Grantham Research Institute on Climate Change and the Environment

Centre for Climate Change Economics and Policy

The CO_2 content of the TLTRO III scheme and its greening

Chiara Colesanti Senni, Maria Sole Pagliari and Jens van 't Klooster

May 2023

Centre for Climate Change Economics and Policy Working Paper No. 422
ISSN 2515-5709 (Online)

Grantham Research Institute on Climate Change and the Environment
Working Paper No. 398
ISSN 2515-5717 (Online)

Economic and Social Research Council

Grantham Foundation for the Protection of the Environment

University of Leeds

The London School of Economics and Political Science

The Centre for Climate Change Economics and Policy (CCCEP) was established by the University of Leeds and the London School of Economics and Political Science in 2008 to advance public and private action on climate change through innovative, rigorous research. The Centre is funded by the UK Economic and Social Research Council. Its third phase started in October 2018 with seven projects:

1. Low-carbon, climate-resilient cities
2. Sustainable infrastructure finance
3. Low-carbon industrial strategies in challenging contexts
4. Integrating climate and development policies for 'climate compatible development'
5. Competitiveness in the low-carbon economy
6. Incentives for behaviour change
7. Climate information for adaptation

More information about CCCEP is available at www.cccep.ac.uk

The Grantham Research Institute on Climate Change and the Environment was established by the London School of Economics and Political Science in 2008 to bring together international expertise on economics, finance, geography, the environment, international development and political economy to create a world-leading centre for policy-relevant research and training. The Institute is funded by the Grantham Foundation for the Protection of the Environment and a number of other sources. It has 13 broad research areas:

1. Biodiversity
2. Climate change adaptation and resilience
3. Climate change governance, legislation and litigation
4. Climate, health and environment
5. Environmental behaviour
6. Environmental economic theory
7. Environmental policy evaluation
8. International climate politics
9. Science and impacts of climate change
10. Sustainable public and private finance
11. Sustainable natural resources
12. Transition to zero emissions growth
13. UK national and local climate policies

More information about the Grantham Research Institute is available at: www.lse.ac.uk/GranthamInstitute

Suggested citation:
Colesanti Senni C, Sole Pagliari M and van 't Klooster J (2023) *The CO_2 content of the TLTRO III scheme and its greening*. Centre for Climate Change Economics and Policy Working Paper 422/Grantham Research Institute on Climate Change and the Environment Working Paper 398. London: London School of Economics and Political Science

The CO_2 content of the TLTRO III scheme and its greening*

Chiara Colesanti Senni† Maria Sole Pagliari‡ Jens van 't Klooster§

Abstract

This paper investigates the climate impact of central bank refinancing operations, with a focus the ECB's TLTRO III program. Notably, we construct a novel database that combines i) confidential data on loans granted by EU banks to non-financial corporations; ii) confidential data on TLTRO III participation and iii) data on sectoral emissions. We find that the emissions content of bank loans granted over the TLTRO III reference period amount to 8% of overall Euro Area 2019 emissions and that more than 80% of total cumulated loans issued in the reference period was directed towards polluting companies. We then investigate the effectiveness of a green credit easing scheme via a general equilibrium model. Our findings are twofold: first, the central bank policy can increase the costs for lending to polluting companies, thus re-directing loans to less-polluting firms; second, the financial stability implications of such a policy should be carefully considered. Finally, we address legal and operational challenges to such a policy by outlining three alternative ways of implementing a "green" TLTRO programme.

Keywords: TLTRO, CO_2 emissions, transition risk, monetary policy, financial stability.

JEL codes: E40, E50, Q50, Q54.

*The views expressed in this paper are those of the authors only and should not be attributed to Banque de France or the ESCB. We would like to thank Skand Goel, Alain Naef, Pierre Monnin, Agnieszka Smoleńska and Ulrich Volz for helpful comments.The authors acknowledge support from the Grantham Foundation and the Economic and Social Research Council through the Centre for Climate Change Economics and Policy.

†CEP & University of Zurich, e-mail: chiara.colesantisenni@bf.uzh.ch

‡Banque de France, e-mail: maria-sole.pagliari@banque-france.fr

§University of Amsterdam, e-mail: j.m.vantklooster@uva.nl

1 Introduction

Climate and environmental risks pose economic, financial and price stability risks. These risks would be minimized under an early and orderly transition to a low-carbon economy (see, for instance, Danmarks Nationalbank (2020), Alogoskoufis et al. (2021), ECB (2022)). Hence, central banks have an interest in supporting the transition to a low-carbon economy. However, the existing literature shows that some monetary policy measures, in particular corporate bond purchase programs and collateral policies, suffer from a carbon bias, meaning that they disproportionately benefit highly emitting sectors and thus cement the carbon lock-in in the economy. For instance, several studies find a carbon bias in central bank bond purchase programs due to the prevalence of manufacturing, utility, automobile and transportation sectors in bond markets which have a high carbon intensity (Matikainen et al. (2017); de Haas and Popov (2019); van 't Klooster and Fontan (2020); Dafermos et al. (2020); Piazessi et al. (2021); Schoenmaker (2021)). The European Central Bank (ECB) has recently pledged to counteract such biases, for example by increasing the share of assets issued by companies with a better climate performance in its programs (Schnabel (2020); Elderson (2021); ECB (2021)).

While the carbon intensity of corporate bond purchase programs has been widely investigated, less attention has been so far devoted to the climate impact of refinancing operations. The confidentiality around both the allocation of refinancing credit and bank lending patterns is an important obstacle to such research. However, refinancing operations are an important tool of monetary policy and have been used already by central banks to support the transition to a low-carbon economy (Colesanti Senni and Monnin, 2021). The Bank of Japan and the People's Bank of China, amongst others, have launched new instruments in the form of green funding-for-lending schemes. Under these schemes, central banks provide loans to banks at a preferential interest rate, conditional on lending being directed to specific economic activities. Similarly, the Monetary Authority of Singapore also announced plans to set aside $15mn to expand its sustainable bond and loan grant schemes. The ECB board members have declared their openness towards a green Targeted Longer-Term Refinancing Operations (TLTRO) program (Schnabel (2022); Deyris (2022)).

With this paper we contribute to the debate about the carbon bias of existing monetary policy operations and the role of green funding-for-lending schemes in the transition to a low-carbon economy. Our work makes three main contributions. First, we provide a preliminary assessment of the emissions content and composition of the loans issued by banks participating in the ECB's TLTRO III program (Section 2). To this end, we use confidential information from the Analytical Credit Dataset (AnaCredit henceforth) registry together with TLTRO III participation data, as well as country-level sectoral emissions data. We estimate absolute emissions content relying on the working assumption that most of the new lending provided by European banks during the special reference period (March 2020 to March 2021) and with a maturity beyond March 2021 are imputable to the scheme (Da Silva et al. (2021)). We find that the overall emissions content of the loans issued in the reference period amount to about 151 CO_2 megatons ($MtCO_2$), which correspond to 8% of overall emissions in the Euro Area as reported at the end of 2019. We also document that additional lending from banks participating to the programme is mainly directed to more polluting sectors. In the reference period, cumulated loans towards polluting companies represent more than 80% of total loans issued.

Second, the high carbon intensity of the TLTRO III program raises the question of how to align the ECB's refinancing operations with its broader climate related objectives. To investigate how to mitigate the carbon bias of the TLTRO III program, we use the model developed by Böser and Colesanti Senni (2021). In this framework, the central bank can implement a green monetary policy by imposing differentiated cost factors on banks, in order to align their lending with the central bank's objective in terms of loan share to non-polluting firms (Section 3). We study how the central bank could set the interest rate on refinancing operations depending on: i) the share of polluting loans in banks' portfolios; ii) the likelihood attached to the transition occurring by private agents. We find that the central bank can support the transition to a low-carbon economy by using differentiated cost factors on bank loans, which in turn re-directs funding towards less-polluting companies. Our calibration also shows that the green monetary policy might weaken financial stability, as it affects the likelihood of banks' losses. This potential side effect warrants for a careful design of this monetary policy tool.

Third, in Section 4 we consider three distinct alternatives for the implementation of a green funding-for-lending scheme by the ECB: i) an EU policy-based design where green lending is directly linked to existing EU policies and disclosure requirements; ii) a bank-based design where the central banks verifies bank-defined approaches to identify green loans; iii) a supervisory expectation-based design where green loans are conditional on the bank's climate and environmental risk management capacities. Our discussion takes into consideration the potential challenges in the implementation of green TLTROs, ranging from the compatibility with the central bank's mandate to the concrete operationalization of the tool.

Related literature. There exists a growing literature on the potential impact of climate change on the macroeconomic aggregates that are relevant for the accomplishment of the monetary policy mandate. Notably, research has shown that climate change poses risks to price stability (Batten (2018); Kim et al. (2021); Faccia et al. (2021); Mukherjee and Ouattara (2021)) and economic growth (Dell et al. (2012); Acevedo et al. (2020); De Bandt et al. (2021)) as well as financial stability (Campiglio et al. (2018); Battiston et al. (2021); D'Orazio and Popoyan (2022)). However, there is considerable evidence for a carbon bias in existing monetary policy programs, which raises questions about policy coherence (Matikainen et al. (2017); Krogstrup and Oman (2019); Oustry et al. (2020); Schoenmaker (2021)).

In this context, our paper relates to two strands of the literature: 1) papers on targeted refinancing operations and their effectiveness in channelling resources to the desired sectors; 2) research on the financial stability implications of monetary policy.

