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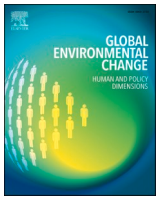

The role of green financial sector initiatives in the low-carbon transition: A theory of change☆

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ABSTRACT

Green financial sector initiatives, including green macroprudential policies, green monetary policies, and green public co-funding, could play an important role in the low-carbon transition by supporting countries in the implementation of their climate objectives. This paper analyzes how green financial sector initiatives could enable the scaling up of green investments while avoiding unintended effects on macroeconomic and financial stability. For each green financial sector initiative, the paper identifies its entry point in the economy, the transmission channels to banks' investment decisions in terms of availability and cost of capital for high- and low-carbon goods, and the resulting impacts on output and greenhouse gas emissions. Building on these insights, the paper develops a theory of change about the role of green financial sector initiatives for climate mitigation, identifying the criteria for applicability and conditions to maximize their impact. It discusses specifically the application of the theory of change to the low-carbon transition in coal and carbon intensive regions in the context of the European net zero climate objective.

1. Introduction

The financial sector, including private and public financial actors, is expected to play a major role in the low-carbon transition, by scaling up capital directed towards low-carbon activities and by divesting from high-carbon activities (see e.g. Art 2.1c of the Paris Agreement, UNFCCC, 2015). However, green capital formation is not occurring yet at the pace and amount needed to achieve countries' climate mitigation ambitions, leading to a *green investment gap* (Kreibiehl et al., 2022). In Europe, this gap is particularly acute in coal and carbon intensive regions (CCIR) for which a major restructuring of the industrial structure is required (Pianta and Lucchese, 2020).

The existing literature has extensively investigated the industrial and technological requirements for the low-carbon transition, and the potential role of industrial policy in this process (see e.g. Rodrik, 2014; Stiglitz, 2016; Kemp and Never, 2017; Mealy and Teytelboym, 2022). Several contributions focused on quantifying the green investment gap and its drivers (Debrah et al., 2022; Calipel et al., 2024; Monasterolo et al., 2024 for Europe). However, although the issue is emerging rapidly on the policy agenda (Boneva et al., 2021; Berg et al., 2023), there is limited understanding of the role that monetary and financial policies can play to help closing the green investment gap. Our aim in this paper is to build-up this understanding by (i) providing a systematic review of the type of financial policies, henceforth green financial sector initiatives (GFSI), that have been identified as potential contributors to climate policy objectives, (ii) characterizing the transmission channels of these policies from the financial to the real sphere and therefrom to Greenhouse gas (GHG) emissions reduction objectives, (iii) developing a

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"theory of change" that analyses under which conditions GFSI could be effectively combined and deployed to support climate change mitigation and economic decarbonization, focusing in particular on the case of coal and carbon intensive regions (CCIR).

Through a review of the academic and policy literature we identify three main types of GFSI: green regulatory policies, green monetary policies, and public funding/co-funding of green investments. Green regulatory policies (GRP) consist of policies that rely on prudential regulation to induce a shift towards low-carbon sectors and technologies in the composition of financial institutions' lending and investment portfolios. They include the green supporting factor (GSF) aimed to lower capital requirements for banks' lending to green investments (initially proposed by the European Commission, see Dombrovskis, 2018), and the "dirty" penalizing factor (Thomä and Hilke, 2018; Dafermos et al., 2021; Dunz et al., 2021). Green monetary policies consist in the preferential purchase of green bonds (Dafermos et al., 2018; Oustry et al., 2020; Bressan et al., 2022) in the context of green quantitative easing and green collateral frameworks (Campiglio et al., 2018; D'Orazio and Popoyan, 2019; Schoenmaker, 2021; Svartzman et al., 2021; Dafermos et al., 2021; McConnell et al., 2022). Public funding and co-funding of green investments are implemented as green portfolio rewards (TCAF, 2021), the capitalization of green national development banks (Griffith-Jones and Gallagher, 2021), and the exploitation of synergies between central banks and state-investment banks, e.g., in the European Union (EU) in the case of the European Central Bank (ECB) and the European Investment Bank (EIB) (Monasterolo and Volz, 2020). More specifically, the Just Transition Mechanism, which is the flagship policy for CCIR, is, to a large extent, a green financial sector intervention consisting in public funding and co-funding of green investments.[1]

Then, by building on the procedures developed in life-cycle analysis (Weidema et al., 2009) and in the GHG protocol (WRI, 2014) for causal chain mapping, for each GFSI we map its transmission channels to banks, to the economy and to GHG emissions. More precisely, we analyze the direct impacts of GFSI on *the cost of capital* for high- and low-carbon activities and *on the quantity of capital* supplied to high- and low-carbon activities. Then, we consider second-order impacts, notably on the *demand* for and on the *quantity* of investments in high- and low-carbon activities, and on *relative prices* for high- and low-carbon activities. Furthermore, we track the propagation of these effects through the real economy and their potential impact on GHG emissions reduction and economic decarbonization.

This analysis enables us to develop a Theory of Change about the role of GFSI in climate mitigation and economic decarbonization. The Theory of Change enables the operationalization of the GFSI, conditioned to the specific green finance policy and instrument transmission channels; the country's initial conditions; economic and financial characteristics; mitigation objectives; and governance. Finally, we investigate its application to CCIR in the context of the European net-zero climate objective.

The paper is organized as follows. Section 2 provides a literature review of the main GFSI discussed and/or implemented, in light of recent research. Section 3 discusses the transmission channels through which each GFSI impacts the real economy, the balance sheet of financial institutions, and GHG emissions reduction. Section 4 presents the Theory of Change for the operationalization of GFSI to achieve climate objectives. Section 5 concludes.

2. Green finance sector Initiatives: A review of the literature

2.1. Analysis of the determinants of the green investment gap

A growing literature has discussed the drivers of the green investment gap. First, the price of high-carbon goods does not fully reflect the negative externalities they have, via GHG emissions, on the environment and on climate change (Stiglitz, 2019; Stern and Stiglitz, 2021). Second, green projects are characterized by short track record and specific (long) time structure and can thus appear riskier to investors (Monasterolo and Volz, 2020). Third, climate policy uncertainty limits investors' ability to embed future climate costs and benefits in their investment decisions and risk management tools (Battiston et al., 2021; Kreibiehl et al., 2022).

These conditions create adverse incentives, both for firms to invest in low-carbon projects, and for investors to finance such projects. To overcome this market failure, the need for the introduction of credible and early climate policies such as a carbon tax has been recognized by scholars (Stiglitz et al., 2017; Cramton et al., 2017; van der Ploeg and Rezai 2019; Hepburn et al., 2020) practitioners and investors. The literature also recognizes that a broader package of policies combining carbon pricing with public investments in low-carbon technologies and welfare policies is needed to support firms and labor in switching to low-carbon activities and jobs (Meckling and Allan, 2020; Bergquist et al., 2020).

2.2. The policy landscape for climate finance

Over 130 central banks and financial regulators have joined the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) and have published individual pledges and long-term strategies.[2] Almost all pledges and strategies involve actions aimed at strengthening micro-and macro-prudential climate-related supervision, by using climate scenario analysis and climate stress tests (see NGFS 2020, and methodological references in Battiston et al., 2017; Reinders et al., 2021), and by issuing supervisory regulation or guidance.[3] There is also a general agreement on the importance of embedding climate-related financial risks in financial risk management (BCBS, 2021a), accounting for investors' exposures to high-carbon activities that could become carbon stranded assets (Leaton, 2011; McGlade and Ekins, 2015; van der Ploeg and Rezai, 2020; Cahen-Fourot et al., 2021; Welsby et al., 2021) and translating such exposures into risk assessment (Battiston et al., 2017, 2023). In a disorderly transition to a low-carbon economy, changes in the value of these assets could have implications for financial stability, both at the level of individual financial institutions and of the financial system (Battiston et al., 2017; NGFS, 2020; BCBS, 2021b; ESRB-ECB, 2021. This matters for central banks and financial regulators that have a financial stability mandate (Dikau and Volz, 2021). Accordingly, the NFGS has recommended to investors to disclose and assess climate risks, and has developed scenarios for climate stress-testing (NGFS, 2020; Bertram et al., 2021) that have been applied by several central banks (see e.g. Allen et al., 2020; Alogoskoufis et al., 2021).

