability, it would therefore align the profitability of their lending activities with the climate policy target.

Several central banks and regulators have already implemented both *multiple* (depending on a banks size, type, and maturity of liability, currency, etc.) and *differentiated* (depending on the targeted sector) RRs aimed at steering credit to specified financial institutions and areas of the economy. China offers a pertinent example of a country using multiple and DRRs as a regular policy tool (Fungáčová et al., 2016; Chang et al., 2018). Another example is the Central Bank of Lebanon that, since 2010, supports green credits by lowering the RR of commercial banks by 100-150% of the loan value in the case in which bank can provide a certificate of energy savings potential of the financial project (BDL, 2009, 2010).

A possible implementation of the DRR is suggested in the following, by pointing out that before its direct application, a calibration of a green factor, σ, is necessary.

$$R_t = \sigma * D_t, \tag{2}$$

where D_t is the stock of deposits hold by the bank at period t and σ is a fraction of attracted deposits to be kept as a reserve; it allows us to distinguish between "green" and "brown" banks, so that $\sigma \in \{\sigma_{brown}; \sigma_{green}\}$. When distinguishing between banks with "green" and "brown" loan portfolios the following holds: $0 < \sigma_{green} < \sigma_{brown}$, where σ_{green} depends on country-specific factors (discussed below), the presence of other macroprudential instruments, the monetary policy stance and declines with increased green taxonomy.

The implementation and efficiency of the DRR depend on the policy frame it serves for (i.e.; monetary, macroprudential, microprudential), and country's characteristics. In the following, we will distinguish between the perspective of developing and developed countries. Before proceeding with our discussion, it is important to note that we consider the RR to be a monetary policy tool when it is used to regulate market liquidity, a macroprudential tool when it is used to corrected the business cycle, and a microprudential tool in the remaining cases. Indeed, when they were first implemented, RR were designed for monetary policy purpose, but as emphasized by Cordella et al. (2014), they have been intensively used by emerging economies as a countercyclical macroprudential instrument. For example, in their analysis for the period 1970-2011, Federico et al. (2014) find that 62% of the sampled countries followed an active RR policy; 2/3 were low-income countries, 1/3 were high-income countries. Moreover, authors note that after 2004 none of major low-income countries were involved in active RR policy. The rationale for the noted differences is threefold. First, low-income countries are usually characterized by undeveloped financial markets, which may limit the efficiency of market-based instruments. Second, their monetary policy is procyclical, due to the need of either defending the local currency in bad times or not attracting more capital inflows in good times. This often implies the need of a countercyclical (prudential) tool (Federico et al., 2014; Cordella et al., 2014; Cerutti et al., 2016). Third, the procyclical behavior of the exchange rate over the business cycle also plays a role. In the presence of open capital flows, the procyclicality of the interest rate constrains the smooth conduct of monetary policy and the use of interest rates as a countercyclical instrument. Therefore, in this framework, RRs are used for stabilizing capital flows and the credit cycle, considering the existing limits on the typical monetary policy ability to smooth the level of credit and/or economic activity (Cordella et al., 2014).

Considering the peculiar framework of low-income countries and the countercyclical use of RRs, i.e., rising it in good times and lowering it in bad times, as substitutes of a procyclical monetary policy, the "green" RR is expected to have overall ambiguous effect. Indeed, although they are designed to stimulate green investments, RRs are still a form of liquidity requirement against the unexpected withdrawal of funds. Consequently, using them to directly subsidize credit for green investments can hinder liquidity management, thus bringing to a suboptimal outcome (Gray, 2011). Additionally, we point out that the use of "green" RR in low-income countries characterized by "fear of capital inflows" and "fear of free falling" behavior, may induce policymakers not to raise interest rates in good times and use higher RRs to cool down the economy, which will bring distortions in either monetary policy conduct or to the green loans flow. Hence more coordination among the harmonized RR (which partially takes the role of monetary policy), the exchange rate policy and green RR is needed in low-income countries.

In the case of high-income countries, instead, the efficiency of "green" RR can be

questioned under the abundance of liquidity in the money market after the post-crisis "new normal" (e.g., quantitative easing, and the capacity of the reserve ratio to act as a constraint on banks' reserve of exposures (see Campiglio, 2016)). Being passive users of RR both for monetary policy purposes (due to colossal central bank's balance sheet and excess liquidity in the market), and for macroprudential stance (under Basel III, the focus is more on liquidity requirements than on reserve ratios), the efficiency of green RR can be found in use with a microprudential option. In fact, as highlighted by Federico et al. (2014), the majority of high-income countries in their dataset have zero legal reserve requirements.

Countercyclical capital buffer (CCyB). CCyBs are designed to reinforce financial institutions defenses against the build-up of systemic vulnerabilities and serve as a cushion during the contractionary phase of a credit cycle (Drehmann and Gambacorta, 2012; Jiménez et al., 2017; Popoyan et al., 2017). Their use is reported to have increased after the global financial crisis (Budnik and Kleibl, 2018), while the literature on its actual activation is scarce (BCBS, 2018) and there is a lack of evidence about its effectiveness (Cerutti et al., 2017; BCBS, 2017).

Considering these features, we suggest that CCyBs can be used to favor financial stability in the transition process from the high-carbon to the low-carbon economy. The mechanism is shown in Figure 5. According to this proposal, building a buffer, i.e., a high capital base, during periods of excessive carbon-intensive credit growth will increase the bank's resilience during the upswing of the carbon-intensive credit cycle acting as "soft" speed limit, thus contributing to the "soft landing". In this way, the CCyB could play an important role in mitigating and preventing excessive credit growth and leverage related to carbon-intensive assets. The buffer add-on contains *ex-ante* the risk of carbon-intensive credit growth, thus helping building buffers to absorb *ex-post* shocks to high-carbon loans (e.g., stranded assets), therefore ensuring a smooth transition process. Thanks to this mechanism, we maintain that CCyB can favor financial stability by having a more direct impact on brown assets and by exerting an important signaling power in the financial market. However, for the CCyB to be effective, an adequate calibration (i.e., the % of a banks total exposures) and early activation (i.e., implement before the cycle changes the phase) are required. Beside level and timing issues, the implementation of the CCyB depends on how banks adjust their capital ratios (BCBS, 2018), as well as on the measure and indicators of climate-related systemic risk, which, as highlighted in previous sections, is a relevant topic of recent research agenda (see Battiston et al., 2017).

