A question of trust? Banks' climate sentiments, lending behavior and the low-carbon transition

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Abstract

We study how banks' climate sentiments affect their lending decisions and economic decarbonization. Banks can form expectations about firms' performance in the low-carbon transition either in a backward-looking (firms' GHG emissions) or forward-looking way (firms' technology alignment). We analyse how such expectations lead to adjustments in investment decisions, macroeconomic and financial indicators, conditioned to the climate scenarios of the Network for Greening the Financial System. We calibrate the EIRIN macro-financial model to Austria and we find that banks' climate sentiments reinforce the impact of orderly carbon tax introduction on decarbonization (- 20% GHG emissions in comparison to current policies) and on co-benefits (avoided GDP losses). However, banks' climate sentiments can also counteract the impact of the policy, depending on how expectations affect the revision of lending conditions for high and low-carbon investments. In particular, expectations leading to credit constraints on low-carbon investments hinder the low-carbon transition.

Keywords: Banks' climate sentiments, Carbon pricing, Banking, Credit risk, Climate finance, Investment, Low-carbon transition, Co-benefits.
JEL: B59, C69, G20, Q50

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1. Introduction

Climate change is already affecting countries' economies. In the European Union (EU) alone, climate-related economic and financial losses are estimated at EUR 487 billion between 1980 and 2020[1]. Climate-related losses are expected to increase (IPCC, 2021), with far-reaching consequences on economic and financial stability (Bank for International Settlements, 2021; Brunetti et al., 2021; Battiston et al., 2021a; OECD, 2021; FSB, 2022; Emambakhsh et al., 2022), if climate policies are not introduced early and orderly (NGFS, 2020, 2021; IPCC, 2022; ECB/ESRB, 2022).

In this regard, a growing debate emerged on the role of climate fiscal and financial policies to signal investors, scale up public and private finance into low-carbon activities, and divesting from high-carbon activities (HLEG, 2018; Krogstrup and Oman, 2019; Stiglitz et al., 2017; Polzin and Sanders, 2020; Monasterolo et al., 2022b). Indeed, while available capital and liquidity would suffice to close the green investment gap, current financial flows are a factor of three to six times lower than the levels needed by 2030 to limit warming to below 2°C (IPCC, 2022).

The banking sector has a key role to play in funding low-carbon activities (Louche et al., 2019), especially in the EU. Indeed, banks' credit represents the major share of the financing structure of euro area firms (Holm-Hadulla et al., 2022) and more than 50% of EU firms' external financing comes from bank borrowing (ECB, 2016), with SMEs being especially reliant on it (ECB, 2022). Moreover, research has shown that bank credit access conditions have a significant impact on firms' investment portfolios and the real economy (Cenni et al., 2015; Bucă and Vermeulen, 2017; Dursun-de Neef and Schandlbauer, 2021). Firms that are faced with credit constraints - both on the price and quantity of loans - significantly reduce their tech and capital investment (Duchin et al., 2010; Gómez, 2019), also foregoing attractive investment opportunities (Campello et al., 2010). Evidence also shows that firms facing lending difficulties can hardly switch to other banks (Jiménez et al., 2012). Finally, limited substitutability for bank financing with other forms of external finance is a barrier to investments in the EU (Casey and O'Toole, 2014). In general, whether banks decide to price climate risks in their lending policies has significant effects on the financial system and the real economy (Nguyen et al., 2022). In the euro area, the European Central Bank (ECB) found that two thirds of banks do not have adequate data and models to assess the climate risk exposure of their portfolios (ECB, 2022). Moreover, the 6th Assessment Report of the IPCC highlighted that poor climate financial risk assessment is a main barrier for capital reallocation in the economy (Kreibiehl et al., 2022).

Banks' lending behaviour is heterogeneous and is largely driven by the business model chosen by bank owners (Behr et al., 2013). This is especially true in the pricing of climate risks due to the uncertainty and lack of common modelling frameworks to assess climate risk exposure (Giglio et al., 2021; Ehlers et al., 2022). Therefore, an important determinant of banks' lending behaviour in the low-carbon transition is the attention they pay to environmental and climate factors, and their resulting expectations i.e. their *climate sentiments*.