Beyond risk management, the debate remains about the role of GFSI in climate mitigation and, in particular, about which GFSI would be best suited for delivering GHG emission reductions, considering the opportunities and barriers in their application by type of country and instrument.

[1] The Just Transition Mechanism is a framework to support national just transition efforts, providing dedicated financial resources and technical assistance to EU member states with the requirement that recipients develop national just transition plans. It includes a 17.5 billion euros ($17.8 billion) Just Transition Fund, along with 13.3 billion euros ($13.5 billion) in grants and loans through other channels to support just transition programs and investments, in addition to co-financing and matching requirements for countries.

[2] The NGFS currently consists of 87 members and 13 observers among financial institutions. See the list of pledges at https://www.ngfs.net/sites/default/files/ngfs_contribution_to_cop26_contributing_members.pdf.

[3] See https://www.ecb.europa.eu/press/key/date/2021/html/ecb.sp211103_1~981d1ed885.it.html.

2.3. Green regulatory policies

Green regulatory policies (GRP) affect capital requirements through changes in the weighting factor used for the computation of risk-weighted assets, as a function of the technological and sectoral characteristics of these assets.

The use of GRP can play an important role in fostering green investment and promoting the low-carbon transition via signaling. However, growing concern emerged that prudential policies introduced in the aftermath of the last financial crisis (i.e., within the Basel III regulatory framework) could negatively affect green investments by setting liquidity requirements that favor short-term investments. This, in turn, could impair banks' financing of green projects, which are characterized by more long-term horizons and are thus currently perceived as riskier (D'Orazio and Popoyan, 2019). The current Basel III framework has been criticized for not considering climate change, including only a narrow definition of climate-related financial risks. At the same time, regulatory capital and liquidity regulations do not explicitly account for the risks stemming from climate change (BCBS, 2016).[4]

In recent years, several macro- and micro-prudential policies have been discussed with the aim to address climate-related financial risks, including capital, liquidity, and reserve requirements, caps on loan-to-value ratios, and minimum credit floors and maximum credit ceilings, also targeted at specific sectors (Campiglio et al., 2018; D'Orazio and Popoyan, 2019). More specifically, the two core policies in this realm are the Green Supporting Factor (GSF) and the Dirty Penalizing Factor (DPF).

The GSF mechanism affects banks' ability to grant credit to firms via adjustments in the minimum Capital Adequacy Ratio (CAR)[5] contingent on a bank's carbon or climate risk profile. The GSF allows banks to commit less capital for loans to "green" activities, which should contribute to accelerating the transition to a sustainable, net-zero economy. In particular, in combination with minimum capital requirements,[6] within a GSF framework, banks are expected to assign lower risk-weights to green projects. Therefore, lending to low-carbon activities, which are currently considered riskier by banks due to limited information about costs and performance, would put less pressure on banks' balance sheets, thus scaling up financing for low-carbon or green projects.

On the one hand, the GSF could contribute to narrow the green investment gap by incentivizing banks' lending to low-carbon activities (Dombrovskis, 2018; HLEG, 2018). On the other hand, the way the GSF is implemented can undermine its effectiveness and may destabilize the banking sector's financial stability. Indeed, introducing a GSF may loosen the regulatory CAR for low-carbon investments (Schoenmaker and van Tilburg, 2016). Thus, in the absence of a standardized taxonomy of green activities, financial risks associated with green investments can be underestimated.[7]

Besides the GSF, a Dirty Penalizing Factor (DPF) has been discussed as a prudential policy tool to scale up green investments. Differently from the GSF, the DPF requires financial institutions to hold more prudential capital for high-carbon assets, i.e., assets that are exposed to climate transition risk, implying adjustments in their lending portfolio if capital constraints are binding.

[4] An update of the principles for the effective management and supervision of climate-related financial risks by the BCBS is currently under consultation (BCBS 2021a).

[5] The CAR is defined as the ratio between a bank's capital and the risk-weighted assets.

[6] As under the Basel III regulatory framework.

[7] Considering high-carbon assets as highly risky does not imply automatically that green assets are safer.

2.4. Green monetary policies (GMP)

Following the Great Financial Crisis (GFC) in 2008, central banks around the world have introduced unconventional monetary policy measures including (Guerini et al., 2018):

- *Balance sheet policies*, focused on using the central banks' balance sheet to influence financial conditions beyond the short-term rate. In particular, asset purchase programs also known as Quantitative Easing (QE) have been deployed to achieve monetary policy objectives when the policy rate hits its lower bound. However, these purchases were carried out by central banks in proportion to the outstanding market shares, thus generating a potential "carbon bias" in central banks' portfolios as high-carbon companies have a larger weight in corporate bond markets (Boneva et al., 2021).
- *Forward guidance policies*, which pertain to the management of the expectations of the policy rate over the medium run, with the aim to provide stimulus when interest rates have reached the zero-lower bound (ZLB).
- *Negative interest rate policies*, aimed at incentivizing lending.

This new set of monetary policy measures could support the implementation of green monetary policies with the objective to induce a shift in the technological and sectoral composition of investments in the economy. The most debated green policies in this respect are green collateral framework (GCF) and green quantitative easing (GQE) (Batten et al., 2016).

- *Green collateral frameworks (GCF)* consist in reviewing the pricing and/or eligibility criteria of the collaterals central banks accept in their lending as a function of their technological and sectoral characteristics. This is implemented as the introduction of a cap (maximum) on the share of high-carbon assets or a threshold (minimum) on the share of low-carbon assets that can be held in the portfolio, and through the modulation of the haircut implying higher haircuts for high-carbon assets, and lower haircuts for low carbon-assets (see Dafermos et al., 2021; Oustry et al., 2020).
- *Green asset purchase program*, also known as *green QE*, consists in an asset purchase program with preferential targeting of low-carbon assets and thus rebalances the central bank's balance sheet towards bonds issued by firms in low-carbon sectors (see Ferrari and Landi, 2021).

GCF and GQE share similar eligibility criteria based on sector, technology and carbon intensity of the assets. In order to carry out preferential purchases, the central bank must have sector and technological standards (e.g. taxonomies) to identify what to purchase and what assets to exclude.

Channels through which the two policies work differ in so far GCF impacts financial institutions' ability to obtain central bank money while GQE impacts more directly securities issuers in the real sector via preferential asset purchase. Finally, the *implications for central banks' balance sheets* differ. In the case of GQE, the central bank's balance sheet increases as a result of asset purchases from the banks while in the case of the GCF, the balance sheet composition of the central bank changes, while the size is essentially unaltered.

One interesting feature of GQE is that a low-carbon allocation can be done without undue market interference (Bressan et al., 2022), within the transmission mechanism of traditional monetary policy (Schoenmaker, 2021). Nevertheless, similarly to QE, the GQE is debated. In particular, the main areas of discussion include: (i) the adequacy of the risk-profile of low-carbon assets with monetary policy objectives and operations, (ii) the compatibility of green monetary policy with the market neutrality principle of central banks (Barkawi, 2017; Volz, 2017; Bressan et al., 2022) and more broadly within their mandates (Boneva et al., 2021).

Overall, implementing GMP would require consistently integrating climate mitigation objectives into central banks' monetary frameworks to adequately account for the impacts of climate change on macroeconomic and financial outcomes, as well as for the impact of financial outcomes on the low-carbon transition.

2.5. Public funding and co-funding of green investments

The creation of green national development banks (NDBs), and the increase of the capitalization of existing national development banks with a green mandate, has been advocated to address the urgent need to mobilize finance and to address the threat of climate change (Griffith-Jones and Ocampo, 2016). The rationale for development banks' intervention in the low-carbon transition stands in recognition of credit rationing and green market failures. Low-carbon investments are usually long-term while having no long track record of past performance. Thus, they are considered as riskier by traditional financial institutions, resulting in higher cost of capital for firms willing to invest. The transition to a low-carbon economy requires long-term, large investments (e.g., in infrastructure and technology), i.e., "patient finance" which may not be available.