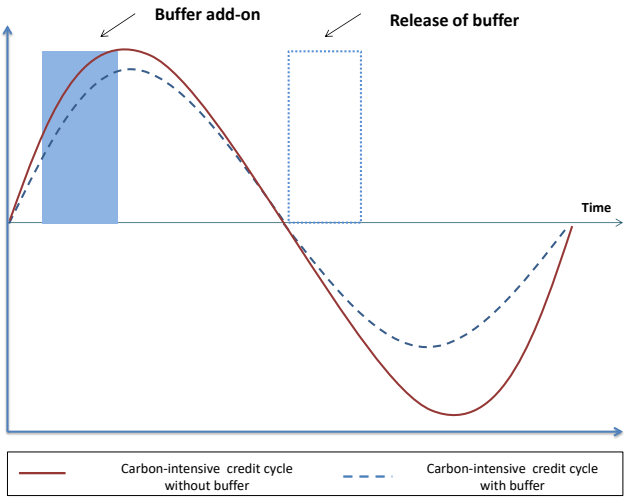

Figure 5: The buffer mechanism over the carbon-intesive credit cycle.

Another way to approach the CCyB could be the application of a negative capital buffer (NCB) in addition to the "green" capital requirement. The NCB would allow for a reduced level of the required minimum bank capital in case in which the bank's credit portfolio appears to be "green enough". Additionally, the NCB can be considered a "compensation" for banks that are not excessively exposed to carbon-intensive industry, or for their active participation in the "green transformation". As for the application of NCB, as in case of GSF, targeted loss-reserves are needed to absorb uncovered and underestimated credit risk while creating an incentivizing mechanism for the green transition.

Sectoral leverage ratio (SLR). While the leverage ratio in Basel III prevents excessive on- and off-balance sheet leverage by defining a non-risk based capital limit in terms of the ratio between bank's equity and total exposures (BCBS, 2014), the SLR hereby proposed could limit an overleveraged position to a targeted group of assets. The underlying logic can be formally expressed as follows:

$$LR_t^{Sector} = \frac{\text{Tier 1 Capital}}{\text{Exposures to carbon-intensive sector}} \geq \gamma, \tag{3}$$

where Tier 1 Capital is the bank's core capital composed of common equity and retained earnings; γ is the leverage ratio set by the regulator.

The relevance of the proposed SLR for financial stability depends on the extent to which highly leveraged financial institutions are exposed to carbon-intensive assets. Therefore, for a better calibration of the leverage ratio, banks' exposure data, as well as the level of carbon intensity of firms' resources, should be adequately disclosed.

The impact the sectoral leverage ratio will have on banks' incentives is similar to

the maximum credit ceiling (discussed below), but different regarding the balance sheet structure. Whereas the credit floor *caeteris paribus* will stabilize a predetermined fraction of the assets' portfolio to be allocated to a particular type of assets, in case of the SLR those assets will need to be backed-up by the bank's equity. Moreover, as confirmed by regulatory design and its effects (see BCBS, 2014a), the leverage ratio will serve as a backstop to a risk-based capital requirement, to avoid the over-leveraging of a particular sector and to keep the adequate capital base against certain groups of risky assets.

Liquidity regulation. The current liquidity requirement imposed by Basel III is aimed at smoothing the maturity mismatch between assets and funding sources. The two primary metrics of liquidity are the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR) (see Hong et al., 2014; Aldasoro and Faia, 2016; Bai et al., 2018, on the efficiency of liquidity regulations). The former aims at "protecting" banks against short-term liquidity crises; the latter constrains banks to fund long-term assets with stable funding of at least one-year maturity. However, they may have unintended consequences on green investment. First, LCR could reshuffle banks balance sheets toward highly-quality liquid assets (e.g., cash, sovereign and central bank bonds that has 0% risk weight, corporate bonds with high rating). Second, to meet the NSFR, banks will use long-term funds (that are usually more costly) to finance long-term assets, which implies that banks will cut the funding budget. In other words, banks will become more sensitive to temporal mismatches between assets and funding, and hence more reluctant to hold long-term assets (Liebreich and McCrone, 2013; Narbel, 2013; Spencer and Stevenson, 2013; Liebreich and McCrone, 2013). As a result, Basel III liquidity rules are likely to make long-term financing more expensive, which will particularly affect "patient" (i.e., long-term) green investments, and they will likely limit the amount of capital available for such financing.

Considering the issues raised above, to align this tool with the "green" objective, we share the view expressed by the European Banking Federation (EBF, 2018). It proposes the introduction of a precise incentive mechanism for the LCR and the NSFR requirements to link the climate-related targets and the liquidity/maturity mismatch requirements in the existing macroprudential setup. The introduction of a lower required stable funding (RSF) factor (η) is considered as promising, under certain conditions, to identify green exposures. We formalize it as follows:

$$NSFR_t = \frac{ASF_t}{RSF_t} = \frac{\sum^n \phi_E E_t + \sum^n \phi_{Liab} Liab_t}{\sum^m \phi_B B_t + \sum^m \phi_G G_t} \geq \eta, \tag{4}$$

where ASF_t and RSF_t stand for available stable funding (ASF) and required stable funding (RSF) respectively. In particular, ASF is composed of Liabilities ($Liab_t$) and Capital (E_t) while RSF contains the brown (B_t) and green (G_t) exposure portfolios. Each

item in the balance sheet included in ASF and RSF is weighed with a *factor* imposed by regulator: ϕ_E and ϕ_{Liab} for equity and liability, and ϕ_B and ϕ_G for brown and green exposures respectively. Considering how the nowadays requirement is designed, the green exposures would exert elevated ϕ_G factor to compare with ϕ_B hence pushing a bank to keep higher ASF. To avoid this carbon bias green long-term finance should be considered as a category of promotional loans (both for NSFR and LCR) and treated with the reduced required stable funding (RSF) factor (i.e. for the same maturity assets $\phi_G = \phi_B - \mu < \phi_B, 0 < \mu < \phi_B$).