The concept of climate sentiments was introduced by Dunz et al. (2021b) as investors' expectations towards climate scenarios, and internalisation in their financial risk assessment and investment decisions. Banks' expectations towards climate policies and impacts can lead to adjustments in risk assessment and thus into lending to firms, by increasing the cost of capital for high-carbon investments and decreasing it for low-carbon investments (Dunz et al., 2021b; Battiston et al., 2021b). Further, sentiments have also been investigated as exogenous preferences that are not motivated by fundamental information (Pástor et al., 2021; Pedersen et al., 2021). Briere and Ramelli (2021) find that investors' green sentiments decrease the relative cost of capital for more environmentally responsible firms, while Delis et al. (2019) find that green banks increasingly consider climate policy and transition risk in their loan pricing decisions.

We build on and complement these insights analysing under which conditions banks' expectations towards climate policies (carbon tax), and their credibility, affect risk assessment, lending decisions to high- and low-carbon firms, and thus the feasibility of the transition. To this aim, we consider banks that form expectations based on two types of firms' climate-relevant information, i.e. i) backward-looking sentiments that consider past firms' Greenhouse Gas (GHG) emissions, and ii) forward-looking sentiments that consider firms' energy technology alignment to the transition scenarios.

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[1] See `https://www.eea.europa.eu/ims/economic-losses-from-climate-related`

To perform our computational experiments we further develop the EIRIN macro-financial model (Monasterolo and Raberto, 2018; Gourdel et al., 2022), and we calibrate it on Austria. EIRIN is a Stock-Flow Consistent (SFC) behavioral model populated by heterogenous agents and sectors (e.g. high/low-carbon, high/low-income) of the economy, connected to financial agents (i.e. banks and the central bank) that invest in the economy. The model's behavioral characteristics allow for the considerations of the deep uncertainty, non-linearity and endogeneity of climate risks (Bordalo et al., 2018; Monasterolo, 2020) in investment and consumption decisions, by relaxing assumptions about agents' perfect foresight, rational expectations, representativeness, and the efficient markets hypothesis. With EIRIN, we investigate the role of the banking sector in financing the low-carbon transition, focusing on the credit channel through which banks' climate sentiments affect firms' investment decisions and, thus, the realization of the transition scenarios.

First, we analyse the macro-financial and decarbonization impacts (Greenhouse Gas (GHG) emissions) of the climate scenarios of the Network for Greening the Financial System (NGFS, 2021). We analyse the endogenous dynamics that lead to direct, indirect and cascading impacts, and their results on main macroeconomic and financial indicators. Second, we analyse the interplay between climate policies, focusing on carbon pricing, and banks' climate sentiments, focusing on endogenous changes in banks' lending behaviour. We study and compare the effects of climate sentiments on endogenous investment decisions of firms and the low-carbon transition, focusing on the Net Zero scenario. Third, we analyse the implications of credit restrictions on loans requests for low-carbon investment on investments, GHG emissions and the realization of the transition scenarios.

The manuscript is organized as follows. Section 2 describes the main structural and behavioral characteristics of the EIRIN model. Section 3 describes the calibration procedure used to generate the benchmark model, which reproduces the characteristics of the Austrian economy and banking sector. Section 4 describes the NGFS scenarios considered, downscales them to Austria, and discusses the green fiscal policies introduced to analyse transition risks. Section 5 describes the banking sector's climate sentiments, the risk assessment and credit restriction channels. Section 6 presents and discusses the simulation results. Section 7 concludes with considerations about climate finance policies for the banking sector in the low-carbon transition.

2. Model description

EIRIN is a Stock Flow Consistent (SFC) model of an open economy populated by a limited number of heterogeneous agents and sectors of the real economy and financial system. SFC models gained relevance in macroeconomics (Godley and Lavoie, 2006; Caverzasi and Godin, 2015; Caiani et al., 2016; Nikiforos and Zezza, 2017; Mazzocchetti et al., 2020), in particular in climate economics (Dunz et al., 2021a; Ponta et al., 2018; Monasterolo and Raberto, 2019; Naqvi and Stockhammer, 2018; Carnevali et al., 2021; Dafermos et al., 2017). SFC models have been recently implemented to study the macro-financial effects of green financial policies and climate risks (Dafermos and Nikolaidi, 2021) and a transition in energy production (Jackson and Jackson, 2021).