NDBs can pursue a green investment strategy through two main channels. First, NDBs can increase (decrease) the funding of low-carbon (high-carbon) activities through the provision of *soft loans*, i.e., loans associated with lower-than-the-market interest rates that would decrease the cost of capital for green investments. Second, NDBs can provide *credit guarantees* for low-carbon investments, in order to de-risk commercial banks' lending to firms that invest in low-carbon projects. Both options can be implemented via several channels, including through the capitalization of a dedicated green development bank, through an increase of the share of green sector investments in the portfolio of existing NDBs, or through green on-lending by commercial banks.

In all cases, NDBs need tailored metrics to support the selection of projects to consider climate and environmental as well as other development goals. The introduction of analytical tools for public development banks was recently advocated in order to inform the selection of operations that would contribute to sustainable development (Marodon, 2020) as well as how much capital they can deploy (Munir and Gallagher, 2020). Such tools would integrate climate and environmental sustainability criteria on top of the current, purely financial ones. Thus, a precondition for the adjustment in investment portfolios of NDBs stands in the implementation of standardized climate financial risk disclosure and climate financial risk assessment.

2.6. Challenges and enabling conditions for GFSI implementation

The literature has also identified a number of challenges associated to the implementation of GSFI and the opportunities to overcome them, which result in a set of enabling conditions.

1. The lack of a *standardized classification of low/high-carbon activities* has been recognized as a barrier for scaling up investments at the global level (Monasterolo, 2020). In 2020, the European Commission (EC) introduced the EU Taxonomy of sustainable activities.[8] However, the EU Taxonomy does not identify "high-carbon" activities. The lack of standardized classification of high-carbon economic activities based on their exposure to climate transition risk prevents the ability to differentiate high- and low- carbon assets and thus is an important obstacle for the implementation of GFSI. A more comprehensive perspective on the classification of economic activities is provided by the Climate Policy Relevant Sectors (CPRS) classification (Battiston et al., 2017).
2. *Climate financial risk disclosure, with regard to transition risk exposure,* is crucial to inform climate financial risk assessment, climate scenario-adjusted financial valuation of financial contracts and investment projects (see e.g. Griffin and Jaffe, 2022; Bingler et al., 2022). In addition, the adjustment of financial valuation of contracts conditioned to climate scenarios (e.g., the NGFS ones), and *the assessment of climate-related risks and opportunities* for investors, contributes to a smooth implementation and governance of the GFSI.
3. *Green conditionality,* i.e. the fact that the support measures of GFSI are conditional on "green" characteristics of the linked investment is key for several aspects of GFSI (see e.g. Johnstone, 2022). The implementation of green conditionality can be informed by the application of the classifications and taxonomies used for climate financial risk disclosure discussed above (see e.g. Alessi et al., 2019).
4. *Investors' climate sentiments* need to be considered in the GFSI implementation. This notion refers to investors' expectations about the impact of GFSI on firms' performance and how this would lead to adjustments in climate financial risk perception (see e.g. Santi, 2023). In turn this has an impact on the realization of national climate mitigation objectives and thus on a successful low-carbon transition (Battiston et al., 2021). Climate sentiments point to the fact that climate risk is endogenous, i.e. the perception of the policy by financial actors could enable or hinder the transition, with implications on asset price volatility and financial stability (Battiston et al., 2021).
5. *Policy complementarity*. Beyond the timely introduction of a carbon price set at an appropriate value per ton of CO2, its alignment with other green fiscal policies (e.g., removal of fossil fuel subsidies, public investments in low-carbon infrastructures, support to firms and worker in the transition), as well as monetary, and macroprudential policies, would strengthen policy coherence and leverage impact investments in the low-carbon transition (Stiglitz, 2016, 2019). A climate finance governance that promotes complementarity of climate fiscal and financial policies, within the institutions' mandates, could contribute (i) to exploit mutually reinforcing effects of policies and (ii) taming potential trade-offs on macroeconomic performance, financial stability, and inequality.
6. *Accounting for the interdependence across financial institutions and financial markets*. Following the 2008 financial crisis, it has become apparent that micro-prudential regulations can have undesirable macro-level repercussions, due to network effects and procyclical effects (Adrian and Shin, 2010) and that macro-prudential regulation should be pursued instead (Borio et al., 2014). In the context of the low-carbon transition, recent balance-sheet climate stress test has analyzed how financial interconnectedness can lead to a reverberation of losses across financial institutions with implications for systemic risk (Battiston et al., 2017). Thus, in order to fully understand the impacts of GFSI we need to take into consideration financial propagation mechanisms and track which sectors/firms are going to be sequentially affected in the economy, and in which direction (i.e., the potential winners and losers).

3. GFSI transmission channels and Impacts: From financial flows to GHG emissions through the real economy

GFSIs work via financial actors that serve as financial intermediaries (usually commercial banks, or national development banks). Hence, it is crucial to analyze the transmission channels of GFSIs to the economy via the financial sector, in order to capture the potential effects on climate change mitigation, on macroeconomic and financial stability. To do so, we build on the notion of causal chain considered in the GHG protocol (WRI, 2014, see also Weidema et al., 2009) and we extend it to the real economy-financial interface. We then map the sequential propagation of

[8] See https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en. Other taxonomies are being developed in a number of jurisdictions (e.g., Chile, Colombia).

GFSIs from financial variables (e.g., cost of capital, availability of capital) to the real economy (e.g., energy prices, investments, technological change), and to GHG emissions reduction. The causal links between these different dimensions are identified on the basis of a review of the empirical and theoretical literature on the impacts of climate, regulatory and fiscal policies.

3.1. Green regulatory policies

3.1.1. Green supporting factor (GSF)

Fig. 1 presents the transmission channels from the GSF to real economic and financial actors (banks). The GSF affects banks' capital requirements via decreasing risk weights of low-carbon or green activities.

The GSF lowers the risk weights for loans to low-carbon firms (European Commission, 2018; Thomä and Gibhardt, 2019) that enter the denominator of the Capital Adequacy Ratio (CAR, direct impact). The resulting higher CAR would lead to higher lending capacity for the banking sector and thus to new (green) business opportunities. Indeed, banks' setting of lower interest rates for low-carbon firms could lead to new investments in low-carbon firms while capital costs and prices would decrease (indirect impacts, see Dafermos and Nikolaidi, 2021). Being more price competitive, the demand and profits of low-carbon firms increase, resulting in higher investment needs of low-carbon firms and, thus, in their supply. This would lead to a reduction of the green investment gap and to a higher exposure of the banking sector to green loans, mitigating the risk of carbon stranded assets in banks' balance sheets (ECB, 2024). At the same time, new low-carbon investments would stimulate low-carbon capital productivity gains, reducing the prices of low-carbon capital goods even further, and making high- (low-) carbon goods less (more) attractive (IEA, 2024).

The higher demand and supply of low-carbon investments could foster the overall economic activity, leading to higher GDP, and employment (WB, 2022). However, the effect on GHG emissions reduction may be ambiguous. On the one hand, the higher investments in low-carbon firms could lead to an additional reduction of GHG emissions (positive spillover effect). On the other hand, the increase in economic activity could also benefit high-carbon activities (e.g., via the production of components for solar PV) and thus at least partially counterbalance GHG emissions reduction (negative spillover effect).

3.1.2. Dirty Penalizing factor (DPF)

Fig. 2 shows the transmission channels through which the DPF affects the banking sector and the real economy, via higher risk weights assigned to high-carbon activities.

The DPF affects the real economy and banking sector through the same transmission channels that characterize the GSF (see section 3.1.1). However, the direct and indirect impacts differ. The DPF increases the risk weights of high-carbon activities, resulting in lower CAR and, thus, into lower banks' ability to lend to firms, and into higher interest rates. In turn, higher interest rates driven by DPF would negatively affect new investments (Dafermos and Nikolaidi, 2021; Thomä and Gibhardt, 2019). In this context, if banks react to the DPF by reducing their lending and by increasing the interest rate for high-carbon companies, lower demand for high-carbon investments could follow, leading to lower investment in high-carbon sectors, and, thus, to lower supply of high-carbon goods (indirect impacts). This mechanism would contribute to lower banks' exposure to high-carbon companies, and reduce climate transition risk, mitigating the implications on banks' financial stability and systemic risk (ECB, 2023a). In addition, lower investment in high-carbon companies would also involve high-carbon capital productivity losses, which further increase the prices of high-carbon capital goods and make low- (high-) carbon investment more (less) attractive (IEA, 2024).