Refinancing operations have been found effective in increasing lending to specific sectors by reducing the borrowing costs for firms (Afonso and Sousa-Leite (2020); Andreeva and García-Posada (2021); Benetton and Fantino (2021); Da Silva et al. (2021)), without however increasing banks' risk taking (Barbiero et al. (2022)). Existing research supports the idea that the ECB's TLTROs have significantly reduced the funding costs of banks, thus ultimately benefiting the real economy. Among others, Andreeva and García-Posada (2021) show that credit standards ease and loan margins narrow with a bank's uptake of TLTROs. In a similar vein, Benetton and Fantino (2021) find that banks participating to TLTROs programs decrease their lending rates compared to non-participating banks and that the effects of TLTROs on the real economy also depend on market concentration and counterparty characteristics (e.g., small versus large firms). Afonso and Sousa-Leite (2020) provide evidence on the role of country characteristics in influencing the pass-through of TLTROs.

So far, there have been a number of proposals for green targeted lending operations (van 't Klooster and van Tilburg (2020); Batsaikhan and Jourdan (2021); Böser and Colesanti Senni (2021); van 't Klooster (2022)). Meanwhile, programs have been launched by the Bank of Japan, the People's Bank of China and the Central Bank of Malaysia, amongst others. Nonetheless, the implementation of these policies is relatively recent and there are as of yet no empirical evaluations of such programs (e.g. BoJ (2022)). In this regard, we contribute to the existing literature by providing a preliminary assessment of the potential impact of such programs through the lens of a general equilibrium model.

A consistent part of the literature has focused on the impact of monetary policy on financial stability (Goodhart et al. (2009); Adrian and Liang (2018); Smets (2018); Grimm et al. (2023)). In this context, our paper relates to the more recent stream of research on the financial stability implications of green monetary policies in the context of the transition to a low-carbon economy. For instance, Diluiso et al. (2021) show that, in the wake of an adverse financial shock triggered in the fossil sector by the transition, green quantitative easing can stabilize financial markets. They also find that fossil penalizing capital requirements are a more promising stabilization tool compared to green supporting schemes, as they directly target assets more exposed to transition risks. In a similar vein, Oehmke and Opp (2021) find that green capital regulation can effectively address climate-related financial risks, although not necessarily reducing emissions. As far as collateral frameworks are concerned, Giovanardi et al. (2022) provide evidence that the preferential treatment of green bonds in the central bank's collateral portfolio might increase the leverage ratio of green firms. This ultimately might raise green bonds default risk.

2 The TLTRO III scheme and its emissions content

TLTROs were first introduced by the ECB in June 2014 to improve the transmission of monetary policy to the real economy. After the implementation of the first TLTRO program, a second and third series were announced in March 2016 and March 2019 respectively. The third series of TLTRO, referred to as TLTRO III, consists of three tranches of operations, for a total of ten operations, each with a three-year maturity. The focus of this paper is on the second tranche of the program, consisting of 4 operations. Like all the other TLTRO schemes, the TLTRO III program features a borrowing allowance, an interest rate rule and a lending target. The program is executed in a decentralized manner by national central banks (NCBs).

Borrowing allowance. Under the TLTRO III, the borrowing allowance of each participant (i.e. the maximum amount that a bank can borrow from the scheme) has gradually increased from 30% (in 2019) to 55% (in 2021) of the total stock of loans to non-financial corporations and households (excluding home mortgages).

Interest rate. The interest rate for each participating bank is calculated ex-post depending on whether the growth of its loan portfolio (the "lending performance") is higher than a threshold set by the ECB (the "lending target") over the special reference periods. The structure of the funding costs for banks has varied over time: pricing was gradually decreasing with the lending performance in the 2019 operations, while it became binary in subsequent operations (2020 and 2021). In March 2020, the applicable interest rate was set 50 basis points below the deposit facility rate as soon as the lending target (which was 0% in 2020) was met. Given a deposit facility rate of -0.5% this implied a refinancing rate as favorable as -1%.

Reference period. The special reference periods are the time spans over which the "lending performance" of the participating financial institutions is evaluated. For TLTRO III the reference periods were i) from April 2019 to March 2021 for 2019 operations (2); ii) from March 2020 to March 2021 for the 2020 operations (4); iii) from October 2020 to December 2021 for the 2021 operations (4).

2.1 Empirical evidence

2.1.1 Take-up and lending activity

The participation to the TLTRO III scheme of eligible institutions has remarkably increased as of March 2020 (around 87% of eligible institutions), that is with the second tranche of operations. The jump in the uptake took place after the decision of the ECB's Governing Council to lower the rate on TLTROs III below the deposit facility rate, which provided banks with a risk-free profit of 50 bps per euro borrowed.[1] To investigate the effectiveness of the program in stimulating new lending to the real economy, we gather information on (1) the borrowing of banks via the TLTRO III and (2) the origination of new loans to non-financial corporations over the reference period for the second tranche of TLTRO III, from March 2020 to March 2021.[2] While we cannot establish a direct link between the TLTRO III participation and the lending activity, it is reasonable to assume that most of the loans originated in the reference period and with a maturity beyond March 2021 are imputable to the scheme, since loans issued over the reference periods are instrumental for banks to access the more favorable interest rate (Da Silva et al. (2021)).

Information on financial institutions participation to TLTRO III is taken from a Eurosystem proprietary bank-level database that reports the amount that banks borrowed under the scheme on a monthly basis. When considering participation to the 2020 operations, we find a certain degree of cross-country heterogeneity both in terms of the number of banks and geographical distribution of funds. In the reference period, France, Italy, Germany and Spain were the largest beneficiaries and took up 75% of the total TLTRO III loans (Figure 1).

Information on the origination of new loans by banks come from the AnaCredit registry maintained by the European System of Central Banks. The dataset includes monthly information on individual loans granted by euro area banks to non-financial corporations, with a minimum threshold of EUR 25.000.[3]

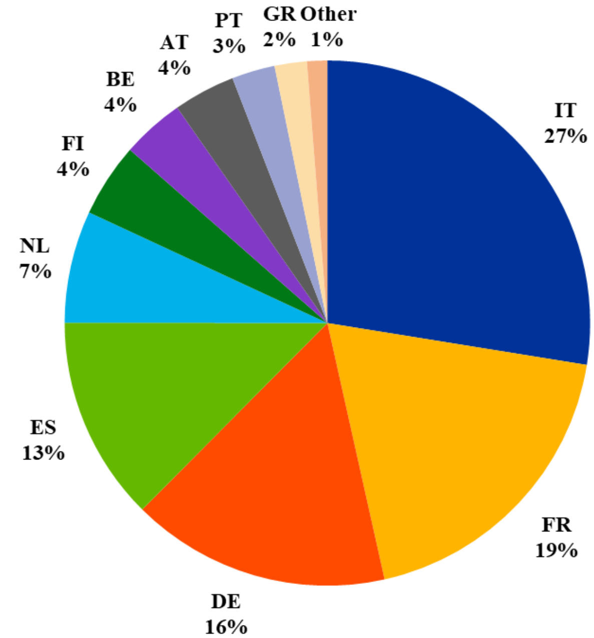
By matching the participation and lending data, we find that out of the around 1000 institutions that participated to the second set of TLTRO III operations, 471 generated new

[1] See ECB's Governing Council decision on 12 March 2020.

[2] Our data sources do not cover lending activity to households.

[3] The database also provides details about the lender, the borrower, the date of loans issuance, the maturity and the guarantor, if any.

Figure 1: TLTRO III allocation by country.



Notes: Time period: March 2020-March 2021.
Sources: Eurosystem and authors' computations

loans in the special reference period with maturity beyond March 2021, which represent a majority of the sector in terms of total assets (65%).[4] There is also evidence that, over the reference period, participating banks have granted a total amount of loans which is around 25% higher compared to non-participating institutions (EUR 217 bn vs EUR 174 bn respectively), as depicted in Figure 2.

AnaCredit also contains information on the country where the borrowing counterpart is located. In most countries participating banks have granted new loans mainly to domestic firms, with the average shares for domestic credit being 88% (Figure 3).[5]

2.1.2 Emissions content of the TLTRO III program

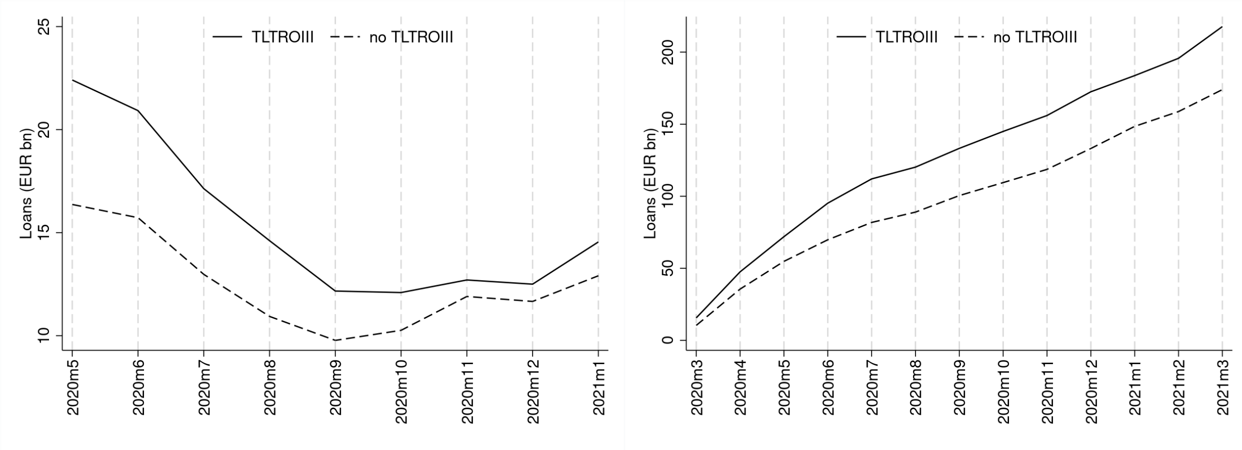
In this section, we derive the emissions content of the loans that banks participating to the TLTRO III granted during the relevant reference period. As highlighted before, this is

[4]According to the Governing Council's original decision of July 2019, institutions participating to the TLTRO III can sort themselves in groups; in this case, a single (head) institution gets the funding and then redistributes it across the other members of the same group. As we do not have information about funds allocation within a group, we attribute the same borrowing amount to all the banks within a given group.