EIRIN is composed by heterogenosu agents and sectors of the real economy and finance (figure 1), which interact in a number of markets (figure 2). In particular, EIRIN's agents and sectors include:

- a wage-earning household (H_W) and a capital income-earning household (H_K)
- a consumption goods (F_K) and a services sector (F_L) that produce for final consumption
- a high-carbon capital goods producer (K_B) and a low-carbon capital goods producer (K_G)
- a utility company that produces energy from fossil fuels (high-carbon, (EN_B)) and one that produces energy from renewables (low-carbon, (EN_G))
- a mining and fossil fuel extraction company (MO)
- a commercial banking sector (BA)
- a government (G) and a central bank (CB) that regulate the economy and the financial system
- the rest of the world (ROW) which provides import and export of commodities

In EIRIN, agents are heterogeneous with respect to characteristics and preferences and make decisions based on behavioral rules and heuristics. Furthermore, EIRIN's agents are endowed with adaptive expectations about the future of the economy[2], allowing us to consider the impact of climate impact uncertainty, and potential mispricing, on economic and financial outcomes of the transition.

The accounting framework is composed of three main matrices: i) a balance sheet matrix that accounts for all the stocks held by agents and sectors; ii) a transaction flow matrix that describes all the flows between agents and sectors at each period; iii) a net worth change matrix that shows how sectors' net worth changes due to both net cash flows and the price changes of financial assets. (see Appendix A, Dunz et al. (2021a) and Gourdel et al. (2022) for details). EIRIN's accounting identities represent structural specifications that have to be fulfilled at any time step in the model simulation, thus providing relevant binding constraints for the model dynamics. Therefore, the SFC constraints contribute to strengthen both the model and code validation, and the transparency and accountability of results, overcoming a main limitation of simulation models. Moreover, the rigorous SFC accounting framework allows us to display the dynamic relations between agents and sectors' balance sheets, and to analyse in a consistent way the chains of causation and transmission channels throughout the economy.

The capital and current account flows of the model are presented in figure 1. The energy firms, the service sector and consumption good producer require capital as an input factor for production. To build-up their capital stock, they invest in capital goods (grey dashed line), which are produced either by the low- or the high-carbon capital goods producer. To finance investment expenditures, firms can use held liquidity or borrow from the commercial bank (red dotted line), which applies an interest rate to their loans (red solid line). Households, firms and the government hold deposits with the commercial bank (dark green dashed line). The commercial bank also holds reserves at the central bank, that could provide refinancing lines (red dotted line). The government pays public employees (pink dashed line) and provides emergency relief and subsidies to firms in the real economy (blue solid line). The government collects tax revenues from households and firms (orange solid line) and finances its current spending by issuing sovereign bonds (dark blue dotted line). Sovereign bonds can be bought by the capitalist household, the commercial bank and the central bank. The government pays coupons on sovereign bonds (dark blue solid line). Households are divided into workers and capitalists, based on their functional source of income: workers receive wage income (pink dashed line); capitalists own domestic firms from which they receive dividend income (purple solid line) and coupon payments for their sovereign bond holdings (dark blue solid line). The rest of the world receives remittances (grey dotted line), exports consumption goods to households (black solid line), and primary resources to firms as inputs for the production process (grey solid line). The rest of the world generates tourism flows and spending in the country, and exports of service sector and industry goods (grey solid line).

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[2] With the term adaptive expectations we mean that agents adapt their current behaviour based on their foresight of the future state of the economy (Arthur, 1994). Crucially, agents' foresight is not only based on rational, intertemporally-optimising expectations, but on *bounded rationality*.