Minimum credit floors and maximum credit ceilings. Although they were heavily criticized due to their non-market based nature, maximum credit limits have been widely used in advanced economies after the recent financial crisis to limit bank exposures to certain type of sectors' activities and loans' categories (see Lim et al., 2011; Van den End, 2016).[10]

As emphasized by Volz (2017), they offer a very straightforward mechanism to channel investments to "green" projects. *Maximum credit ceilings* to certain carbon-intensive or polluting activities (sectors), or alternatively *minimum credit floors*, that require banks to allocate a predefined fraction of their loans' portfolio to a "green" sector, are thus worth considering for the aim of closing the green finance gap. In contrast to a maximum credit ceiling (Farahbaksh and Sensenbrenner, 1996), which creates incentives for banks to limit lending to less sustainable sectors, the minimum credit floor is a "hard" limit set by the regulatory authority.

Large exposure limit. The large exposures limit is aimed at containing the maximum possible losses a bank could incur in the case of a failure of a single counterpart or a connected group of counterpart, to a level that does not compromise the bank's solvency. It complements the Basel's risk-based capital standard because the latter is not designed specifically to protect banks from large losses resulting from the sudden default of a single counterparty (BCBS, 2014b).

When applied for low-carbon transition purposes, the exposure limit could, on one hand, limit banks' overexposed position towards counterparts with highly carbon-intensive assets; on the other hand, act in a macroprudential manner to safeguard the banks during the transition and from systemic risks. This tool, therefore, contains an allocative feature very similar to credit ceilings with a difference that credit ceiling points a group or a type of assets, while Large exposure limit relies on the identification of counterpart (s) with high

[10]Note that minimum credit floors and maximum credit ceilings were used much before the financial crisis as a classical instrument for credit policy. In post-crisis era time-varying Minimum credit floors and maximum credit ceilings they were classified as macroprudential instruments to be adjusted through the credit and leverage cycle (see Claessens, 2014, for more details).

participation in carbon-intensive activities and limits the exposures of the banks towards the latter.

As emphasized by Schoenmaker and Van Tilburg (2016), credit limits could be the most appropriate regulatory instrument to deal with material climate-related risks. Their implementation implies, however, a high effort on disclosing and reporting every large exposure connected to a single, group or interconnected carbon-intensive firms. For an effective implementation, two further steps are thus required. The first suggests a precise definition of what large exposures to the carbon-intensive sector is. For example, large exposures to carbon-intensive sectors could be defined as carbon-intensive exposures to clients or groups of connected clients where the value of it is equal, or exceeds, certain percentage (defined by regulator) of the eligible capital of the bank. The ratio of exposures to eligible capital to indicate the large exposure could be calibrated considering the country characteristics, the concentration of carbon-intensive firms, the presence of other stringent requirements, etc. The second implies a definition of the maximum large exposure limit itself to a single counterparty, or a group of connected counterparties, which has not to be higher than a certain percentage of bank's regulatory capital base.

Instruments	Pros	Cons	Alternative Proposals	Reference	Proposed complementary actions	Reference2
CAR-GSF	Favours green investments by incentivizing the presence of green loans in banks' portfolios	Underestimates risks possibly related to green loans	To increase risk weights for brown loans	Schoenmaker et al., 2016		
		Undermines the resilience of the financial system	To set up a Brown Penalising Factor (i.e., an higher CAR for banks with brown assets)	2DII, 2018		
					To develop a risk-sensitive approach: definition of a common taxonomy for green metrics before implementing it	Our proposal based on existing literature
					To set up a creditworthiness indicator based on carbon-intensity exposures	Our proposal based on existing literature
					To set up of a targeted loan-loss reserve which could be able to absorb the risk that cannot be backed-up by regulatory capital	Our proposal based on existing literature

Instruments	Pros	Cons	Alternative Proposals	Reference	Proposed complementary actions	Reference2
DRR	Canalizes exposures to green sectors	In Low-/Medium-Income Countries, it is suboptimal for liquidity management	To activate the DRR according to country-specific policy features, policy stance and goals	Our proposal based on existing literature		
	Aligns the banks' profitability with the sustainability policy target	In High Income Countries, it is inefficient both as liquidity and macroprudential instrument, due to liquidity abundance				
CCyB	Favors financial stability	Depends on the measure/indicator of the climate-related system risk	To build a Negative Capital Buffer	Our proposal based on existing literature		
	Mitigates excessive “brown” credit growth	Requires adequate calibration	To build a buffer during the carbon-intensive credit cycle	Our proposal based on existing literature		
	It entails a signalling power in the financial market	Requires early activation				
		Depends on capital ratios adopted by banks				

Instruments	Pros	Cons	Alternative Proposals	Reference	Proposed complementary actions	Reference2
NSFR	Reduces maturity mismatch between assets and funding	Favours short term (brown) assets	To set a lower Stable Fund Ratio	EBF(2018)		
	Favours financial stability					
LCR	Protects banks against liquidity crises	Limits bank capital available for green (long-term) assets		Our analysis based on existing literature		
SLR	Limits exposure of a bank to brown assets	It depends on the appropriate disclosure of bank's exposures, which are difficult to be relied on		Our analysis based on existing literature	To improve disclosure mechanisms	Our proposal based on existing literature
	Limits over-leveraging	It is difficult to calibrate the ratio				
Minimum credit floors	Allocates a defined fraction of loans to the green sector	Possible market distorsions		Volz, 2017		
		Low incentives for green lending		Our analysis based on existing literature		
Maximum credit ceilings	Limits lending to non-sustainable sectors	Possible market distorsions		Our analysis based on existing literature		
Large exposures limits	Limits exposure to carbon-intense assets	Depends on appropriate disclosure by banks		Our analysis based on existing literature	To improve disclosure mechanisms	Our proposal based on existing literature
	Guarantees banks' solvency					
	Safeguards banks against transition and systemic risk					

Figure 6: Green macroprudential instruments: overview of their policy implications and alternative measures.

4 Conclusions

By looking at the current financial framework, financial risks related to physical, liability and transition risks do not seem to be adequately considered by financial institutions nor by regulators and markets. The attention is usually devoted to the causal relation that goes from the green transition process to the financial sector, while the effects of monetary and macroprudential policies on the so-called green structural change are often overlooked. Taking into account the climate-related financial risks and the need to fill the green finance gap, in the paper, we argue that prudential authorities can play a potentially important role in leading the transition to a low-carbon economy.