[5]In the case of Lithuania (LT), all the loans originated by domestic banks in the same period have been allocated to domestic firms.

Figure 2: Loans granted over the reference period

(a) New loans **(b)** Cumulated loans



Notes: Figure 2a displays 4-month moving averages.
Sources: AnaCredit, Eurosystem and authors' computations

an indicative measure because it rests on the assumption that the loans originated in the reference period and with maturity after March 2021 are induced by the TLTRO III program. We compute the emissions content of lending activities by combining information about the lending flows with sectoral emissions in different countries, as reported by Eurostat.[6]

We define the emissions content of lending activities (EC) as the loans from each bank to a country-sector pair times the domestic sectoral emission intensity. The latter is given by emissions in a sector over the total country emissions. Formally, the emissions content of loans by bank i to company j sector k in country l is given by

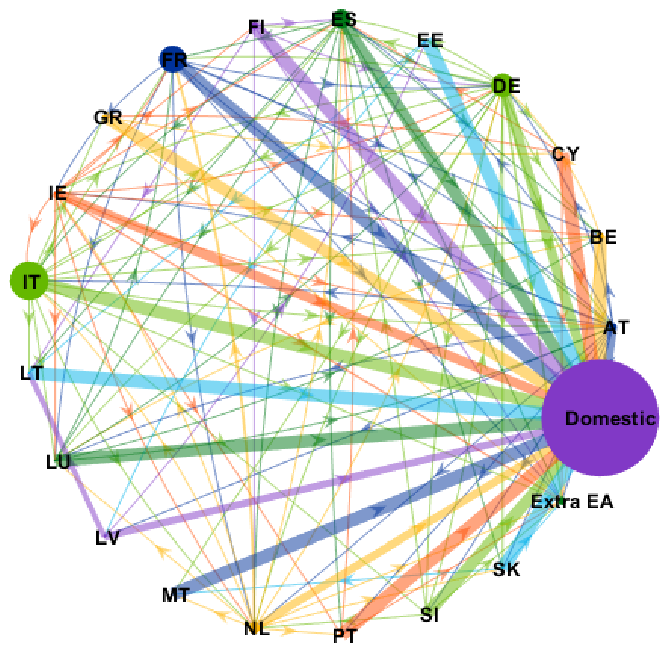
$$EC_{i,j,k,l} = \frac{Loans_{i,j,k,l}}{\sum_{j\in k} Loans_{i,j,k,l}} \times CO_{2k,l}.$$

The overall emissions content of the lending activities in a country is thus the sum of the emissions content of loans across banks and sectors: $\overline{EC}_l = \sum_k \sum_i EC_{i,k}$. We find that the emissions content of loans issued over the reference period across the euro area by participating institutions is around 151 CO_2 megatons ($MtCO_2$), which corresponds to the 8% of all emissions produced in the euro area in 2019.

In Figure 4, we display the emissions content by country. Generally speaking, the emis-

[6] Yearly sectoral CO_2 emissions at the country level are expressed in tonnes. To compute lending emission intensity, we take as reference the 2019 emission data, to exclude the impact of the Covid-19 pandemic.

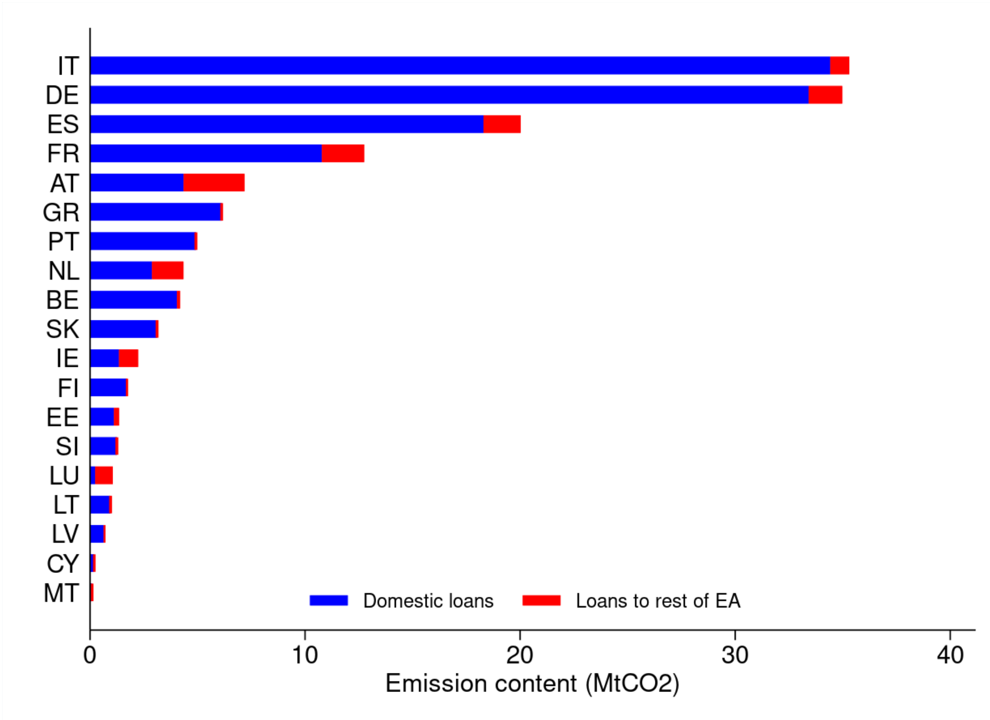
Figure 3: Network of loans originated over the TLTRO III reference period.



Notes: Cumulated loans originated over the period March 2020-March 2021. For individual countries, bubbles are proportional to the TLTRO III amounts received; for domestic and extra EA aggregates, bubbles are a cross-country weighted average of loans granted by banks to counterparties in the two categories, with weights given by the share of TLTRO III funds received by each country. The size of the arrows represents the share of bank loans flowing across countries during the reference period.
Sources: AnaCredit and authors' computations.

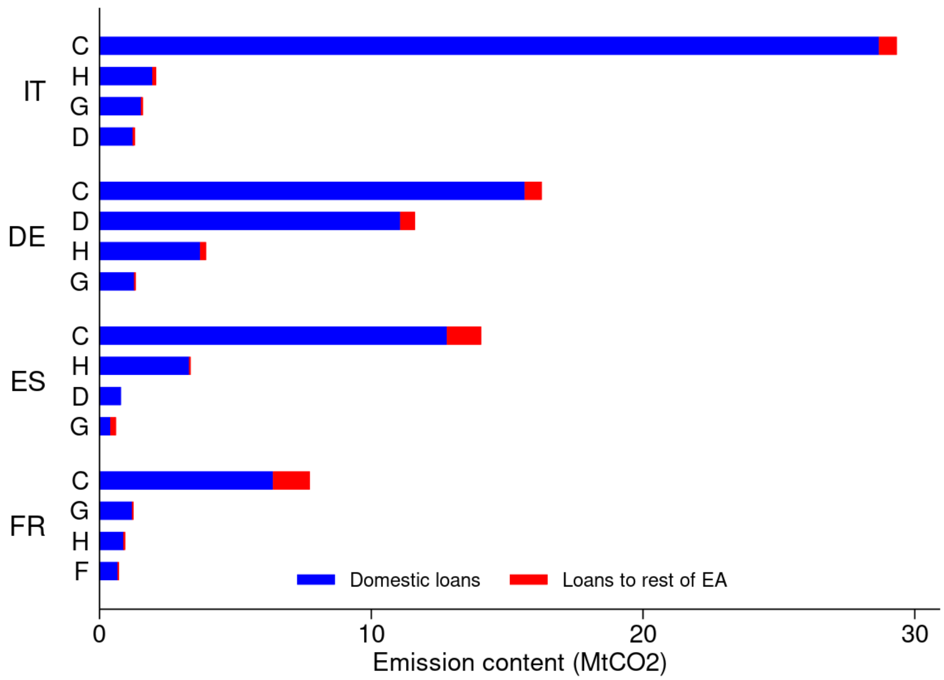
sions content of loans is mainly associated with domestic activities (with some exceptions like Austria and Luxembourg), which reflects the fact that most lending activities induced by the TLTRO III program are domestic. In terms of magnitudes, the countries recording the highest values are Italy and Germany, followed by Spain and France, though on a smaller scale. For that reason, we further break down the emissions content of loans by sector for these four countries (Figure 5). Overall, loans to the manufacturing sector (C) are found to feature the highest emissions content. This is especially true for Italy, where the emissions content of loans to this sector is more than twice than that of the other countries.

Figure 4: Emissions content of banks' lending activities by country.



Notes: The emissions content of loans is computed as the total amount of loans to each sector times the emission intensity of that sector in the receiving country. Time span: March 2020-March 2021.
Sources: AnaCredit and authors' computations

Figure 5: Emissions content of lending activities of banks by country-sector pair.