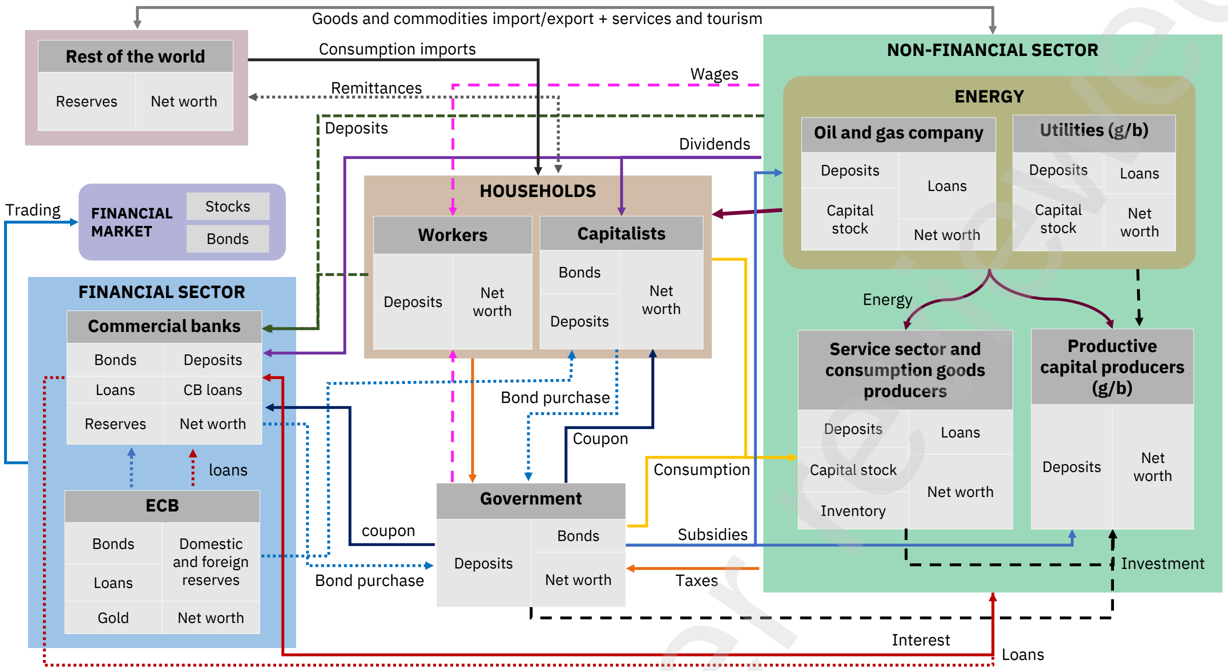

Figure 1: The EIRIN model framework: capital and current account flows of the EIRIN economy. For each sector and agent of the economy and finance, a representation in terms of their balance sheet entries (i.e. assets and liabilities) and their connections, is provided. The dotted lines represent the capital account flows, while the solid lines represent the current account flows.
Source: Authors' own elaboration.

In figure 2 we display the main agents and sectors of the EIRIN economy (grey boxes), and the markets through which they interact. In particular, financial markets (light blue box) include the markets for government bonds and stock shares (see Monasterolo et al. (2022a) for details), and the credit market. The real markets (wheat box) include consumption goods and service markets, the labor market, the energy market, the tourism market, the capital goods markets, and the raw material market (oval boxes).

The EIRIN model is initialised with calibrated quantities for each balance sheet entry and each parameter which determines the functional form of the behavioural equations. Consequently, the model is simulated for a predetermined number of periods within which it converges to stability. In the current setting each period represents a six-months time span. The next section describes the sequence of events that take place at each simulation period.