To support our claim, we have examined the existing and novel prudential approaches to incentivize the decarbonization of banks' balance sheets and promote green investments. Moreover, we have critically discussed their pros & cons in channeling the financial flows to sustain a smooth transition, while reducing the systemic risk and the procyclicality of the financial sector.

Additionally, we have reviewed official central banks documents to provide an up-to-date mapping of green prudential regulations and tools currently available at the OECD, low-income countries and European level. Because of the variety of institutional arrangements and forms of cooperation among central banks, commercial banks and government that can be distinguished theoretically, there does not exist a "one-size-fits-all" approach to greening the financial system, because path-dependencies and the peculiarity of national institutional frameworks play a crucial role in the process of change that is needed to achieve a greener economy.

Regarding the adoption of green macroprudential tools, an interesting heterogeneous picture emerges from our analysis. While many low-income countries are adopting mandatory prudential instruments to channel credit towards green sectors, high-income countries seem to lag behind by staying still satisfied by an "all talk, no walk" strategy.

According to our investigation, while policymakers are increasingly contributing to the development of a green macroprudential regulation, many existing policy intervention and proposals are prone to destabilizing effects for the financial sector. We thus suggest a set of alternative strategies to greening the existing Basel III. Among them, we suggest to adopt a countercyclical (or negative) capital buffer along the carbon-intensive credit cycle, a sectoral leverage requirement which targets exposures toward a specific green sector, a liquidity regulation to dampen short-termism in financial intermediation, minimum (maximum) credit floors (ceilings) and large exposure limit to constrain an intermediary exposure to brown sectors. In particular, in the case of the establishment of a minimum capital requirement with Green Supporting Factor, we suggest two alternatives. In our view, it would be necessary to either adopt a more risk-sensitive capital requirement, with the GSF based on a common taxonomy and disclosure standards for green assets, combined

with implementations of loan-loss reserves or rather opt for a Brown Penalising Factor. Regarding the application of DRR as a possible green macroprudential instrument, we see it more suitable for low-income countries rather than high-income countries, where the legal reserve requirements are close to zero. We also point out that it can hinder liquidity management, bringing to a suboptimal outcome and tangle the conduct of monetary policy; hence, a strong coordination issue arises.

Moreover, although the empirical evidence on the effectiveness of the standard macroprudential tools is still scarce, and the quantitative approach is of limited guidance for the calibration of green macroprudential tools, we suggest that these instruments could play an important role. However, according to us, the current harmonized Basel III financial regulatory setup can be used to align climate and financial stability objectives. This implies on one side, the set up of a commonly defined taxonomy of environmentally sustainable economic activities and an agreed-upon disclosure framework, on the other side, some degree of experimentation left for policymakers and regulators, in an attempt to strike a balance between "boldness and realism" (Borio, 2011). We think, indeed, that although it exists the risk to attribute overly-ambitious goals to central banks, the window of opportunity offered by the proposed green policy framework to tackle climate change cannot be missed. As the financial crisis has to lead to the build-up of instruments to ensure the system's resilience against financial instability, we envisage a similar dynamic for the development of green prudential instruments to tame financial risks related to physical, transition and liability risks, and contribute to increase the financial resources to be devoted to green investments.

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References

2DII (2018). The green supporting factor. quantifying the impact on european banks and green finance. Technical report, 2 degrees Investing Initiative.

Aiyar, S., C. W. Calomiris, J. Hooley, Y. Korniyenko, and T. Wieladek (2014). The international transmission of bank capital requirements: Evidence from the uk. *Journal of Financial Economics 113*(3), 368–382.

Aldasoro, I. and E. Faia (2016). Systemic loops and liquidity regulation. *Journal of Financial Stability 27*, 1 – 16.

Alexander, K. (2014). Stability and sustainability in banking reform: are environmental risks missing in basel iii. *CISL & UNEPFI: Cambridge and Geneva*.

Allen, B., K. K. Chan, A. Milne, and S. Thomas (2012). Basel iii: Is the cure worse than the disease? *International Review of Financial Analysis 25*, 159 – 166. Banking and the Economy.

Angelini, P., L. Clerc, V. Cúrdia, L. Gambacorta, A. Gerali, A. Locarno, R. Motto, W. Roeger, S. Van den Heuvel, and J. Vlček (2015). Basel iii: Long-term impact on economic performance and fluctuations. *The Manchester School 83*(2), 217–251.

Angelini, P., S. Nicoletti-Altimari, and I. Visco (2012). Macroprudential, microprudential and monetary policies: conflicts, complementarities and trade-offs. Technical report, Bank of Italy.

Bai, J., A. Krishnamurthy, and C.-H. Weymuller (2018). Measuring liquidity mismatch in the banking sector. *The Journal of Finance 73*(1), 51–93.

Balint, T., F. Lamperti, A. Mandel, M. Napoletano, A. Roventini, and A. Sapio (2017). Complexity and the economics of climate change: A survey and a look forward. *Ecological Economics 138*, 252 – 265.

Batten, S., R. Sowerbutts, and M. Tanaka (2016). Let's talk about the weather: the impact of climate change on central banks. Technical report, Bank of England.

Battiston, S., A. Mandel, I. Monasterolo, F. Schütze, and G. Visentin (2017). A climate stress-test of the financial system. *Nature Climate Change 7*(4), 283–288.

BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems. *Basel Committee on Banking Supervision*.

BCBS (2014). Basel iii leverage ratio framework and disclosure requirements. Technical report, BCBS -Basel Committee on Banking Supervision.

BCBS (2014a). Basel iii leverage ratio framework and disclosure requirements. *BIS Published Documents* (January).

BCBS (2014b). Supervisory framework for measuring and controlling large exposures. *BCBS*.

BCBS (2016). Guidance on the application of the core principles for effective banking supervision to the regulation and supervision of institutions relevant to financial inclusion.

Bank of international Settlements September.

BCBS (2017). Range of practices in implementing the countercyclical capital buffer policy. Technical report, BCBS - Basel Committee on Banking Supervision.

BCBS (2018). Towards a sectoral application of the countercyclical capital buffer: A literature review. Technical report, BCBS - Basel Committee on Banking Supervision.

BDL (2009). Bdl environmental loans. Technical report, Presentation by Banque Du Liban Financing Unit.

BDL (2010). Intermediate circular on reserve requirements. Technical report, Intermediate Circular No. 236, Beirut: Banque du Liban.