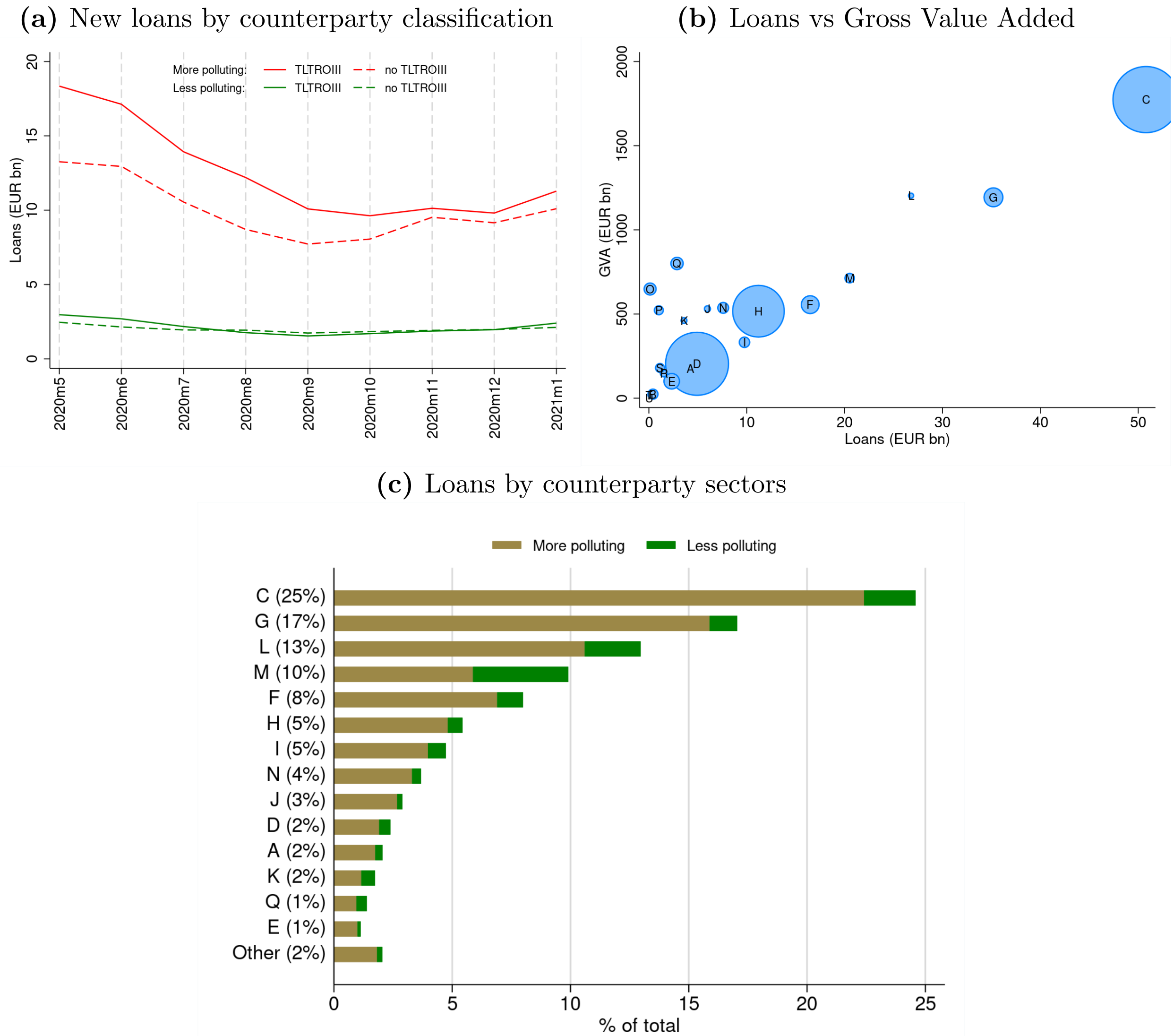
Notes: The emissions content of loans is computed as the total amount of loans to each sector times the emission intensity of that sector in the receiving country. The four letter codes represent the sectors "Manufacturing" (C), "Wholesale and retail trade, repair of motor vehicles and motorcycles" (G) and "Transporting and storage", "Electricity, gas, steam and air conditioning supply" (D). See also Appendix A. Time span: March 2020-March 2021.
Sources: AnaCredit and authors' computations

The size of the balks in Figures 4 and 5 could be driven by either the amount of loans provided to the sector or the emissions generated by that sector. To disentangle these two components, Figure 6a depicts the evolution of new lending over the reference period by distinguishing between more or less polluting the counterparties, whereas Figure 6b relates the total amount of loans to each sector to the gross value added produced by the same sector as of the end of 2019, with bubbles being proportional to the overall amount of emissions by each sector at the end of 2019.

Figure 6a shows that the increase in new lending by participating institutions during the reference period is driven by loans to more polluting sectors, whereas lending to less polluting ones is basically identical across the participating and non-participating institutions. In the reference period, cumulated loans towards polluting companies represent more than 80% of total loans issued. Moreover, Figure 6b confirms that manufacturing (C) is the sector receiving the highest amount of loans over the reference period. This is also the sector producing the highest gross value added (GVA) in 2019 and emitting the most. Other polluting sectors like electricity and gas supply (D) and transportation (H), instead, were granted less loans and produced less GVA compared to other less polluting sectors. While this evidence suggests that banks' credit choices are based on economic efficiency (i.e. more loans go to more productive sectors), these decisions seem to abstract from environmental considerations.

The economic activities within sectors, and hence their emissions content, differs across member states. For this reason, it is interesting to investigate how loans were allocated over sectors within the single member states. With this aim, we consider the participating banks' counterparties and we classify their sectors as more or less polluting, depending on whether the corresponding emissions are above or below the respective European sectoral averages. We then evaluate the lending activity in the euro area over the reference period, broken down according to the carbon footprint of the counterparties' sectors (Figure 6c). Preliminary evidence suggests that lending of participating institutions was mostly directed towards sectors whose emissions are above the European average, with manufacturing and wholesale and retail trade receiving almost half of new loans and contributing the most to new emissions.

Figure 6: Lending footprint



Notes: Figure 2a displays 4-month moving averages. In Figure 6b, bubbles are proportional to the amount of emission produced by each sector in 2019. In Figure 6c, sectors are ordered according to the total amount of loans received by each sector across EA countries (percentages are shown in parentheses on the y-axis). More (less) polluting sectors are defined as those sectors whose CO_2 emissions in 2019 were above (below) the sectoral average at the euro area level. For letter codes in Figures 6b and 6c, refer to Appendix A. Time span: lending data March 2020-March 2021; gross value added and emissions 2019.
Source: Eurostat, AnaCredit and authors' computations.

3 Theoretical Model

The TLTRO program was designed to encourage additional bank lending to the private sector. However, as shown in Section 2 above, the TLTRO III program has promoted new loans that are disproportionately allocated to polluting sectors. There are three reasons why this is a concern from the perspective of the ECB's own monetary and prudential objectives (Elderson (2021); Schnabel (2022)). First, while these funds may have helped achieve the TLTRO III's objective of spurring economic activity, this could have adverse consequences for price and financial stability as the pace of transition picks up. Second, the ECB's secondary mandate also entails a legal obligation to support the broader economic policies of and in the EU, which is unambiguously geared towards decarbonization. Finally, a reason for the carbon-intensity of the TLTRO program is that euro area banks underestimate their exposure to transition risk and as a consequence bank lending is disproportionately allocated to carbon intensive activities (ECB (2022); Baranović et al. (2021)). This risk-taking by ECB counterparties, however, also exposes the ECB itself to financial risk.

Central banks can mitigate the banks' neglect of transition risks in the allocation of loans through prudential policy (ECB (2020); Dikau et al. (2022)). As a supporting measure, central banks can use the design of TLTRO programs to incentivize more green lending (van 't Klooster and van Tilburg (2020); Batsaikhan and Jourdan (2021)). In this regard, a TLTRO program that differentiates bank cost factors for loans to more or less polluting companies allows the central bank to align bank lending with its sustainability targets, thus supporting the broader EU climate transition. However, as we will see, prudential and monetary measures should be used together rather than as substitutes.

In this section, we calibrate the static general equilibrium model developed by Böser and Colesanti Senni (2021) to evaluate the effects of a "green" credit easing scheme, where the central bank would impose differentiated interest rates depending on the emission intensity of banks' loans. With this exercise we contribute to the current debate on green monetary policy tools and provide a formal analysis to understand the mechanism behind a possible "green TLTRO".

3.1 Model setup

The model includes firms, households, banks and a central bank (as part of the government sector), which provides liquidity to banks in the form of reserves. Households maximize utiliy and and firms maximize profits. There are two types of firms: high polluting (risky as they face a higher transition risk) and low polluting (non-risky).Banks maximize the shareholder value, grant loans to polluting and non-polluting firms and need reserves to settle interbank liabilities.

Transactions among agents generate deposit outflows and banks need central bank reserves to settle the resulting interbank liabilities. The share of deposit outflows, ψ, can be interpreted as the demand for liquidity by banks over their outstanding deposits.

The central bank sets the deposit rate r_{CB}^D and the cost factors κ_h and κ_l on loans to risky and non-risky firms, respectively. These parameters ultimately determine the interest rate r_{CB}^L on reserve loans.

Two scenarios can materialize: either the economy remains in the current regime (business as usual) or a transition to a low carbon economy occurs (transition scenario). Moreover, the central bank and the private agents can disagree on the likelihood of the transition, by assigning different probabilities to it, η_g and η_p, respectively. The disagreement between the central bank and the other agents in the economy implies that, in the decentralized equilibrium, the allocation of loans to the polluting firms might be larger than the allocation that would emerge if the central bank's beliefs would prevail.

In order to reduce lending towards polluting firms, the central bank can optimally choose the cost factors κ_h and κ_l, so that

$$\kappa_h = a\kappa_l + \frac{a-1}{\psi} \qquad \text{and} \qquad \zeta\kappa_l + (1-\zeta)\kappa_h \geq 0,$$

where

$$a := \frac{\mathbb{E}_p[A_{h,s}]}{\mathbb{E}_g[A_{h,s}]} \qquad \text{and} \qquad \zeta^* := \left[1 + \left(\frac{\mathbb{E}_g[A_{h,s}]}{A_l}\right)^{\frac{1}{1-\alpha}}\right]^{-1}.$$

with $\mathbb{E}_i[A_{h,s}] = \eta_i A_{h,t} + (1-\eta_i)A_{h,b}$, $i = \{p, g\}$ and ζ^* representing the optimal share of bank loans towards less polluting firms. In this context, ζ^* can be thought of as a sort of climate objective that the central bank wants to achieve on the basis of its beliefs in the transition. The optimal cost factors, in turn, determine the interest rate that the central bank charges on reserves

$$r_{CB}^L(\zeta^*) = \max\{(1 + r_{CB}^D)[1 + \zeta^*\kappa_l + (1-\zeta^*)\kappa_h] - 1, 0\}, \tag{1}$$

which thus depends on three elements:

i) the optimal share of banks' lending to less polluting companies (ζ^*);

ii) the central banks' optimally chosen cost factors for loans to more or less polluting companies (κ_h and κ_l) and

iii) the beliefs about the likelihood of the transition on the part of the central banks and private agents (η_g and η_p).