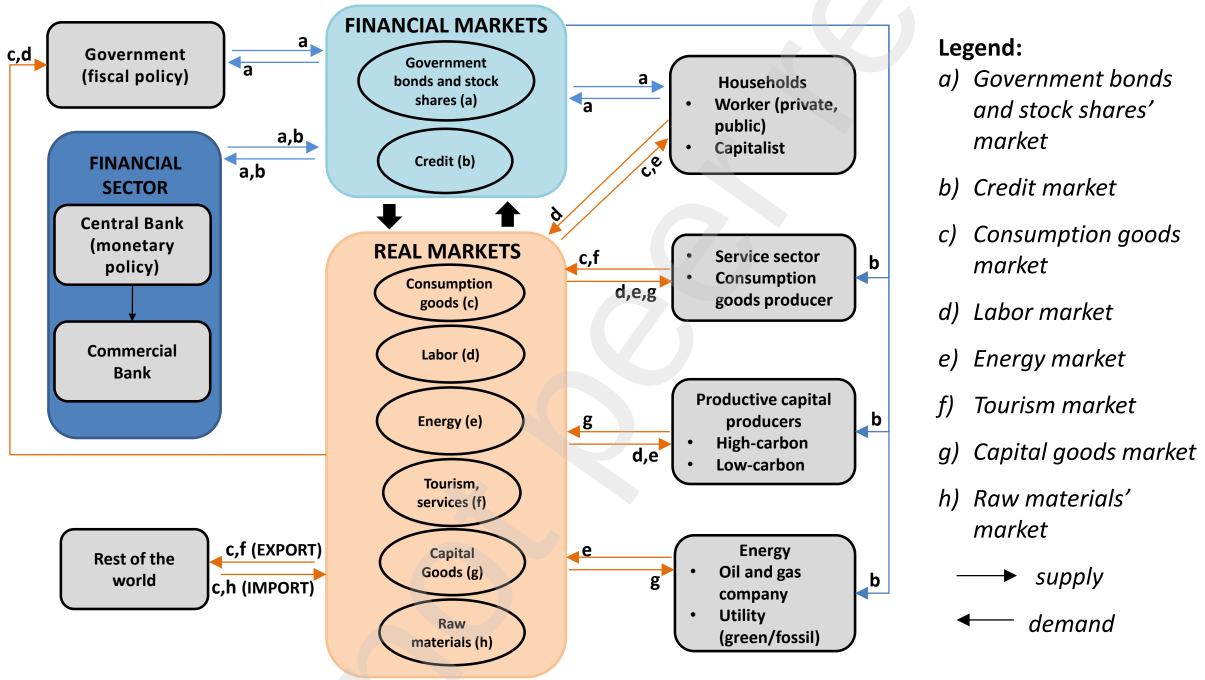

Figure 2: Agents, sectors and markets of the EIRIN economy.
Black boxes include agents and sectors, the light blue box contains financial markets and the light orange box includes the real markets. The agents and sectors interact through real and financial markets; outgoing arrows represent supply, while incoming arrows represent demand.
Source: Authors' own elaboration.

2.1. Sequence of events

At each simulation step, some transactions are performed in all markets. The sequence of events in the EIRIN economy is the following:

1. *Policy makers take their policy decisions.* The central bank sets a new baseline interest rate according to a Taylor-like rule depending on inflation and unemployment rates. The government calculates its budget to GDP and adjusts tax rates accordingly. It also decides how much to refinance debt through the emission of bonds.
2. *Wage bargaining and capital goods pricing.* The new level of wages is set via the use of a Phillips curve à la Keen (2013)[3]. The price of raw materials, oil and energy are calculated. The price of capital is set by capital producers, given that the inputs for capital goods production are only labour, energy and raw materials.
3. *Goods and services market.* The worker and capitalist households set their nominal demand for consumption goods and services. The manufacturing and services sectors provide supply based on the available inputs and set unit costs at a fixed markup on production costs. F_K and F_L set their production plans for the next period, setting their investment targets. The quantity of low-carbon and high-carbon capital that will be purchased depends on the net present value (NPV) of investing in either of them.
4. *Credit market.* New investment plans for all sectors are financed partly through retained liquidity and partly through credit, determining its demand. The supply for credit depends on the commercial bank's Capital Adequacy Ratio (CAR) and thus the Probability of Default (PD) of the firms. The price of credit – the interest rate – depends on the baseline rate set by the central bank and on the PD of each firm.
5. *Capital goods, labour and energy markets.* After having received credit the F_K and F_L firms purchase capital in the desired combination. Capital is supplied by capital producers based on the demand and the inputs available. Given that the level of available capital is determined, the F_K and F_L sector determine their energy and labour demand to satisfy expected demand in the next period.
6. *Financial market.* The government issues new bonds to finance its debts, while the CB can enter the bonds market to perform quantitative easing via open market operations. Dividends are distributed to the capitalist households and the commercial bank based on profit rates. Consequently, H_K and BA set their desired portfolio allocation of financial wealth on securities and trade shares at their new prices.
7. *Accounting.* All transactions and financial flows are recorded, taxes are paid and all the balance sheet entries are updated. Variables that have an exogenous growth rate (e.g. labour productivity) are updated.