As in the case of the GSF, the DPF could lead to higher low-carbon investments and economic activity, and to lower unemployment (WB, 2022). The lower attractiveness of high-carbon firms could foster investments in low-carbon firms, potentially leading to a reduction of GHG emissions. Nevertheless, as for the GSF, the overall effect on GHG emissions reduction may be ambiguous and depend on relative strengths of the macroeconomic effects with potential rebound effects for high- or low-carbon investments.

3.1.3. Green collateral framework (GCF)

Fig. 3 shows the transmission channels from the GCF to the financial sector and real economy, via changes of the eligibility criteria of high and low-carbon assets, which directly affect the central bank money lending to the banking sector.

Major central banks supply reserves to commercial banks mainly through Main Refinancing Operations (MROs) and Long-Term Refinancing Operations (LTROs). These operations are introduced by central banks to ensure the smooth functioning of the banking system. Central banks lend to the banking sector and obtain assets as collaterals, such as sovereign or corporate bonds. The use of collaterals allows central banks to protect themselves from financial losses, e.g., when banks are unable to pay back received loans. Financial assets that are accepted as a collateral are defined as *eligible assets* (BIS, 2013, 2015).

Within the GCF, eligible assets that banks can use to borrow from central banks must include certain shares of low and high-carbon assets (Dafermos et al., 2021; ECB, 2022). In particular, the GCF sets a minimum share of low-carbon assets and a maximum share of high-carbon assets that can be used as collateral by banks (direct impact). Banks would react to the change in the eligibility criteria of low and high-carbon assets by changing the composition of their portfolio, increasing the amount of low-carbon assets, and reducing high-carbon assets. This result can be achieved following criteria that set sector-based and technology-based targets. Higher (lower) demand of low- (high-) carbon assets increases (decreases) asset prices, while decreasing (increasing) their yields. Thus, GCF could improve financing conditions for low-carbon companies (indirect impacts), which in turn would contribute to foster green investment and reduce the green investment gap (ECB, 2023b). Implications for macroeconomic performance and financial stability, and GHG emissions reduction would unfold (spillover effects).

3.2. Green monetary policies

3.2.1. Green quantitative easing (GQE)

Fig. 4 presents the transmission channels from the GQE to the financial sector and real economy, via changes of the eligibility criteria of high and low-carbon assets, the expansion of central banks' balance sheets and the increase in banks' liquidity.

The GQE is characterized by three direct impacts. First, it contributes to expanding the central bank's balance sheet by creating new banks' reserves in exchange of the assets purchased by the central bank (Lenza et al., 2010; Gagnon et al., 2011; Kapoor and Peia, 2021). Second, it contributes to change the eligibility criteria of banks' assets that can be purchased by the central banks.[9] Third, it leads to an increase in banks' liquidity, thus increasing the amount of money in the economy (Rodnyansky and Darmouni, 2017; Christensen and Gillan, 2022). These three direct impacts could give rise to different transmission channels, and into adjustments of financial and real economy variables. Here we focus on the effects of the second and third direct impacts, thus leaving aside the consequences of the expansion of the central bank's balance sheet.

With reference to the change in eligibility criteria, the transmission channels are similar to those described in section 3.3. In particular, banks would react to the change in the eligibility criteria of low-carbon and high-carbon assets by changing the composition of their portfolio,

[9] See, e.g., https://www.ecb.europa.eu/press/pr/date/2021/html/ecb.pr210708_1~f104919225.en.html.

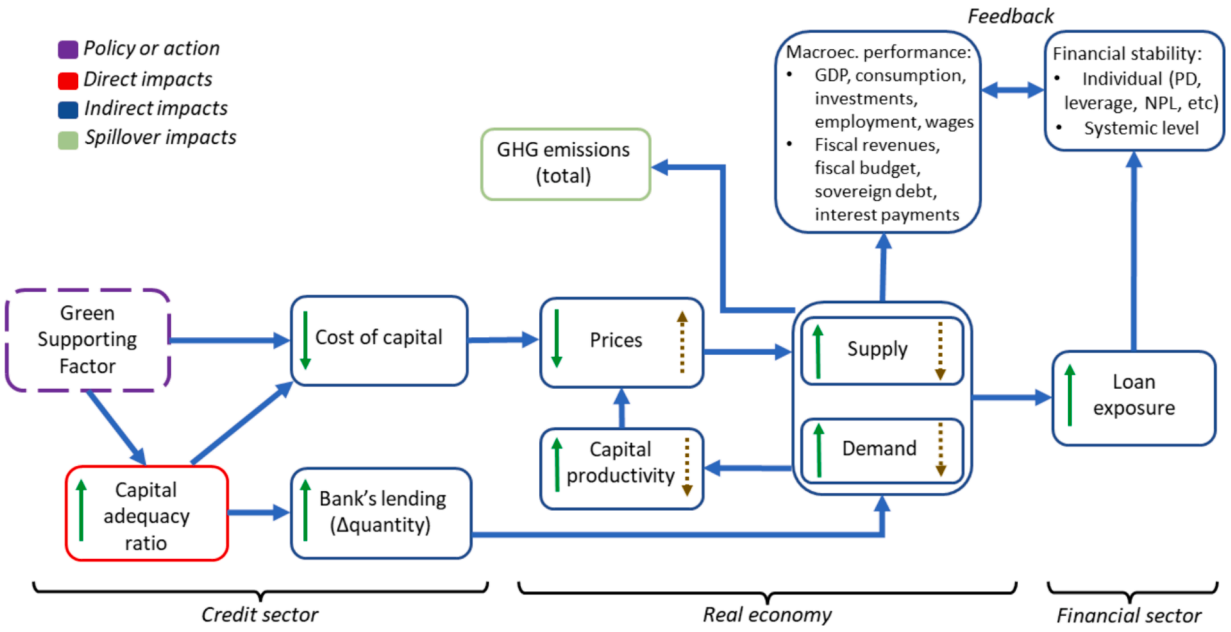

Fig. 1. Macro-financial transmission channels of the Green Supporting Factor. The purple box indicates the policy. Upward-facing arrows in the boxes: positive trend. Downward-facing arrows in the boxes: negative trend. Green arrows: policy impacts on low-carbon firms. Red boxes: direct impacts. Blue boxes: indirect impacts. Green boxes: spillover impacts. Dotted arrows: potential effects on the high-carbon sector. PD stands for probability of default and NPL for non-performing loans.