This formulation allows us to account for the zero lower bound (ZLB), in that the lending rate can never go below 0. At the ZLB, the central bank's policy space to set differentiated cost factors is reduced.

Against this backdrop and conditional on the policy, the actual amount of loans to non-risky firms, ζ_p, is ultimately determined in the decentralized equilibrium by banks as follows:

$$\zeta_p = \left[1 + \left(\frac{\mathbb{E}_p[A_{h,s}]}{A_l}\frac{1+\psi\kappa_l}{1+\psi\kappa_h}\right)^{\frac{1}{1-\alpha}}\right]^{-1}. \tag{2}$$

By construction, $\zeta_p = \zeta^*$ as long as $\eta_g = \eta_p$. However, if agents' beliefs do diverge, there might be a discrepancy between the optimal capital allocation and the market equilibrium which can be corrected via the policy tool. In our baseline setting, we consider a configuration where the two cost factors are optimally chosen so that the decentralized equilibrium coincides with the optimal level of capital allocation. The latter is in turn endogenously determined on the basis of the other parameters, whose baseline calibration is reported in Table 1.

In particular, after classifying sectors as high or low polluting, we define productivity in the business as usual scenario as the ratio of the sector's gross value added to the total number of employees, by using information from the Eurostat.[7] Following Böser and Colesanti Senni (2021), we assume that the productivity of low-polluting firms remains unchanged in the transition scenario whereas that of high-polluting firms declines. We assume a decline of 2% in line with the results from the NGFS net zero 2050 scenario exercise, whereby GDP is forecast to decline by 2% in 2050 (see NGFS (2021)). ψ is computed by dividing the daily

[7]For the numerical simulations, we normalize the productivity of green firms to 1 and we then re-scale the productivity of brown firms in business as usual and transition scenarios accordingly.

average turnover processed by TARGET2 in 2019 by the sum of the 2019 averages of deposit liabilities vis-à-vis euro area MFIs, the deposit liabilities vis-à-vis euro area NFCs and the deposit liabilities vis-à-vis euro area households in millions of euros. All the variables are stocks reported by MFIs (excluding ESCB) in the euro area. The capital intensity, α, is set to 0.6, based on aggregate data from the Eurostat.[8] Furthermore, in our baseline setup we fix the central bank's deposit rate (DFR) to 0, as the ZLB was prevailing before 2022. Finally, we consider values for η_g and η_p in the range between 0.1 and 0.9 (from low to high probability attached to the transition).

Table 1: Baseline calibration

Parameter	**Description**	**Value**	**Source**
A_l	Productivity of non-risky firms	1	Eurostat
$A_{h,b}$	Productivity of risky firms in the business as usual	1.02	Eurostat
$A_{h,t}$	Productivity of risky firms in the transition	1	NGFS scenarios
ψ	Share of deposits outflowing	0.11	Trans-European Automated Real-time Gross settlement Express Transfer system and Balance Sheet Items - ECB Statistical Data Warehouse
α	Capital intensity	0.6	Eurostat
r^D_{CB}	Central bank's deposit rate	0	
η_g	Probability attached by the central bank to the transition	$[0.1, 0.9]$	
η_p	Probability attached by private agents to the transition	$[0.1, 0.9]$	

3.2 Baseline Results

The numerical simulations produce two main results. First, the central bank can counteract the carbon bias of the banking system by differentiating the two cost factors, thus implementing a green TLTRO scheme. Such a policy could be used to reduce lending to polluting companies and hence align the allocation of funds with the ECB's understanding of the likely transition pathway. Second, in a greener economy (where a higher share of loans goes to

[8] Notably, we compute the ratio between total non-financial assets on firms' balance sheets and total gross domestic product in the euro area at the end of 2019.

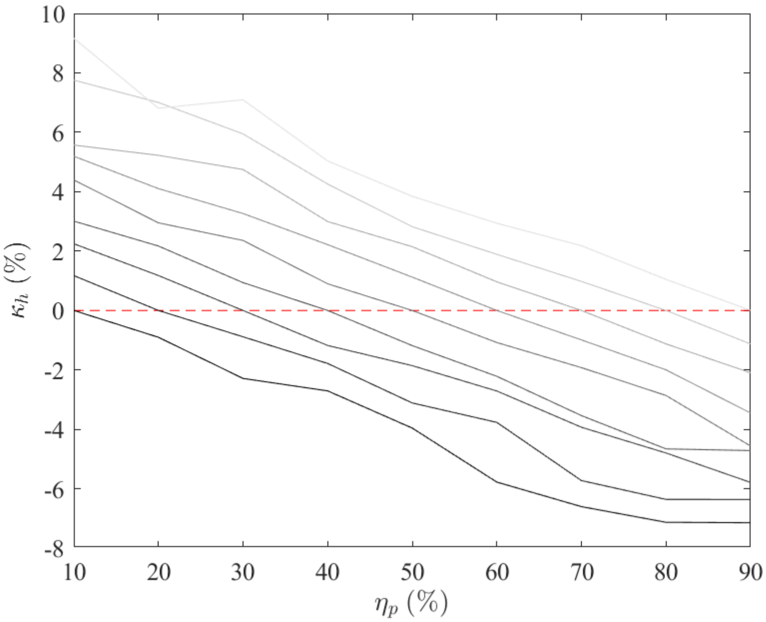
less-polluting firms), the central bank can set lower rates across the board. The effect is stronger if private agents attach a higher likelihood to the transition.

As to the first finding, in our model the higher the banking sector's underestimation of transition risks relative to the central bank ($\eta_g - \eta_p > 0$), the higher the cost factor on polluting loans. The central bank can mitigate the carbon bias in banks portfolios by setting $\kappa_h > \kappa_l$, thus increasing the refinancing costs for banks lending to risky firms. This entails worse funding conditions for polluting firms and, hence, constraints their activities. If, on the contrary, there is a convergence between the beliefs of private agents and those of the government sector ($\eta_g \approx \eta_p$), no intervention is needed and the two cost factors are identical: $\kappa_l = \kappa_h$. Figure 7 depicts the optimal cost factor chosen by the central bank for loans to polluting firms (κ_h) under our baseline calibration. For any given η_p, the more positive $\eta_g - \eta_p$, the higher is κ_h. Accordingly, for any given η_g, the stronger the private agents' beliefs ($\eta_p \uparrow$), the lower κ_h. As an example, consider the case where $\eta_g = 0.7$ and $\eta_p = 0.5$. Under such configuration, the central bank can align bank lending with its objective by adding a cost factor of around 2% to loans to risky firms (Figure 8). This would make the equilibrium level of loans to low polluting firms increase by 0.002 percentage points, from 49.38% to 49.63% of the total, i.e. the optimal level.

Our second finding follows from the analysis of the behaviour of the interest rate as a function of η_g and the corresponding ζ^*, for given values of η_p (Figure 9). The bigger η_g, the larger ζ^*, which implies a lower $r^L_{CB}(\zeta^*)$. Moreover, $r^L_{CB}(\zeta^*)$ is decreasing in η_p for any value of ζ^* and gets equal to 0 as soon as $\eta_p \geq \eta_g$. This seems to suggest that the central bank might have the incentive to change its strategy and get out of the ZLB if ($\eta_g - \eta_p$) is big enough.[9] Overall, then, the central bank can steer the lending behaviour of banks by means of a targeted credit easing tool aimed at aligning their portfolios with some climate objectives (ζ^*). However, this result crucially depends on the agents' prior beliefs about the future transition, which in our model are treated as given parameters. If, instead, η_p reacted to the central bank's policy, banks' behavior could re-align without further interventions. Such a scenario is left for future research.

[9] In this framework, we postulate that all agents can perfectly observe the parameters of interest, thus abstracting from any consideration about asymmetric information.

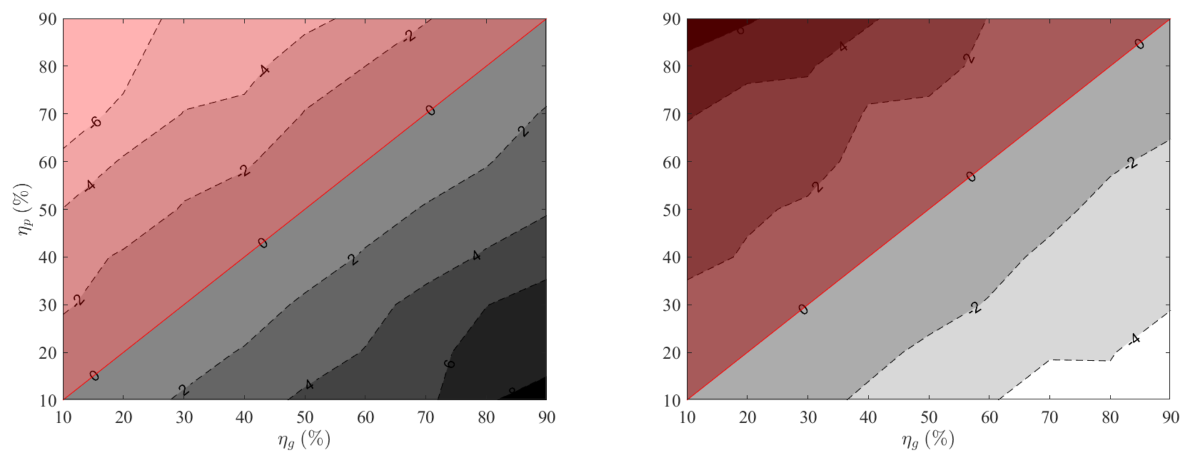
Figure 7: Cost factor on polluting loans as function of beliefs.