Bhattacharya, A., J. Oppenheim, and N. Stern (2015). Driving sustainable development through better infrastructure: Key elements of a transformation program. *Brookings Global Working Paper Series*.

Blundell-Wignall, A. and P. Atkinson (2010). Thinking beyond basel iii. *OECD working paper*.

Borio, C. (2003). Towards a macroprudential framework for financial supervision and regulation? *CESifo Economic Studies 49*(2), 181–215.

Borio, C. (2011). Implementing a macroprudential framework: Blending boldness and realism. *Capitalism and Society 6*(1).

Borio, C. (2014). The financial cycle and macroeconomics: What have we learnt? *Journal of Banking & Finance 45*, 182–198.

Bovari, E., G. Giraud, and F. M. Isaac (2018). Coping with collapse: A stock-flow consistent monetary macrodynamics of global warming. *Ecological Economics 147*, 383 – 398.

Buchner, B. K., P. Oliver, X. Wang, C. Carswell, C. Meattle, and F. Mazza (2017). Global landscape of climate finance 2017. Technical report, Climate Policy Initiative.

Budnik, K. B. and J. Kleibl (2018). Macroprudential regulation in the european union in 1995-2014: introducing a new data set on policy actions of a macroprudential nature. *ECB Working Paper No 2123/January 2018*.

Caldecott, B. (2017). Introduction to special issue: stranded assets and the environment. *Journal of Sustainable Finance & Investment 7*(1), 1–13.

Caldecott, B. and J. McDaniels (2014). Financial dynamics of the environment: Risks, impacts, and barriers to resilience. *Documento de trabajo del Estudio del PNUMA. UNEP Inquiry/Smith School, Oxford University*.

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

Campiglio, E., Y. Dafermos, P. Monnin, J. Ryan-Collins, G. Schotten, and M. Tanaka (2018). Climate change challenges for central banks and financial regulators. *Nature Climate Change 8*(6), 462.

Campiglio, E., A. Godin, E. Kemp-Benedict, and S. Matikainen (2017). The tightening links between financial systems and the low-carbon transition. In *Economic Policies since the Global Financial Crisis*, pp. 313–356. Springer.

Carney, M. (2015). Breaking the tragedy of the horizon - climate change and financial stability (speech). *Bank of England, Speech*.

Carney, M. (2018). A transition in thinking and action. *Bank of England, Speech*.

Cerutti, E., S. Claessens, and L. Laeven (2017). The use and effectiveness of macroprudential policies: new evidence. *Journal of Financial Stability 28*, 203–224.

Cerutti, M. E. M., M. R. Correa, E. Fiorentino, and E. Segalla (2016). Changes in prudential policy instruments: a new cross-country database. *IMF Working papers* (WP/16/110).

Chang, C., Z. Liu, M. M. Spiegel, and J. Zhang (2018). Reserve requirements and optimal chinese stabilization policy. Federal Reserve Bank of San Francisco.

Chen, M., J. Wu, B. N. Jeon, and R. Wang (2017). Do foreign banks take more risk? evidence from emerging economies. *Journal of Banking & Finance 82*, 20–39.

Claessens, S. (2014). An overview of macroprudential policy tools. *IMF Working Paper* (14/214).

Cook, J., D. Nuccitelli, S. Green, M. Richardson, B. Winkler, R. Painting, R. Way, P. Jacobs, and A. Skuce (2013). Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environmental Research Letters 8*(2), 024024.

COP (2015). Adoption of the paris agreement. *UN-Framework Convention on Climate Change*.

COP (2016). Marrakech action proclamation for our climate and sustainable development. *UN-Framework Convention on Climate Change*.

Cordella, T., P. Federico, and C. Vegh (2014). *Reserve requirements in the brave new macroprudential world*. World Bank Publications.

Covington, H. and R. Thamotheram (2015). The case for forceful stewardship (part 1): The financial risk from global warming.

Dafermos, Y., M. Nikolaidi, and G. Galanis (2017). A stock-flow-fund ecological macroeconomic model. *Ecological Economics 131*, 191–207.

Dafermos, Y., M. Nikolaidi, and G. Galanis (2018). Climate change, financial stability and monetary policy. *Ecological Economics 152*, 219–234.

Delis, M. D., K. de Greiff, and S. Ongena (2018). Being stranded on the carbon bubble? climate policy risk and the pricing of bank loans.

Dietz, S., A. Bowen, C. Dixon, and P. Gradwell (2016). "climate value at risk" of global financial assets. *Nature Climate Change 6*(7), 676.

Dikau, S. and J. Ryan-Collins (2017). Green central banking in emerging market an developing country economies.

DNB (2017). Waterproof? an exploration of climate-related risks for the dutch financial

sector. *De Nederlandsche Bank, working paper*.

Dombrovskis, V. (2017). Greening finance for sustainable business. *Speech by Vice-President for the Euro and Social Dialogue, Financial Stability and Financial Services Valdis Dombrovskis* (SPEECH/17/5235).

Doran, P. T. and M. K. Zimmerman (2009). Examining the scientific consensus on climate change. *Eos, Transactions American Geophysical Union 90*(3), 22–23.

D'Orazio, P. and L. Popoyan (2018). Green macroprudential instruments: objectives and geographical diffusion. *Data in Brief, submitted*.

D'Orazio, P. and M. Valente (2018). The role of finance in environmental innovation diffusion: an evolutionary modeling approach. *Working paper*.

Dore, R. (2008). Financialization of the global economy. *Industrial and Corporate Change 17*(6), 1097–1112.

Draghi, M. (2017). Response to a letter of the members of the european parliament. *L/MD/17/382*.

Drehmann, M. and L. Gambacorta (2012). The effects of countercyclical capital buffers on bank lending. *Applied Economics Letters 19*(7), 603–608.

Duca, J. V., L. Popoyan, and S. M. Wachter (2018). Real estate and the great crisis: Lessons for macroprudential policy. *Contemporary Economic Policy*.

EBA (2016). European banking authority report on smes and sme supporting factor. *EBA/OP*, 2016/04.

EBA (2018). Green finance: Encouraging green loans is a sensible idea. (originally published in dutch daily het financieele dagblad on 16 january 2018).

EBF (2018). Towards a green finance framework. *European Banking Federation report*.