The determination of demand, supply and prices are independent in all market except for the credit market. In the credit market, demand depends on the demand for capital goods and their prices. There can be temporary imbalances between demand and supply in each market, which are solved by demand rationing. The capital goods market can be an example of this. In each market, the prices are determined on the supply side as a markup on unitary costs. The next sections describe the core components of the sectors' stocks and flows.

2.2. Agents and sectors' behaviour

We detail here the main model's behaviours. First, we introduce the notation used. Let i and j be two agents. Then, p_i is the price of the output produced by i, while $p_i^\dagger$ is the price of the security issued by i. $D_{i,j}$ is the demand by j of what i produces, and $\mathbf{D}_i = \sum_j D_{i,j}$. Moreover, $\mathbf{q}_i$ is the total production of i and $q_{i,j}$ is the part of it that is given to j. We also denote by M_i the liquidity of i, akin to holdings of cash, and by K_i its stock of productive capital where applicable.

By building on Goodwin (1982), households are divided in two classes.

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[3] For a detailed description of the wage setting in EIRIN see Gourdel et al. (2022)

The working class (H_W) lives on wages, with gross revenues

$$Y_{H_W}^{gross} = \sum_i N_i \cdot w_i \tag{1}$$

where w_i is the wage paid by i and N_i the size of the workforce it employs (we omit the time dimension for simplicity as all variables are contemporaneous). The labour market mechanism[4], determines the final workforce N_i of each agent based on the total N_{tot} of workers available and the demand for labour of firms. It also determines the salary level $w_i(t)$ paid by i, based on the required skills of employing firms.

The capitalist class (H_K) earns its income out of financial markets through government bonds' coupons and firms' dividends:

$$Y_{H_K}^{gross} = c_G \cdot n_{H_K,G} + \sum_i d_i \cdot n_{H_K,i} \tag{2}$$

where d_i are the dividends of i and c_G represents the coupon's rate, and $n_{H_K,G}$ and $n_{H_K,i}$ are the quantity of government bonds and firm's shares held by private households respectively.

Both households are then taxed, with τ_{H_W} being the rate of the income tax, and τ_{H_K} the rate of the tax on profits from capital. Furthermore, both household classes receive net remittances RM_i from abroad. All households pay their energy bill.

This leaves them with Y_i^{net} as net disposable income:

$$\forall i \in \{H_W, H_K\}, \quad Y_i^{\text{net}} = \underbrace{(1-\tau_i)\cdot Y_i}_{\text{net income}} - p_{EN} q_{EN}^i + \mathrm{RM_i} \tag{3}$$

Households' consumption plans (eq. 4) are based on the Buffer-Stock Theory of savings (Deaton, 1991; Carroll, 2001), with consumers adjusting their consumption path considering a target liquid wealth to income ratio ρ_i and the speed of adjustment of consumption ϕ_i. In particular, consumers spend more (less) than their net income if their actual liquid wealth to income ratio is higher (lower) than the target level. This results in a quasi target wealth level that households pursue. Then, households split their consumption budget C_i between consumption goods and services, also importing a share β_0 from the rest of the world.