Notes: Cost factors are expressed as function of the transition probability of private agents (η_p) for increasing transition beliefs on the part of the central bank (from 10% in black to 90% in very light gray).
Sources: Authors' computations

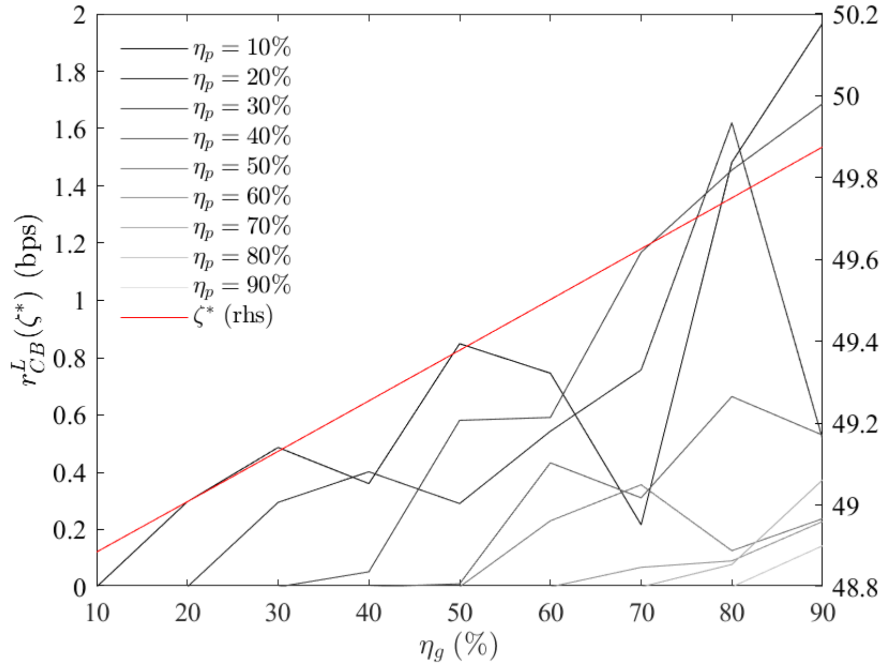
Figure 8: Cost factors for different beliefs.

(a) κ_h (%) **(b)** κ_l (%)



Notes: Level curves of κ_h and κ_l for different values of η_g and η_p. The red lines and shaded areas indicate configurations where the ZLB binds.
Sources: Authors' computations

Figure 9: Optimal policy rate.



Notes: The central bank's lending rate is here expressed as function of η_g and ζ^* (red line on the right-hand scale) and computed for different values of η_p (from 10% in black to 90% in very light gray).
Sources: Authors' computations

3.2.1 Financial stability implications

The baseline model also allows to investigate the financial instability implications of the green monetary policy described in Section 3. Banking operations are generally risky as loan repayment is uncertain, depending on the prevailing scenario. The central bank can shape the risk of default by setting the costs of interest payments on deposits and reserve borrowing.

We define bank leverage as the ratio of assets over bank equity: $\varphi = (L + D^{CB})/K$, where L are loans and D^{CB} are deposits at the central bank. Since expected profits from granting loans to firms are zero in equilibrium, the equity return in the business as usual scenario cannot be negative. In the transition scenario, instead, banks can default if φ is large enough and loan repayment of risky firms is not sufficient to meet their obligations towards depositors and the central bank. The threshold leverage above which banks default is given by:

$$\varphi^S(\zeta^*) = \frac{\mathbb{E}_p[A_{h,s}](1+\psi)}{(1+\psi\kappa_h)(1-\eta_p)(A_{h,b}-A_{h,t})(1-\zeta^*)}$$

and depends on the beliefs of private agents about the likelihood of the transition, on the optimal cost factor set by the central bank, κ_h and the corresponding ζ^*. These, in turn, depend on beliefs as shown above.

The higher the value of the threshold, the lower the banks' probability to default. Changes in agents' beliefs have an impact on the threshold via two channels: i) the cost factor on loans to risky firms, κ_h; ii) the optimal loans allocation, ζ^*. We take as starting point the configuration where $\eta_g = \eta_p = 50\%$ and $\kappa_h = \kappa_l = 0$, which implies that $\zeta^* = \zeta_p = 49.38\%$; we normalize the related default threshold to 100. In order to investigate the impact of a change in monetary policy on the default threshold, we start by assuming that the stock of loans cannot be immediately reallocated across risky and non-risky firms. Hence, we fix ζ to 49.38% and assess the behavior of φ^S as a function of agents' beliefs. Results show that if the probability attached to the transition by the central bank increases (that is, if η_g and, consequently, κ_h go up) the threshold value decreases and it becomes more likely for banks to default. However, if private agents also revise their beliefs upward (that is, if η_p increases), the central bank can lower κ_h, which in turn makes the default threshold increase, thus reducing financial stability risks.

Table 2: Default threshold values - ζ fixed

η_g \ η_p	10	20	30	40	50	60	70	80	90
10	55.28	62.07	70.80	82.43	98.72	123.16	163.89	245.34	489.71
20	55.46	62.27	71.02	82.70	99.04	123.55	164.41	246.13	491.27
30	55.64	62.47	71.25	82.96	99.36	123.95	164.94	246.92	492.85
40	55.81	62.67	71.48	83.23	99.68	124.35	165.47	247.71	494.44
50	56.00	62.87	71.71	83.50	**100.00**	124.75	166.01	248.51	496.04
60	56.18	63.08	71.95	83.77	100.33	125.16	166.55	249.32	497.66
70	56.36	63.28	72.18	84.05	100.65	125.57	167.09	250.14	499.29
80	56.55	63.49	72.42	84.32	100.99	125.98	167.64	250.97	500.93
90	56.74	63.70	72.66	84.60	101.32	126.40	168.20	251.80	502.59

We then assess the role of loan allocation, ζ, by allowing it to readjust immediately to the new policy environment so to ensure that $\zeta^* = \zeta_p$ – i.e. we treat ζ as an *endogenous* variable.

Results reported in Table 3 show a quite different picture, in that now the default threshold *increases* with η_g. The intuition is that when η_g increases, the central bank chooses a higher κ_h, which induces banks to relocate funds to less polluting firms. This, in turn, decreases their costs of funding at the central bank, thus lowering their probability of default.

Table 3: Default threshold values - ζ endogenous

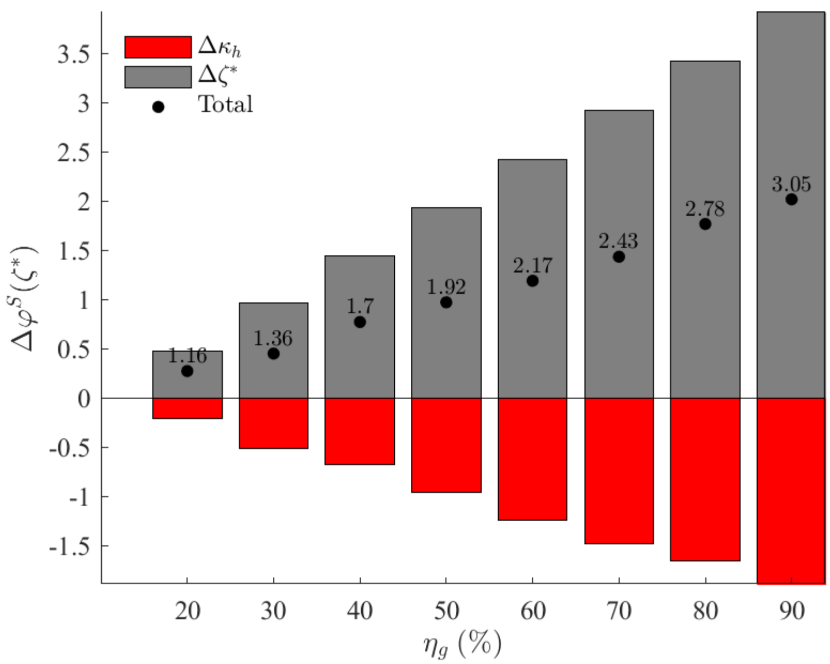
η_g \ η_p	10	20	30	40	50	60	70	80	90
10	56.00	62.94	71.87	83.75	100.49	125.41	167.07	250.59	500.53
20	55.52	62.41	71.26	83.06	99.62	124.36	165.85	248.45	495.91
30	55.59	62.49	71.36	83.20	99.72	124.52	165.92	248.62	496.80
40	55.67	62.57	71.46	83.29	99.89	124.75	166.25	249.19	497.41
50	55.73	62.67	71.53	83.42	**100.00**	124.90	166.36	249.30	498.54
60	55.81	62.74	71.63	83.50	100.12	125.06	166.60	249.67	499.15
70	55.93	62.82	71.69	83.63	100.26	125.23	166.82	250.05	499.63
80	55.93	62.85	71.77	83.73	100.43	125.42	167.06	250.36	500.34
90	55.99	63.02	71.86	83.86	100.57	125.58	167.25	250.69	500.96

Figure 10 depicts the decomposition of *cumulated* changes in $\varphi^S(\zeta^*)$ by disentangling between the two channels, κ_h and ζ^*.[10] As it can be noticed, an increase in η_g leads to: i) a decrease in $\varphi^S(\zeta^*)$ due to a rise in κ_h; ii) an increase in $\varphi^S(\zeta^*)$ due to the change in the optimal loan allocation. Given $\eta_p = 0.5$ and the baseline calibration of the model, the latter effect predominates. It can be shown that this result holds across different values of η_p. Therefore, this represents a specific case where monetary policy intervention can induce a greening of the lending portfolio, without generating financial stability risks and *regardless of the private agents' beliefs*.