Ehlers, T. and F. Packer (2017). Green bond finance and certification. *BIS Quarterly Review*.

ESRB (2016a). Macroprudential policy beyond banking: an esrb strategy paper. Technical report, Advisory Scientific Committee of the European Systemic Risk Board.

ESRB (2016b). Too late, too sudden: Transition to a low-carbon economy and systemic risk. (6).

Farahbaksh, M. M. and M. G. Sensenbrenner (1996). *Bank-by-bank credit ceilings: issues and experiences*. International Monetary Fund.

Federico, P., C. A. Vegh, and G. Vuletin (2014). Reserve requirement policy over the business cycle. *NBER Working Paper Series* (20612).

Finance Watch (2018). A green supporting factor would weaken banks and do little for the environment. *http://finance-watch.org/hot-topics/blog/1506-green-supporting-factor*.

Fontana, G. and M. Sawyer (2016). Towards post-keynesian ecological macroeconomics. *Ecological Economics 121*, 186 – 195.

Friedlingstein, P., R. M. Andrew, J. Rogelj, G. Peters, J. G. Canadell, R. Knutti, G. Luderer, M. R. Raupach, M. Schaeffer, D. P. van Vuuren, et al. (2014). Persistent growth

of co2 emissions and implications for reaching climate targets. *Nature geoscience 7*(10), 709–715.

Fungáčová, Z., R. Nuutilainen, and L. Weill (2016). Reserve requirements and the bank lending channel in china. *Journal of Macroeconomics 50*, 37–50.

Galati, G. and R. Moessner (2017). What do we know about the effects of macroprudential policy? *Economica*.

Gauthier, C., A. Lehar, and M. Souissi (2012). Macroprudential capital requirements and systemic risk. *journal of Financial Intermediation 21*(4), 594–618.

Gersbach, H. and J.-C. Rochet (2012). Aggregate investment externalities and macroprudential regulation. *Journal of Money, Credit and Banking 44*(s2), 73–109.

Gersbach, H. and J.-C. Rochet (2017). Capital regulation and credit fluctuations. *Journal of Monetary Economics 90*, 113–124.

Ghosh, A. R., J. D. Ostry, and M. Chamon (2016). Two targets, two instruments: monetary and exchange rate policies in emerging market economies. *Journal of International Money and Finance 60*, 172–196.

Gray, S. (2011). Central bank balances and reserve requirements. *IMF Working Paper* (11/36).

Gros, D., P. Lane, S. Langfield, S. Matikainen, M. Pagano, D. Schoenmaker, J. Suarez, et al. (2016). Too late, too sudden: Transition to a low-carbon economy and systemic risk. Technical report, European Systemic Risk Board.

Hahm, J.-H., F. S. Mishkin, H. S. Shin, and K. Shin (2012, January). Macroprudential policies in open emerging economies. Working Paper 17780, National Bureau of Economic Research.

Haldane, A. (2011). The short long, 29th société universitaire européene de recherches financiéres colloquium: New paradigms in money and finance?, brussels. Technical report, Bank of England.

Haldane, A. (2013). Why institutions matter (more than ever). In *Speech delivered at Centre for Research on Socio-Cultural Change (CRESC) Annual Conference, School of Oriental and African Studies, London. Available at: http://www. bankofengland. co. uk/publications/Documents/speeches/2013/speech676. pdf.*

HLEG (2018). Final report on financing a sustainable european economy. *Interim Report - High-Level Expert Group on Sustainable Finance*.

Hong, H., J.-Z. Huang, and D. Wu (2014). The information content of basel iii liquidity risk measures. *Journal of Financial Stability 15*, 91 – 111.

Jiménez, G., S. Ongena, J.-L. Peydró, and J. Saurina (2017). Macroprudential policy, countercyclical bank capital buffers, and credit supply: evidence from the spanish dynamic provisioning experiments. *Journal of Political Economy 125*(6), 000–000.

Kahou, M. E. and A. Lehar (2017). Macroprudential policy: A review. *Journal of Financial Stability 29*, 92–105.

Kelly, S. and J. Reynolds (2016). Unhedgeable risk: How climate change sentiment impacts investment. *Central Banking, Climate Change and Environmental Sustainability*.

Kemp-Benedict, E. (2018). Investing in a green transition. *Ecological Economics 153*, 218 – 236.

King, M. R. (2013). The basel iii net stable funding ratio and bank net interest margins. *Journal of Banking & Finance 37*(11), 4144–4156.

Lamperti, F., G. Dosi, M. Napoletano, A. Roventini, and A. Sapio (2018). Faraway, so close: coupled climate and economic dynamics in an agent-based integrated assessment model. *Ecological Economics August*, 315–339.

Liebreich, M. and A. McCrone (2013). Financial regulation-biased against clean energy and green infrastructure?'. *Clean energy-White Paper*.

Lim, C. H., A. Costa, F. Columba, P. Kongsamut, A. Otani, M. Saiyid, T. Wezel, and X. Wu (2011). Macroprudential policy: what instruments and how to use them? lessons from country experiences. *IMF Working Paper* (11/238).

Matikainen, S. (2017). Green doesnt mean risk-free: why we should be cautious about a green supporting factor in the eu. *Grantham Research Institute on Climate Change and the Environment*, http://www.lse.ac.uk/GranthamInstitute/news/eu–green–supporting–factor–bank–risk/.

Matikainen, S., E. Campiglio, and D. Zenghelis (2017). The climate impact of quantitative easing. Technical report, London School of Economics.

Mazzucato, M. (2013). Financing innovation: creative destruction vs. destructive creation. *Industrial and Corporate Change*, dtt025.

Mazzucato, M. and G. Semieniuk (2018). Financing renewable energy: Who is financing what and why it matters. *Technological Forecasting and Social Change 127*, 8 – 22.

Minsky, H. P. (1982). *Can 'It' Happen Again? Essays on Instability and Finance*. New York: M.E. Sharpe.

Minsky, H. P. (1992). The Financial Instability Hypothesis. Working Paper 74, The Jerome Levy Economics Institute of Bard College.

Mishkin, F. S. (2017). Rethinking monetary policy after the crisis. *Journal of International Money and Finance 73*(Part B), 252 – 274. Global Economy: Future Financial and Macro Challenges.