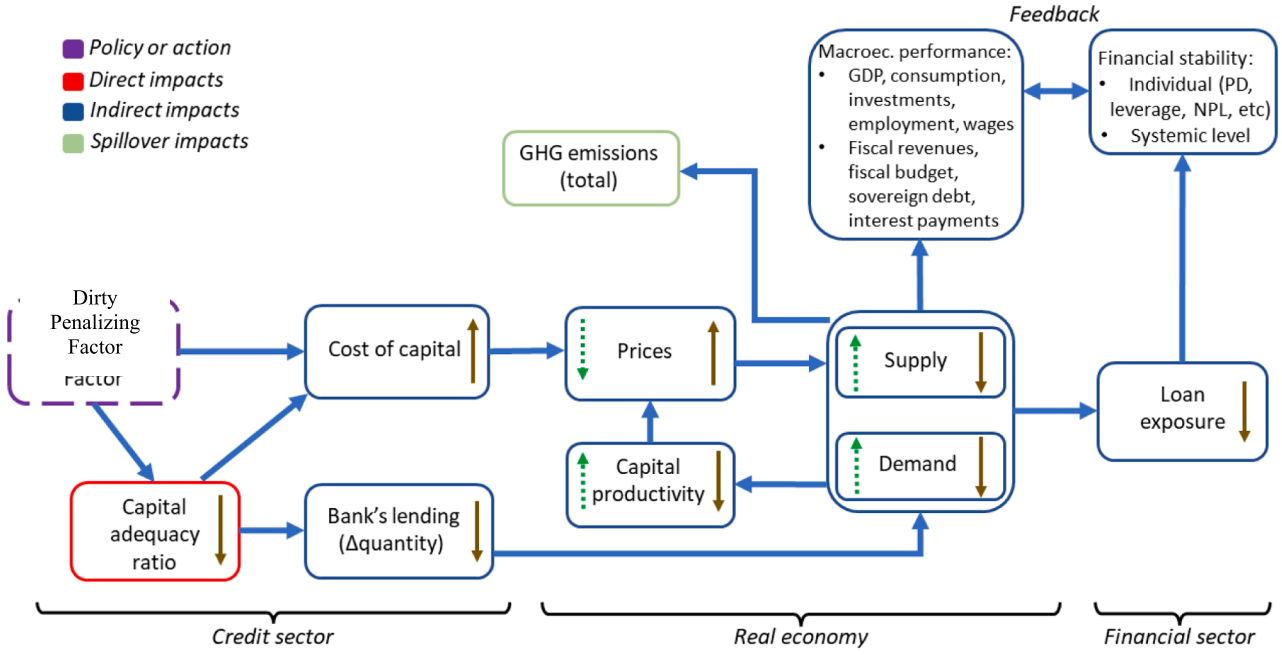

Fig. 2. Macro-financial transmission channels of the Dirty Penalizing Factor. The purple box indicates the policy. Upward-facing arrows in the boxes: positive trend. Downward-facing arrows in the boxes: negative trend. Brown arrows: policy impacts on high-carbon firms. Red boxes: direct impacts. Blue boxes: indirect impacts. Green boxes: spillover impacts. Dotted arrows: potential effects on the low-carbon sector.

by increasing the amount of low-carbon assets and by reducing the quantity of high-carbon assets (Aloui et al., 2023). The resulting higher (lower) demand of low (high) carbon assets increases (decreases) asset prices and decreases (increases) their yields, improving financing conditions for low-carbon companies (indirect impacts). This channel could contribute to foster low-carbon investment and reduce the green investment gap, if banks adjust investment spending (dotted arrows), thus affecting macroeconomic performances, and potentially reducing GHG emissions (spillover effects).

Within the third direct impact, the green QE leads to an increase in banks' liquidity. By purchasing assets from banks, central banks create new reserves, increasing the supply of money. An increase in banks' liquidity and money in the economy can foster banks' lending and financial activity, thus stimulating investments and spending, with positive effects on macroeconomic performance.

However, it is important to highlight that in absence of a clear conditionality on the use of the banks' liquidity created out of the GQE, banks could also increase investments and lending to high-carbon

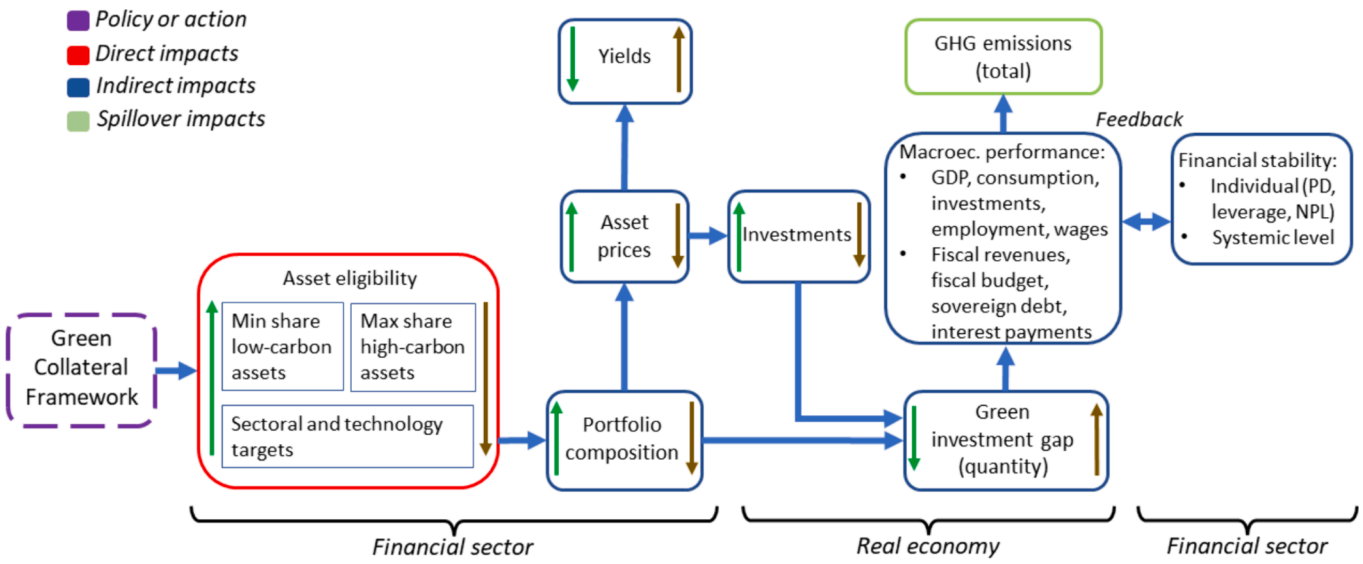

Fig. 3. Macro-financial transmission channels of the green collateral framework. The purple box indicates the policy. Upward-facing arrows in the boxes: Positive trend. Downward-facing arrows in the boxes: negative trend. Green arrows: policy impacts on low-carbon firms. Brown arrows: policy impacts on high-carbon firms. Red boxes: direct impacts. Blue boxes: indirect impacts. Green boxes: spillover impacts.

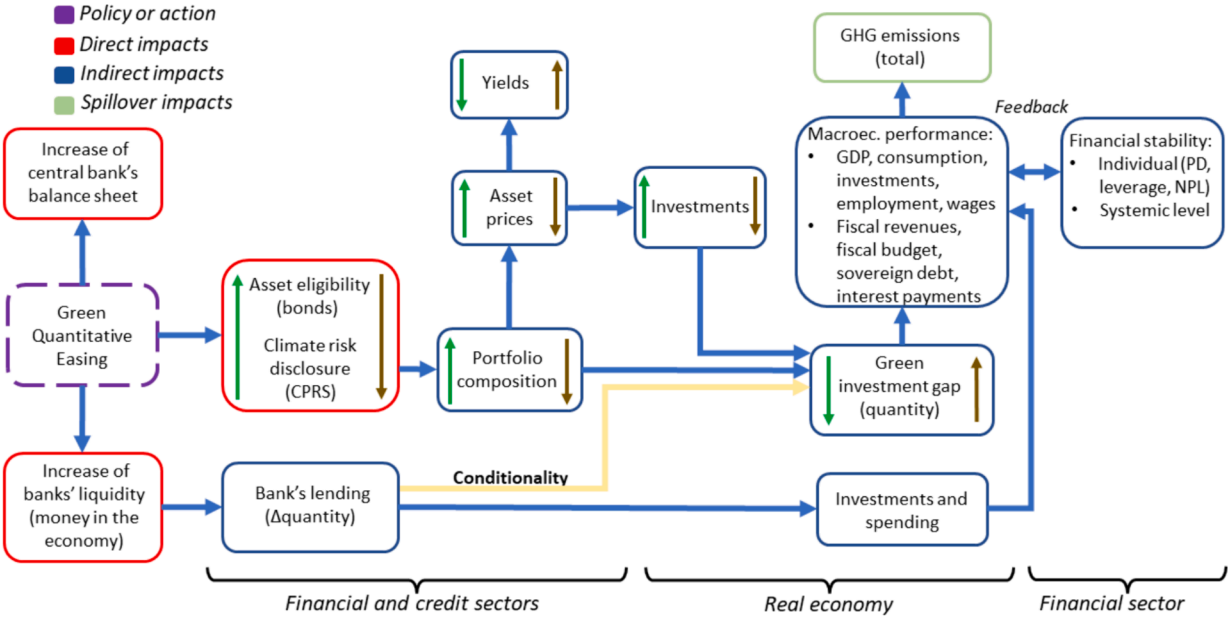

Fig. 4. Macro-financial transmission channels of green quantitative easing. The purple box indicates the policy. Upward-facing arrows in the boxes: Positive trend. Downward-facing arrows in the boxes: negative trend. Green arrows: policy impacts on low-carbon firms. Brown arrows: policy impacts on high-carbon firms. Yellow arrow: conditionality. Red boxes: direct impacts. Blue boxes: indirect impacts. Green boxes: spillover impacts.

activities, thus partially vanishing the effects described above in relation to the second direct impact, i.e., the eligibility criteria..