$$C_i = Y_i^{\text{disp}} + \rho_i \left(M_i - \phi_i \times Y_i^{\text{disp}} \right) \tag{4}$$

$$D_i^{F_L} = (1-\beta_0) \times \beta_1 \times C_i \tag{5}$$

$$D_i^{F_K} = (1-\beta_0) \times (1-\beta_1) \times C_i \ . \tag{6}$$

The service firm F_L (labour intensive) and consumption goods producer F_K (capital intensive) produce their respective outputs by relying on a Leontief technology. This implies no substitution of input factors, meaning that if an input factor is constrained (e.g. due to limited access to credit to finance investments), the overall production is proportionately reduced:

$$\forall j \in \{F_L, F_K\}, \quad \mathbf{q}_j = \min\left\{\gamma_j^N N_j,\ \gamma_j^K K_j\right\} \ . \tag{7}$$

In contrast, several macroeconomic models allow for substitution of input factors (elasticity of substitution equals 1) by using a Cobb-Douglas production technology. In our case, this would imply a substitution of constrained input factors such as capital stock with labour, while still generating the same level of output.

The two firms set their goods' price as a mark-up μ_j on their labour costs w_j/γ_j^N, capital costs $\kappa_j L_j$, energy $p_{EN} q_{EN,j}$ and resource costs $p_R q_{R,j}$, such that

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[4] For details see Gourdel et al. (2022)

$$\forall j \in \{F_L, F_K\}, \quad p_j = (1+\mu_j) \times (1+\tau_{\text{VAT}}) \left[\frac{w_j}{\gamma_j^N} + \frac{\kappa_j L_j + p_{EN} q_{EN,j} + p_R q_{R,j}}{q_j} \right] . \tag{8}$$

In particular, final prices can be affected by firms' interest rates κ_j on loans, more expensive imports (p_R), energy and/or wages. Higher prices of consumption goods and services constrain households' consumption budgets, which in turn lower aggregate demand. This represents a counterbalancing mechanism on aggregate demand.

The minimum between real demand of the two consumption goods and the real supply (eq. 9 and 10) determines the transaction amount $\tilde{q}_j$ that is traded in the goods and services market. The supply of capital intensive consumption goods also takes firm's inventories (IN_{F_K}) into account.

$$\tilde{q}_{F_K} = \min\left(\mathrm{IN}_{F_K} + q_{F_K},\ \frac{1}{p_{F_K}} \left(D_{H_W}^{F_K} + D_{H_K}^{F_K} + D_G^{F_K} + D_{RoW}^{F_K} \right) \right) \tag{9}$$

$$\tilde{q}_{F_L} = \min\left(q_{F_L},\ \frac{1}{p_{F_L}} \left(D_{H_W}^{F_L} + D_{H_K}^{F_L} + D_G^{F_L} + D_{RoW}^{F_L} \right) \right) \tag{10}$$

In case that demand exceeds supply, both capitalist and worker households are rationed proportionally to their demand. The share of newly produced but unsold products add up to the inventory stock of F_K (IN_{F_K}). Finally, both consumption goods producers make a production plan $\hat{q}_j$ for the next simulation step based on recent sales and inventory levels.

Both F_L and F_K make *endogenous investment decisions* based on the expected production plans $\hat{q}_j$, which determine a target capital stock level $\hat{K}_j$. The target investment amount $I_j^\dagger$ is set by the target capital level $\hat{K}_j$, considering the previous capital endowment $K_j(t-1)$ subject to depreciation $\delta_j \cdot K_j(t-1)$, hence

$$I_j^\dagger(t) = \max\left\{ \hat{K}_j(t) - K_j(t-1) + \delta_j \cdot K_j(t-1), 0 \right\} \tag{11}$$

Differently from supply-led models (Solow, 1956), in EIRIN, investment decisions are fully endogenous and they are based on firms' Net Present Value (NPV). This, in turn, is influenced by six factors:

(i) investment costs, (ii) expected future discounted revenue streams (e.g. endogenously generated demand), (iii) expected future discounted variable costs, (iv) the agent's specific interest rate set by the commercial bank, (v) the government's fiscal policy and (vi) government's subsidies.