Monasterolo, I., S. Battiston, A. C. Janetos, and Z. Zheng (2017, Nov). Vulnerable yet relevant: the two dimensions of climate-related financial disclosure. *Climatic Change*.

Monasterolo, I. and M. Raberto (2018). The eirin flow-of-funds behavioural model of green fiscal policies and green sovereign bonds. *Ecological Economics 144*, 228–243.

Monnin, P. (2018). Central banks and the transition to a low-carbon economy. Technical report, Discussion note 2018/1. Zurich: Council on Economic Policies.

Moody's (2018). Moody's raps eu plans for lower capital charges on banks' green investment. *Reuters, https://uk.reuters.com/article/eu-climatechange-banks-moodys/moodys-*

raps-eu-plans-for-lower-capital-charges-on-banks-green-investment-idUKL8N1OI2BA.

Moody's (2018). Rating scale and definition.

Narbel, P. A. (2013). The likely impact of basel iii on a bank's appetite for renewable energy financing. *Norwegian School of Economics Working papers, https://core.ac.uk/download/pdf/52096366.pdf*.

OECD/IEA (2014). World energy investment outlook. *Publishing Paris, https://www.iea.org/publications/freepublications/publication/WEIO2014.pdf*.

Oreskes, N. (2004). The scientific consensus on climate change. *Science 306*(5702), 1686–1686.

Popoyan, L., M. Napoletano, and A. Roventini (2017). Taming macroeconomic instability: Monetary and macro-prudential policy interactions in an agent-based model. *Journal of Economic Behavior & Organization 134*, 117–140.

Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin, E. F. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. J. Schellnhuber, et al. (2009). A safe operating space for humanity. *Nature 461*(7263), 472–475.

Rozenberg, J., S. Hallegatte, B. Perrissin-Fabert, and J.-C. Hourcade (2013). Funding low-carbon investments in the absence of a carbon tax. *Climate Policy 13*(1), 134–141.

Schoenmaker, D. and R. Van Tilburg (2016). What role for financial supervisors in addressing environmental risks? *Comparative Economic Studies 58*(3), 317–334.

Schotten, G., S. van Ewijk, M. Regelink, D. Dicou, and J. Kakes (2016). Time for transition: An exploratory study of the transition to a carbon-neutral economy. *Occasional Studies*, 14–2.

Sevillano, J. and L. Gonzalez (2018). The risk of climate change for financial markets and institutions: challenges, measures adopted and international initiatives. *Bank of Spain, Financial Stability Review Issue 34*.

Smets, F. et al. (2014). Financial stability and monetary policy: How closely interlinked? *International Journal of Central Banking 10*(2), 263–300.

Spencer, T. and J. Stevenson (2013). Eu low-carbon investment and new financial sector regulation: What impacts and what policy response. *IDDRI Sciences Po, Paris*.

Stiglitz, J. E., N. Stern, M. Duan, O. Edenhofer, G. Giraud, G. Heal, E. La Rovere, A. Morris, E. Moyer, M. Pangestu, et al. (2017). Report of the high-level commission on carbon prices. *Carbon Pricing Leadership Coalition 29*.

Stolbova, V., I. Monasterolo, and S. Battiston (2018). A financial macro-network approach to climate policy evaluation. *Ecological Economics 149*, 239 – 253.

TCFD (2017). Final report: Recommendations of the task force on climate-related financial disclosures. *Task Force on Climate-related Financial Disclosures*.

Thanassoulis, J. (2014). Bank pay caps, bank risk, and macroprudential regulation. *Journal of Banking & Finance 48*, 139–151.

Thoma, j., W. C. F. M. A. S. and H. Chenet (2016). Transition risk toolbox: Scenarios,

data, and models. *2 Degree Investing Initiative*.

UN-Environment and G. World Bank (2017). Roadmap for a sustainable financial system. *Inquiry: design of a sustainable financial system*.

Van den End, J. W. (2016). A macroprudential approach to address liquidity risk with the loan-to-deposit ratio. *The European Journal of Finance 22*(3), 237–253.

Van Lerven, F. and J. Ryan-Collins (2018). Adjusting banks' capital requirements in line with sustainable finance objectives. *New Economics Foundation, Briefing note*.

Villeroy de Galhau, F. (2018). Green finance - a new frontier for the 21st century. Technical report, Banque de France.

Volz, U. (2017). On the role of central banks in enhancing green finance. *UN Environment Inquiry Working Paper 17/01*.

WEF (2013). The green investment report: The ways and means to unlock private finance for green growth. *World Economic Forum, http* : $//www3.weforum.org/docs/WEF_GreenInvestment_Report_2013.pdf$.

World Bank, W. B. (2014). State and trends of carbon pricing 2014. *World Bank Publications*.

World Bank, W. B. (2016). State and trends of carbon pricing 2016. *World Bank Publications*.

A Macroprudential tools under Basel II and Basel III

BASEL II		
Pillar I	**Pillar II**	**Pillar III**
Minimum capital requirement	***Supervisory review***	***Market discipline***
Minimum standards for management of capital: • Credit risk • Operational risk • Market risk	- Capital adequacy strategies - Evaluation internal models - Level of capital charge - Proactive monitoring of capital levels and ensuing remedial action	Risk management: • credit • operational • market
BASEL III		
Pillar I	**Pillar II**	**Pillar III**
Enhanced minimum capital & liquidity requirements	***Enhanced supervisory review***	***Enhanced risk disclosure & market discipline***
Additional tools: - Liquidity coverage ratio (LCR) - Net Stable Funding Ratio (NSFR) - Leverage ratio - Capital conservation buffers - Countercyclical capital buffers - Enhanced loss absorption clause - Quality and level of capital - Securitization - Trading risk - Counterparty credit risk	*Additional tools:* - ICAAP - Supervisory review Evaluation process - Stress tests	*Additional tools:* - Regulatory capital components - Regulatory capital ratios - Securitisation exposures

Table 3: Overview and comparison of the 3 Pillars framework of Basel II (upper panel) and Basel III (lower panel).