3.3. Public funding and co-funding of green investments

3.3.1. Soft loans and credit guarantee

Fig. 5 includes the transmission channels from the soft loans and credit guarantees to the financial sector and real economy, encompassing the increase of NDBs' balance sheet and projects' eligibility.

NDBs can influence the low-carbon transition by *granting soft loans* to finance low-carbon projects, and by *providing credit guarantees* to mitigate the risks of the lending institutions that finance low-carbon projects (direct impacts). Both instruments contribute to foster investments in low-carbon activities (Dalhuijsen et al., 2023).

The main difference between the soft loans and the credit guarantees is that the soft loans represent direct lending to low-carbon projects, while the guarantees indirectly affect the decision of lenders to grant loans to low-carbon projects, by providing guarantees in case of possible losses. Soft loans have a direct impact on lowering the cost of capital for new green investments, on macroeconomic performance (e.g., new green jobs) and on GHG emissions. In contrast, the impact of guarantees on lowering the cost of capital for green investments, on macroeconomic performance and GHG emission reduction is indirect and depends on the lending conditions, which are eventually decided by banks.

Either the creation of a Green National Development Bank (GNDB), an individual loan/guarantee program of an existing GNDB or of other

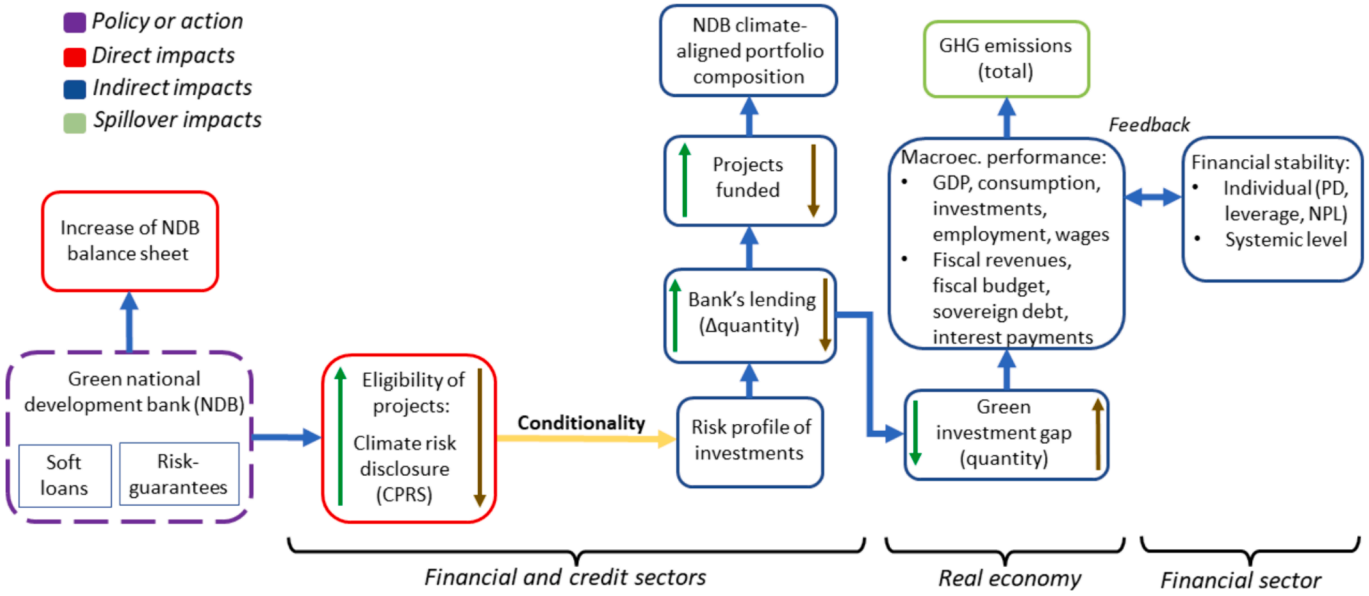

Fig. 5. Macro-financial transmission channels of green development banks and national development banks (NDB) via soft loans and credit guarantees. The purple box indicates the policy. Upward-facing arrows in the boxes: Positive trend. Downward-facing arrows in the boxes: negative trend. Green arrows: policy impacts on low-carbon firms. Brown arrows: policy impacts on high-carbon firms. Yellow arrow: conditionality. Red boxes: direct impacts. Blue boxes: indirect impacts. Green boxes: spillover impacts.

public finance providers, could support the funding of low-carbon companies and reduce investment in high-carbon companies (Griffith-Jones and Gallagher, 2021).

The increase of low-carbon investment driven by soft loans and risk guarantees has a positive effect on narrowing the green investment gap and on improving macroeconomic performance, because higher low-carbon investment leads also to higher workforce needed, increasing employment in low-carbon activities. However, the overall effect on GHG emissions reduction can be ambiguous. On the one hand, the higher investments in low-carbon activities could also lead to a reduction of GHG emissions (positive spillover effect). On the other hand, the increase in economic activity could benefit high carbon activities (e.g., production of components for solar PV), and increase GHG emissions (negative spillover effect).

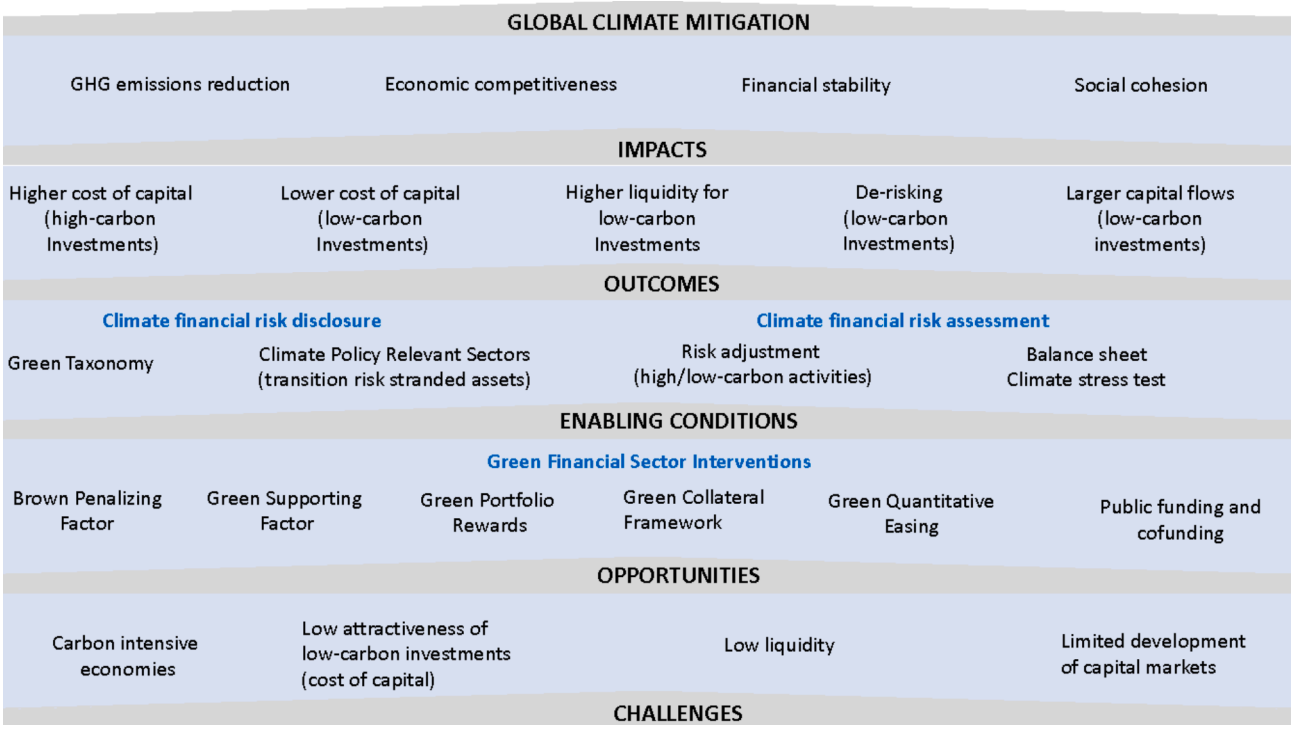

Fig. 6. Diagram illustrating the building blocks of a Theory of Change (ToC) of GFSI for climate mitigation. The diagram should be read from the bottom ('challenges') to the top ('global climate mitigation').