Overall, our results suggest that not only can the central bank steer bank lending towards less-polluting activities, but also that the short-term implications for financial stability should be carefully considered, in particular against the current loan portfolio composition of euro area banks. Indeed, if banks cannot change their loan allocation in the short-run, a higher cost factor might pose risks to financial stability, depending on the speed of re-adjustment of private agents' beliefs.

[10] For illustration purposes, we assume here that $\eta_p = 0.5$.

Figure 10: Decomposition of $\Delta\varphi^S(\zeta^*)$



Notes: $\eta_p = 0.5$.
Sources: Authors' computations

4 Is a green TLTRO operationally feasible?

The real world implementation of a green TLTRO program raises new questions pertaining to the central bank's monetary policy mandate as well as concrete operational issues. Legal challenges result from the narrow mandate of the central bank, whose primary task is to maintain price stability. Operational challenges result from the practical obstacles that central banks face in evaluating, measuring and verifying the climate-alignment of bank lending (Drudi et al. (2021)). In what follows we discuss how green TLTROs can meet these challenges.

4.1 Legal considerations

Climate-related economic shocks matter to monetary policy first and foremost because they can undermine the broader economic preconditions of monetary and financial stability (Batten (2018); Schnabel (2020)). For the ECB, as we saw, legal obligations to take climate change into account also follow from its secondary mandate for supporting the broader economic policies in the EU, its contributing role in promoting financial stability and its obligation to manage risk to its balance sheet (Elderson (2021)). Against this background the ECB's 2021 climate agenda formulates three objectives: i) managing and mitigating the financial risks associated with climate change and assessing its economic impact; ii) promoting sustainable finance to support an orderly transition to a low-carbon economy; iii) sharing expertise to foster wider changes in behaviour.

As we document, the TLTRO program would do better in supporting these objectives by differentiating refinancing costs based on the lending profile of institutions.Existing TLTROs promote lending that is misaligned with the low carbon transition, which may negatively impact its monetary policy objectives. Moreover, current lending behaviours of banks are not based on adequate risk management practices with regard to climate and environmental risks risks. Most banks lack adequate systems to incorporate the these risk into their lending decisions (ECB (2022)). This means that misaligned lending exposes the banking sector to additional risks. By incentivizing lending to less polluting companies through its own operations the ECB would counteract this bias.

Two important legal constraints follow from the ECB's mandate. First, the design of a green TLTRO program should not prejudice the primary objective of price stability. In particular, it should not reduce the flexibility of the central bank in responding to changing inflationary conditions. As designed in 2019, the ECB's TLTRO III program reflects an accommodative policy stance, where TLTRO serve to "preserve favourable borrowing conditions for banks and stimulate bank lending to the real economy" (ECB (2022)). In this context, higher interest rates for polluting sectors can go together with low rates for the rest of the economy. However, there are also good reason to implement a TLTRO program in concert with rising interest rates. Rather than promoting new investment, the program would shield green investments from high interest rates. A sharp rise in funding costs could potentially negatively affect investment in clean energy production, energy efficiency and adaptation to extreme weather and environmental degradation (Schmidt et al. (2019)). For example, in a scenario where project funding costs rise to 4.29% in 2023 the costs of funding new wind energy project could go up 25% (Schmidt et al. (2019)). A green TLTRO program would protect investments in sustainable energy from higher financing costs. In both contexts, the program would help align bank lending with expected economic trajectory of the climate transition.

A second constraint that follows from the nature of the ECB's narrow mandate is that a green TLTRO program should be supportive of government economic policies rather than replacing or contradicting these. The ECB should avoid going too far in setting climate policy by itself, which falls outside its mandate and expertise (Ioannidis et al. (2021)). However, since ample existing policies exist on the EU-level concerning the overall orientation of climate policy, there is no need for the ECB to make policy on these topics autonomously. First, the ECB could refer to the Taxonomy regulation, which sets out what constitutes an environmentally sustainable economic activity. Second, the ECB could support existing efforts to improve sustainability related disclosures, which it has already done by linking collateral eligibility conditions to disclosure in line with the EU's Corporate Sustainability Reporting Directive (CSRD). Third, the ECB could also link its refinancing operations to more targeted programs, such as the May 2022 REPowerEU action plan, which seeks to address the climate-crisis while also ending the EU's dependence on Russian fossil fuels. Finally, the design of the TLTROs could also be used to support the ECB's own prudential initiatives in relation to climate and environmental risk, in particular the efforts to improve bank risk-management in relation to climate and environmental risks risk. In all cases the green TLTRO program would support existing policies rather than constituting autonomous policymaking.

4.2 Operational aspects of green TLTROs

An effective green TLTRO program should be designed to (i) evaluate to what extent bank lending is green as well as (ii) verify whether information provided by banks is accurate and "ensure that the fungible funds provided by banks are correctly and effectively used by individual borrowers to finance green projects" (Drudi et al. (2021)). Like TLTRO III, green TLTRO would work on an opt-in basis. The program incentivizes participation through the price of refinancing.

We consider three design options: one where green lending is determined based on existing EU policies, one where banks design dedicated frameworks to identify green investments and one where bank funding depends on the supervisor's evaluation of the bank's climate and environmental risk management capacities.

EU policy-based design. The simplest model for Green TLTROs would be to rely on existing EU environmental criteria for investments, such as the EU Taxonomy regulation or the REPowerEU action plan. From 2024 onwards, the Corporate Sustainability Reporting Directive (CSRD) will oblige not only banks but also publicly listed companies and insurance companies with over 500 employees to disclose the climate impact of their business activities from a perspective of double materiality (including taxonomy alignment). The European Banking Authority (EBA) has developed rules for the disclosure of a Green Asset Ratio for the largest European banks. Clear criteria are already available for a number of sectors. Almost all investments in renewable energy production, for example, are compliant. The criteria for the construction of new buildings and renovation are based on Energy Performance Certificates, which are already mandatory. Since housing is at the heart of the business model of European banks, a targeted housing program could effectively improve the environmental impact of the TLTRO. A similarly targeted programme could focus on the energy sector. With clear criteria in place, verification of reported lending patterns could be left to the bank's external auditor.

Bank-based design. Drawing lessons from the Bank of Japan (BoJ), the selection of what counts as a green investment could also be left to systems developed by banks and evaluated by the central bank. As part of the BoJ's Climate Response Financing Operations, eligible counterparties are required to develop internal systems to screen bank loans based on "targets and actual results for their investment or loans" (BoJ (2022)). As long as the bank's systems are deemed adequate by the BoJ, the choice which loans are sufficiently green is ultimately left to the banks. Similarly, eligibility in a green TLTRO program could be made conditional on bank's having adequate internal systems to identify loans that are EU-policy compliant, support the REPower EU agenda or for more targeted programs geared towards energy efficient buildings. The ECB's role would be to evaluate the adequacy of bank screening criteria, while the external auditor could be asked to certify reported lending.

Supervisory expectations-based design. Green TLTROs could also be use to support existing financial stability policies in which supervisors scrutinize banks internal risk management capacities for climate and environmental risk screening. Eligibility in the program could be made available for lending by banks that meet the expectations set out in the ECB's Guide on climate-related and environmental risks (ECB (2020)). The Guide sets out what adequate climate and environmental risks risk management looks like with regard to the bank's lending practices, business strategy, management expertise and incentive structures, as well as the disclosure of risk to investors. For now, however, most banks lack adequate systems to incorporate climate and environmental risks risks into their lending decisions (ECB (2022)).

5 Conclusion

In this paper, we studied the climate impact of central bank refinancing operations. Focusing on the ECB's TLTRO III programme, we showed that the lending activities originated over the period March 2020 to March 2021 from the institutions participating in the TLTRO III program generated around 151 MtCO_2, about 8% of overall euro area emissions in 2019. We also showed that additional lending under the programme drove loans to more polluting sectors, while lending to less polluting sectors is almost identical across participating and non-participating firms. In the reference period, cumulated loans towards polluting companies represent more than 80% of total loans issued.

Against this backdrop, we discussed how the central bank can direct lending towards less polluting companies through its refinancing operations by means of a theoretical framework (Böser and Colesanti Senni (2021)). The model assumes that the optimal choice of the interest rate by the central bank depends on the cost factors imposed by the central bank on loans to polluting and non-polluting firms, the beliefs of the central bank and private agents in the likelihood of the transition, and the share of loans to polluting companies in banks' portfolios. Our findings are twofold. First, by using differentiated cost factors, the central bank can counteract the carbon bias in bank loans by re-directing lending towards less-polluting companies. Moreover, regardless of private agents' beliefs about the transition, a lending portfolio more tilted towards less polluting sectors enables the central bank to set a lower interest rate across the board. Second, the "green" credit easing scheme has financial stability implications. The beliefs of agents in the economy and the corresponding optimal cost factors and loan allocation can affect the probability of banks' default. This in turn warrants for a careful design of the policy tool.

Finally, we discussed the legal and practical feasibility of a green TLTRO program. We proposed three design options for implementation: (1) an EU policy-based design, based on existing EU environmental criteria for investments such as the EU Taxonomy; (2) a bank-based design, where bank would decide on how green investments are and (3) a supervisory expectations-based design, where central banks or financial supervisors would determine eligibility criteria.

These novel insights into the potential role of green lending schemes could be extended in several directions. We would be interested to explore alternative identification strategies for the impact of participation to credit easing schemes on lending. Similarly, one could consider a dynamic version of the theoretical model, featuring financial frictions and where polluting firms could endogenously decide to reduce their emissions. While clearly permissible within the ECB's legal mandate, operational implications concerning feasible levels of interest rate differentiation and financial market implications deserve further study.