B Focus on Europe

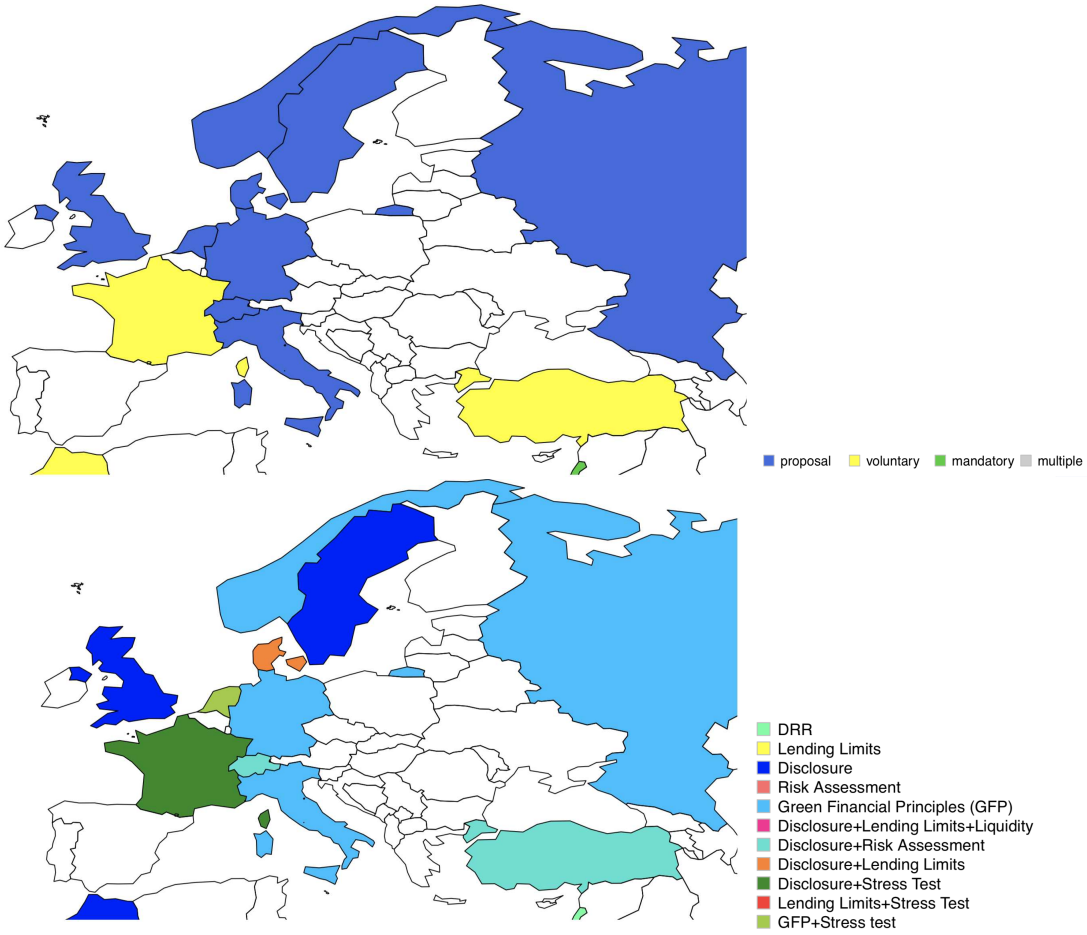

Figure 7: The diffusion of green prudential instruments: an European perspective

C Focus on Asia

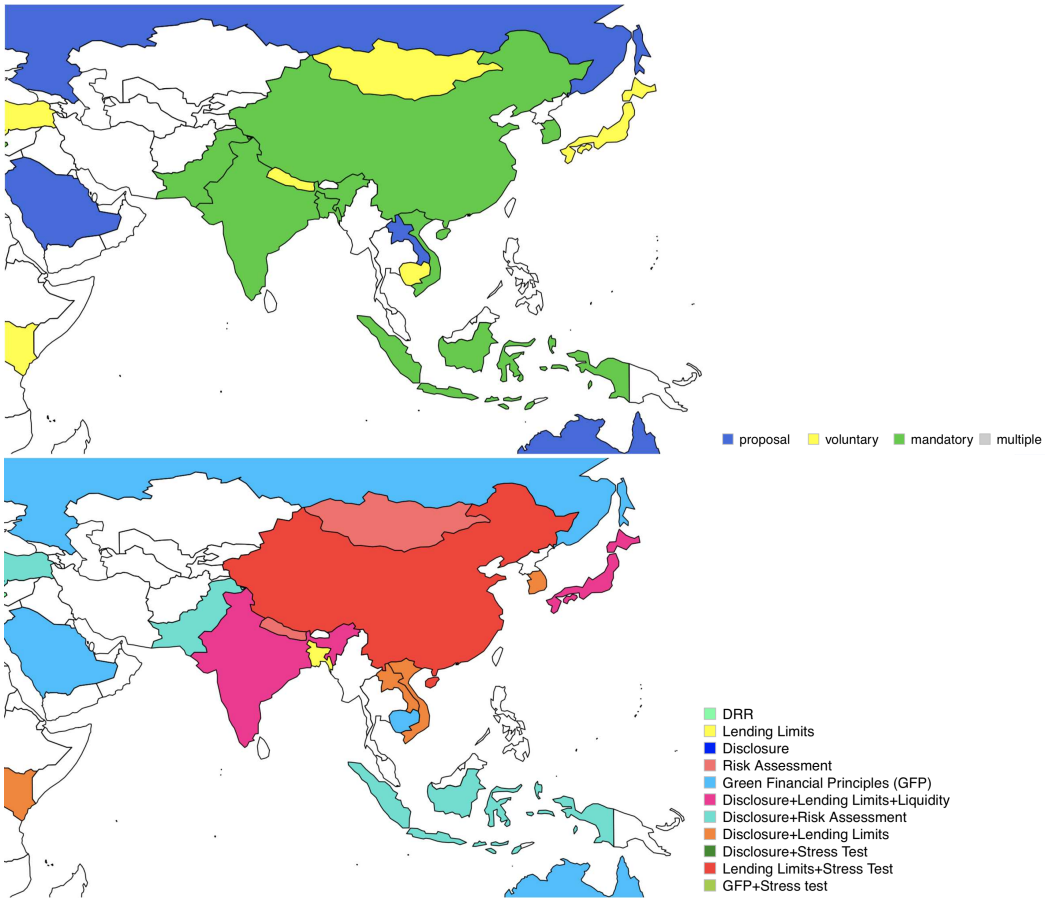

Figure 8: The diffusion of green prudential instruments: an Asian perspective