4. A theory of change (TOC) for the role of green financial sector initiatives in climate mitigation and decarbonization

We build on the insights of the previous section to develop a Theory of Change (ToC) aimed to operationalize GFSIs for climate mitigation and decarbonization objectives. We focus on its application in the context of CCIRs, given the major challenges that they face in terms of structural change in the low-carbon or net zero transition.

Fig. 6 illustrates the structure of the ToC, which is organized into (i) challenges, (ii) opportunities, (iii) enabling conditions, (iv) outcomes, and (v) expected impacts.

Challenges. Challenges for a low-carbon transition include the initial high-carbon composition of the economy (i.e. the role of high-carbon activities on revenues and gross value added), the low attractiveness of low-carbon investments (e.g., due to higher costs of capital, lack of available renewable energy technologies that can be readily deployed at the country level, limited access to the raw materials needed to develop the low-carbon technology), low firms' liquidity or financial fragility, and the limited international capital flows (e.g., due to national/regional business environment and governance).

Opportunities. The above-mentioned challenges can be addressed with tailored GFSIs, which act here as *potential solutions*. For instance, a DPF could help to decrease the current carbon intensity of the economy, and its climate transition risk exposure. In contrast, the GSF and the green monetary policies considered can increase the attractiveness of low-carbon investments by affecting the cost of capital and relative prices. Green monetary policies could contribute to increase the liquidity in the system posing the conditions for higher banks' lending (in theory). Finally, public funding and co-funding de-risk investments in low-carbon technologies and economic activities.

Enabling conditions. Two enabling conditions play a crucial role for moving from opportunities to *outcomes*. Standardized, science-based *climate financial risk disclosure* should be introduced by all financial actors that implement GFSIs. By learning from international best practices, this could consist of the implementation of a green taxonomy (e.g., on the example of the EU Taxonomy). Importantly, green taxonomies should go beyond GHG emissions-based metrics, which suffer of poor reporting and are influenced by prices (e.g. emissions intensity) and include the technology profile and business model of the firms. An example is the classification of economic activities' exposure to climate transition risk CPRS. A robust analysis of firms' exposure to climate risk is a necessary step to conduct climate financial risk assessment, such as climate stress testing of balance sheets (see e.g., Battiston et al., 2017; Roncoroni et al., 2021; Allen et al., 2020; Reinders et al., et al., 2021; Alogoskoufis et al., 2021). These involve the following steps: (i) *classifying economic activities into a standardized taxonomy that includes carbon stranded assets (*e.g. CPRS), (ii) *adjusting the financial valuation* of firms' financial contracts and securities conditionally to forward looking climate mitigation scenarios, (iii) *adjusting financial risk metrics* conditionally to climate scenarios, (iv) *assessing the largest losses conditionally to the climate scenarios*, considering reverberation of losses due to financial interconnectedness, through a balance sheet climate stress test (Battiston and Monasterolo, 2024).

Outcomes. The implementation of specific GFSI – depending on the challenges identified at the country level – would lead to adjustments in the sector and technology composition of the economy, i.e., in a decrease in high-carbon investments and an increase in low-carbon investments. Other relevant implications would imply more liquidity available for banks and firms willing to invest in low-carbon activities, the de-risking of low-carbon investments and larger incoming capital flows.

Impacts. The socio-economic and mitigation *impacts* would include: (i) GHG emissions reduction for the country, enabling it to narrow its GHG emissions gap and to achieve ambitious climate mitigation targets, (ii) smoothing the short-term negative economic impacts (e.g., unemployment, lower fiscal revenues, distributive effects) of climate policies, (iii) strengthening financial stability by mitigating risks of a disorderly transition, and (iv) promoting social cohesion, by taming large distributive effects for poorer cohorts of the population.

The ToC provides an operative framework for delivering the transformational change in climate finance needed to achieve ambitious climate mitigation objectives, in the short time available.

Fig. 7 illustrates the ToC implementation framework composed of four steps, i.e., (i) the identification of a country's decarbonization goals and relevant GFSI, (ii) the analysis of the transmission channels to the economy and finance, considering the country-specific socio-economic and financial characteristics, (iii) the conditions and challenges for GFSI introduction, and (iv) the design of the governance framework for successful implementation. Note that, in principle, the ToC and its implementing framework can be tailored and applied to any country.

Step 1. The first step of a ToC is to identify the country's decarbonization goals and their policy credibility. This includes a comparison of its Nationally Determined Contributions (NDCs) and most recent climate pledges with climate economic policies already implemented or foreseen, an analysis of the economic sectors and regions that would play a main role in this process (either because exposed to climate transition risks, or relevant for the production of renewable energy and electricity and low-carbon assets). Indeed, the adjustments in cost and availability of capital entailed by GFSI can work best if GFSI complement climate economic policy packages that make such adjustment persistent over time. In the absence of a country's credible commitment on a NetZero path, GFSI could lose effectiveness, because eventually interest rates, cost of capital and risk scores for low carbon firms would revert to the levels of the high-carbon ones.

Step 2. Second, the identification of the national and regional decarbonization challenges, and of their financial characteristics, should guide the selection of the relevant GFSI and their implementation. Challenges may include potential trade-offs between phasing out highly climate-relevant activities (e.g., coal and metals extraction) and respective socio-economic implications (e.g. employment, fiscal revenues, GDP). For instance, in settings where fossil fuels extraction and value chain play a large role in the economy, it would be preferable to implement first a GSF, and/or a GQE (if the corporate bond market is functioning) than a DPF. With regards to financial stability objectives, the degree of preparedness of financial institutions, as well as the degree of deepening and interconnectedness of the financial market matter and should be considered.

Step 3. Third, the implementing conditions are crucial for the success of the selected GFSI. In countries where central banks have limited space of action (e.g., due to their narrow mandate), limited human capital and limited supervisory power, GCF or GQE could be challenging to implement. In contrast, in countries with a limited degree of financial deepening and poorly regulated capital markets, implementing GSF or DPF could be little effective with regards to the scaling up of green investments in the short term. Challenges for individual financial stability could emerge, potentially requiring central banks' intervention in line with their financial stability objectives. In addition, all the GFSI that work via the credit channel would be little effective in countries where firms are generally small (or micro), have limited or no credit record and thus face severe limitations in access to credit. Thus, increasing the capitalization of NDBs, and greening public development banks, could be a preferable solution.

Step 4. Governance would guide the implementation of the ToC via a set of GFSI that involve fiscal, monetary and macroprudential policies. Good governance would improve the effectiveness of GFSI substantially. Importantly, the TOC allows for considering each GFSI beyond the logic of local interventions and project funding, and to create an enabling environment for climate finance. Therefore, the governance dimension is important here. First, the comparative analysis of GFSI transmission channels, including their direct, indirect and spillover impacts for economic decarbonization, helps to understand the conditions for policy implementation and impact on mitigation. Second, it provides the tools

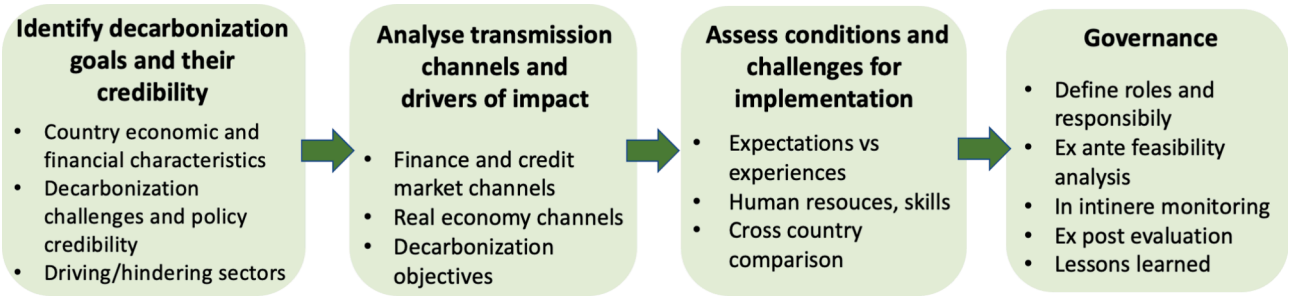

Fig. 7. ToC implementing framework in four interconnected steps.

to understand where synergies across GFSI could emerge, in order to leverage on complementarities and maximize impact. Third, it contributes to inform their design, programming, and implementation in the context of international climate finance, and their tailoring at country level, considering countries' climate challenges, and socio-economic and financial characteristics.