References

[1] Acevedo, S., Mrkaic, M., Novta, N., Pugacheva, E., and Topalova, P. "The effects of weather shocks on economic activity: what are the channels of impact?". *Journal of Macroeconomics*, 65:103207, 2020.

[2] Adrian, T. and Liang, N. "Monetary policy, financial conditions, and financial stability". *International Journal of Central Banking*, (2), 2018.

[3] Afonso, A. and Sousa-Leite, J. "The transmission of unconventional monetary policy to bank credit supply: evidence from the tltro". *The Manchester School*, 88:151–171, 2020.

[4] Alogoskoufis, S., Dunz, N., Emambakhsh, T., Hennig, T., Kaijser, M., Kouratzoglou, C., Muñoz, M. A., Parisi, L., and Salleo, C. *ECB economy-wide climate stress test: Methodology and results*. Number 281. 2021.

[5] Andreeva, D. C. and García-Posada, M. "The impact of the ecb's targeted long-term refinancing operations on banks' lending policies: The role of competition". *Journal of Banking & Finance*, 122:105992, 2021.

[6] Baranović, I., Busies, I., Coussens, W., Grill, M., Hempell, H. S., et al. "The challenge of capturing climate risks in the banking regulatory framework: is there a need for a macroprudential response?". *Macroprudential Bulletin*, 15, 2021.

[7] Barbiero, F., Burlon, L., Dimou, M., and Toczynski, J. "Dual interest rates and the transmission of monetary policy". *SUERF Policy Brief*, 461, 2022.

[8] Batsaikhan, U. and Jourdan, S. "Money looking for a home". *Positive Money Europe*, 2021.

[9] Batten, S. "Climate change and the macro-economy: a critical review". *Bank of England Working Paper*, (706), 2018.

[10] Battiston, S., Dafermos, Y., and Monasterolo, I. "Climate risks and financial stability". *Journal of Financial Stability*, 54:100867, 2021.

[11] Benetton, M. and Fantino, D. "Targeted monetary policy and bank lending behavior". *Journal of Financial Economics*, 142(1):404–429, 2021.

[12] BoJ. "Principal terms and conditions of the funds-supplying operations to support financing for climate change responses". *Bank of Japan*, 2022.

[13] Böser, F. and Colesanti Senni, C. "CAROs: Climate risk-adjusted refinancing operations". *Available at SSRN 3985230*, 2021.

[14] Campiglio, E., Dafermos, Y., Monnin, P., Ryan-Collins, J., Schotten, G., and Tanaka, M. "Climate change challenges for central banks and financial regulators". *Nature climate change*, 8(6):462–468, 2018.

[15] Colesanti Senni, C. and Monnin, P. "Aligning central bank refinancing operations with the G20 agenda". *Council on Economic Policies Briefing*, 2021.

[16] Da Silva, E., Grossmann-Wirth, V., Nguyen, B., and Vari, M. "Paying Banks to Lend? Evidence from the Eurosystem's TLTRO and the Euro Area Credit Registry". *Banque de France Working paper*, (848), 2021.

[17] Dafermos, Y., Gabor, D., Nikolaidi, M., Pawloff, A., and van Lerven, F. "Decarbonising is easy: Beyond market neutrality in the ecb's corporate qe". 2020.

[18] De Bandt, O., Jacolin, L., and Thibault, L. "Climate change in developing countries: global warming effects, transmission channels and adaptation policies". *Banque de France Working Paper*, (822), 2021.

[19] de Haas, R. and Popov, A. "Finance and Carbon Emissions". CEPR Discussion Papers 14012, C.E.P.R. Discussion Papers, Sept. 2019.

[20] Dell, M., Jones, B. F., and Olken, B. A. "Temperature shocks and economic growth: Evidence from the last half century". *American Economic Journal: Macroeconomics*, 4 (3):66–95, 2012.

[21] Deyris, J. "Too green to be true? Forging a climate consensus at the european central bank". *New Political Economy*, pages 1–18, 2022.

[22] Dikau, S., Robins, N., Smolenska, A., Van 't Klooster, J., and Volz, U. "Net zero transition plans: a supervisory playbook for prudential authorities". Policy Report, Grantham Research Institute on Climate Change and the Environment, London, 2022.

[23] Diluiso, F., Annicchiarico, B., Kalkuhl, M., and Minx, J. C. "Climate actions and macro-financial stability: The role of central banks". *Journal of Environmental Economics and Management*, 110:102548, 2021.

[24] Drudi, F., Moench, E., Holthausen, C., Weber, P.-F., Ferrucci, G., Setzer, R., Nino, V. D., Barbiero, F., Faccia, D., Breitenfellner, A., et al. "Climate change and monetary policy in the euro area". *ECB Occasional Paper No. 2021/271*, 2021.

[25] D'Orazio, P. and Popoyan, L. "Realising central banks' climate ambitions through financial stability mandates". *Intereconomics*, 57(2):103–111, 2022.

[26] ECB. "Guide on climate-related and environmental risks, supervisory expectations relating to risk management and disclosure". *European Central Bank*, 2020.

[27] ECB. "ECB presents action plan to include climate change considerations in its monetary policy strategy". *European Central Bank*, 2021.

[28] ECB. "Supervisory assessment of institutions' climate-related and environmental risks disclosures". *European Central Bank*, 2022.

[29] ECB. "Targeted longer-term refinancing operations (TLTROs)". *European Central Bank*, 2022.

[30] Elderson, F. "Greening monetary policy". *ECB Blog*, 2021.

[31] Faccia, D., Parker, M., and Stracca, L. "Feeling the heat: extreme temperatures and price stability". *ECB Working Paper*, (2626), 2021.

[32] Giovanardi, F., Kaldorf, M., Radke, L., and Wicknig, F. "The preferential treatment of green bonds". *Deutsche Bundesbank Discussion Paper*, (51), 2022.

[33] Goodhart, C., Osorio, C., and Tsomocos, D. P. "Analysis of monetary policy and financial stability: A new paradigm". *CESifo Working Paper Series*, (2885), 2009.

[34] Grimm, M., Jordà, Ò., Schularick, M., and Taylor, A. M. "Loose monetary policy and financial instability". *National Bureau of Economic Research*, (30958), 2023.

[35] Ioannidis, M., Hlásková, S. J., and Zilioli, C. "The mandate of the ecb: Legal considerations in the ecb's monetary policy strategy review". *ECB Occasional Paper*, (2021276), 2021.

[36] Kim, H. S., Matthes, C., and Phan, T. "Extreme weather and the macroeconomy". *Federal Reserve Bank of Richmond*, (14R), 2021.

[37] Krogstrup, S. and Oman, W. "Macroeconomic and financial policies for climate change mitigation: A review of the literature". *IMF Working Papers*, (185), 2019.

[38] Matikainen, S., Campiglio, E., and Zenghelis, D. "The climate impact of quantitative easing". *Policy Paper, Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science*, 36, 2017.

[39] Mukherjee, K. and Ouattara, B. "Climate and monetary policy: do temperature shocks lead to inflationary pressures?". *Climatic change*, 167(3-4):32, 2021.

[40] Oehmke, M. and Opp, M. "Green capital requirements". *Swedish House of Finance Research Paper*, (16), 2021.

[41] Oustry, A., Erkan, B., Svartzman, R., and Weber, P.-F. "Climate-related risks and central banks' collateral policy: A methodological experiment". *Banque de France Working Paper*, (790), 2020.

[42] Piazessi, M., Papoutsi, M., and Schneider, M. "How unconventional is green monetary policy?". Technical report, 2021.

[43] Schmidt, T. S., Steffen, B., Egli, F., Pahle, M., Tietjen, O., and Edenhofer, O. "Adverse effects of rising interest rates on sustainable energy transitions". *Nature Sustainability*, 2(9):879–885, 2019.

[44] Schnabel, I. "When markets fail–the need for collective action in tackling climate change". *Speech at the European Sustainable Finance Summit, Frankfurt am Main*, 28, 2020.

[45] Schnabel, I. “Monetary policy tightening and the green transition”. In *Intervention at the International Symposium on Central Bank Independence, Sveriges Riksbank, Stockholm*, 2022.

[46] Schoenmaker, D. “Greening monetary policy”. *Climate Policy*, 21(4):581–592, 2021.

[47] Smets, F. “Financial stability and monetary policy: How closely interlinked?”. *35th issue (June 2014) of the International Journal of Central Banking*, 2018.

[48] van ’t Klooster, J. and Fontan, C. “The myth of market neutrality: A comparative study of the european central bank’s and the swiss national bank’s corporate security purchases”. *New Political Economy*, 25(6):865–879, 2020.

[49] van ’t Klooster, J. and van Tilburg, R. “Targeting a sustainable recovery with green tltros”. *Sustainable Finance Lab Positive Money Europe*, 2020.

[50] van ‘t Klooster, J. “The European Central Bank’s strategy, environmental policy and the new inflation: a case for interest rate differentiation.”. *Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London School of Economics and Political Science.*, 2022.

Appendices

A NACE sectors

Letter	Sector
A	Agriculture, forestry and fishing
B	Mining and quarrying
C	Manufacturing
D	Electricity, gas, steam and air conditioning supply
E	Water supply, sewerage, waste managment and remediation activities
F	Construction
G	Wholesale and retail trade, repair of motor vehicles and motorcycles
H	Transporting and storage
I	Accommodation and food service activities
J	Information and communication
K	Financial and insurance activities
L	Real estate activities
M	Professional, scientific and technical activities
N	Administrative and support service activities
O	Public administration and defence, compulsory social security
P	Education
Q	Human health and social work activities
R	Arts, entertainment and recreation
S	Other services activities
T	Activities of households as employers, undifferentiated goods and services producing activities of households for own use
U	Activities of extraterritorial organisations and bodies