4.1. Potential application to CCIRs

Financial regulators worldwide are developing innovative strategies to scale up climate finance, involving both private and public finance. However, challenges related to the limited fiscal capacity, public debt and large structural challenges that characterise the transition, such as in CCIR, limit government support to climate investing.

These strategies often also include GFSIs. While the practical applications of GFSIs are still relatively limited, and insights on their performance and impact on financial stability and inclusivity is still developing, their application is being explored in some advanced economies (e.g. EU) and in Emerging Markets and Developing Economies (EMDEs, such as Indonesia, Bangladesh, China) (World Bank, Forthcoming). However, international institutions have yet to provide clear guidelines for the implementation of green financial instruments. Indeed, their adoption is influenced by various factors such as proven past effectiveness (i.e. existence of applications), the specific country context, concerns about misleading green claims (e.g. "greenwashing"), and potential for market disruption which could lead to financial instability (World Bank, Forthcoming).

In this context, NDFIs are pivotal in tackling green market shortcomings and fostering new markets. They achieve this by providing tools that attract private investment, utilizing methods like de-risking instruments and blended finance, both within the European Union and in EMDEs. According to a recent World Bank study (Dalhuijsen et al., 2023), out of 22 NDFIs examined, 15 have set specific targets for green financing. These environmental goals are frequently embedded within the NDFIs' foundational mission and strategy, consistent with their pre-established legal mandates. Nevertheless, a ToC about their implementation and potential impacts, including trade-offs and unintended effects, is still missing, and thus the contribution of our work.

The European context offers an illustration of our ToC, through the actual and potential implementations of GFSI to catalyze the low-carbon transition, notably in CCIRs. European climate objectives are clear: the aim is to reach climate neutrality by 2050. Challenges are also salient: (i) distributional consequences, first and foremost in CCIR, undermine political support and impair implementation of climate policies, (ii) there are major investment needs in CCIR but the balance sheet of relevant economic actors (e.g., national and regional governments, European utilities and industries) are fragile while the supply of low-carbon assets needs to be increased. In order to overcome these challenges, Europe has put forward the Just Transition Mechanism which consists of three pillars: direct investments through the just transition fund (first pillar) and the just transition scheme (second pillar), and a public sector loan facility (third pillar) through the European Investment Bank (EIB).

The Just Transition Mechanism is, to a large extent, a green financial sector intervention consisting in public funding (through the public sector loan facility) and co-funding (through the just transition mechanism and the just transition fund) of green investments. A specificity of the just transition mechanism is its bottom-up implementation at the regional level, with a particular focus on CCIR. This regional approach is aligned with the broader EU objectives of regional cohesion. It creates both additional risks and additional opportunities with respect to the more "conventional" country-based approach to GFSIs. Clustered funding at the regional scale can, if a latent innovation/investment potential is present, enable a virtuous circle for the development of innovative firms and industries. Indeed, the improvement of the financing conditions of innovative firms can foster their development, leading to technological spillovers at the industry and regional level. This shall improve macro-economic performance at the regional level, improve the fiscal position of local governments and strengthen the balance-sheet of financial and industrial actors in the regions. In turn, this eases further investments, technological development and growth. However, the success of such a policy requires the presence of an innovation potential in the region as well as the availability of a private investment base. Indeed just transition mechanisms require co-financing and their success hinges on the crowding in of private investments. The regional focus might be a risk from this perspective because the innovation or the investment potential might be lacking in the target regions, the balance-sheet of regional actors might be too weak to complement public investments, and invested capital might rapidly outflow from the region.

5. Conclusion

In this paper, we have developed a Theory of Change (ToC) for the role of Green Financial Sector Initiatives (GFSI) in the decarbonization of the economy and in the low-carbon transition, with a focus on coal and carbon intensive regions (CCIR). First, we have identified and analyzed the most debated GFSIs, their specific transmission channels to the banking sector and to the real economy, at the light of the literature. Then, we discussed implementation challenges and enabling conditions, considering the case of CCIRs in particular. Finally, we developed a ToC for the operationalization of GFSI considering challenges, opportunities, enabling factors, outputs and impact on climate change mitigation.

The results of the literature review and the qualitative analysis show that GFSIs work via three main channels, i.e., *the price/interest rate channel*, *the quantity channel* (lending to the real economy) and *investors' portfolio rebalancing*. Depending on the structural (socio-economic, environmental and financial) characteristics of the country, and its specific challenges, the GFSI would lead to an adjustment in the sector and technology composition of the economy (decrease in high-carbon, increase in low-carbon ones), higher liquidity available for banks and firms willing to invest in low-carbon activities, de-risking of low-carbon investments and larger capital flows.

However, potential rebound effects on GHG emissions could emerge as a result of the larger liquidity, and of the consequent potential larger

lending to the real economy, if the GFSI is not accompanied by green conditionality and science-based climate risk assessment. Indeed, large positive spillover effects on demand for investments in the economy generated by the liquidity and capital availability of the GFSI could also benefit high-carbon activities and lead to unintended higher GHG emission intensity in the economy.

Those indirect effects pose several challenges when aiming to quantify the impact of GFSI on macroeconomic and financial risk variables, and on GHG emission reductions. In particular, the quantification of the impact of each GFSI on GHG emissions depends on the conditions of GFSI implementation, which in turn might vary across time and space. More broadly, our analysis shows that transmission channels can be complex and involve several feedback loops.

Our results show the importance to consider the analysis of risk transmission channels, and to identify country and GFSI-specific direct, indirect impacts, and feedback effects to better understand the full GHG emission impacts. Yet, challenges remain given the level of uncertainty associated, and the limited availability of the required data/models for the quantification. In this context, climate financial risk disclosure and risk assessment are a precondition for a successful application and tailoring of the ToC to the country context, and the effective implementation of the GFSI at the country level.

Finally, the role of GFSI policy complementarity deserves attention. The EU context offers a clear illustration of the challenges for the efficient implementation of GFSI. Substantial public funding and co-funding investments have been budgeted in the context of the just transition mechanism to support the low-carbon transition in CCIR. These public investments will strengthen the balance-sheet of economic actors engaging in the low carbon transition. These actors could issue assets of higher credit quality whose demand by the private sector would increase if green regulatory and monetary policies were implemented. In this regard, the development and implementation of the EU taxonomy is an important enabler for disclosure. In contrast, green monetary and regulatory policies are harder to enact although the synchronization of policies is a crucial factor to generate synergies.

More broadly, GFSI can support GHG emission reductions only if the country engages on a decarbonization path by means of economic policies. A country's credible commitment on a net-zero path, by means of coherent and credible policy measures, such as the phasing out fossil fuel subsidies and measures to support firms and workers in affected sectors, implies that a higher cost of capital for high-carbon firms make economic sense and is in line with financial valuation. Thus, the adjustments in financial risk assessment, which affects the adjustment in the cost and availability of capital entailed by GFSIs, can work best if they complement climate economic policy packages that ensure persistence over the years of the transition. In contrast, in the absence of a country's credible commitment on a net-zero path, GFSI could lose momentum and effectiveness. Financial actors may not trust governments' climate-related declarations, and thus not represent an enabler to the transition, not revising their risk assessment. Therefore, interest rates, cost of capital and risk scores for low carbon firms would revert to the levels of the high-carbon ones.

CRediT authorship contribution statement

Irene Monasterolo: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Antoine Mandel:** Conceptualization, Methodology, Supervision, Writing – original draft. **Stefano Battiston:** Conceptualization. **Andrea Mazzocchetti:** Conceptualization, Methodology, Writing – review & editing. **Klaus Oppermann:** Conceptualization. **Jonathan Coony:** Conceptualization. **Stephen Stretton:** Conceptualization, Methodology. **Fiona Stewart:** Conceptualization. **Nepomuk Dunz:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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