More precisely, the planned investment is given by $I_j^\star(t) = \left(\varphi_j \cdot M_j(t-1) + \Delta^+ L_j(t)\right)/p_{K,j}(t)$, where φ_j is the share of liquidity that j uses to finance investment, $\Delta^+ L_j$ is the part that comes from new credit, and $p_{K,j}$ is the average price of capital, which depends on the ratio of low- and high-carbon capital, at unit prices p_{K_G} and p_{K_B} respectively. The NPV calculations allow us to compare the present cost of real investments in new capital goods to the present value of future expected (positive or negative) cash flows. We differentiate in that regard between low- and high-carbon capital (K_G and K_B respectively), that is, for a level ι of investment, the related NPVs are

$$NPV_j^{\mathsf{low}}(\iota, t) = -p_{K_G}(t) \cdot \iota + \sum_{s=t+1}^{+\infty} \frac{\mathrm{CF}_j^{\mathsf{low}}(\iota, t, s)}{(1+\kappa_i)^{s-t}} \tag{12}$$

$$NPV_j^{\mathsf{high}}(\iota, t) = -p_{K_B}(t) \cdot \iota + \sum_{s=t+1}^{+\infty} \frac{\mathrm{CF}_j^{\mathsf{high}}(\iota, t, s)}{(1+\kappa_i)^{s-t}} \tag{13}$$

where $\mathrm{CF}_j(\iota, t, s)$ includes the total expected cash flows expected at time s from the new investment[5]. Cash flows are discounted using the sector's interest rate κ_j set by the commercial bank. The final realised

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[5] Details of the cash flows calculations are provided in Gourdel et al. (2022)

investment $I_i(t)$ is divided into low- and high-carbon capital such that $I_i = I_i^{\mathsf{low}} + I_i^{\mathsf{high}}$. Then, it is potentially constrained by the supply capacity of the producers.

The energy sector (EN) is divided into low- and high-carbon energy producers (EN_G and EN_B respectively) and produces energy, demanded by households and firms for consumption and for production, respectively. We assume that all demand is met, even if EN_B might have to buy energy from the foreign sector, such that $\mathbf{q}_{EN} = \mathbf{D}_{EN}$. Households' energy demand is inelastic (i.e. the daily uses for heat and transportation), while firms' energy requirements are proportional to their output. The high-carbon energy company requires capital stock and oil as input factors for production, and only productive capital for its low-carbon counterpart but in higher quantity. The energy price is common and endogenously set from the unit cost of both firms (see Gourdel et al. (2022) for a detailed description).

H_W and H_K subtract the energy bill from their wage bill as shown by their disposable income (eq. 4), while firms transfer the costs of energy via mark-ups on their unit costs to their customers (eq. 8). To be able to deliver the demanded energy, the energy sector requires capital stock and conducts investments to compensate capital depreciation and expand its capital stock to be able to satisfy energy demand (further details are provided in Gourdel et al. (2022)). The oil and mining company MO supplies EN_B with oil and exports to the rest of the world as well. It faces no restriction on extraction but requires a proportional amount of productive capital to operate.

The capital goods producers (K, divided into low- and high-carbon capital producers, K_G and K_B respectively) supply productive capital to fulfill the production capacity of F_L, F_K, MO and EN:

$$\mathbf{q}_{K_G} = I_{K_G}^{F_L} + I_{K_G}^{F_K} + I_{K_G}^{EN_G} + I_{K_G}^{MO} \leq \mathbf{D}_{K_G}, \quad \mathbf{q}_{K_B} = I_{K_B}^{F_L} + I_{K_B}^{F_K} + I_{K_B}^{EN_B} \leq \mathbf{D}_{K_B}\ . \tag{14}$$

Newly produced capital goods will be delivered to the consumption good producers and the energy firms at the next simulation step. The capital good producers rely on energy, raw materials and high-skilled labour as input factors. There are differences between the low- and high-carbon versions of capital goods in both their production and their use. In production, low-carbon capital requires more skilled labour than the high-carbon one, as well as more material imported from the rest of the world. The latter condition represents the more complex supply chain and international dependencies that can be involved in low-carbon capital production, such as rare metals for batteries. Therefore, a unit of low-carbon capital is more expensive than a unit of high-carbon capital (for the same productive capacity). In addition, in their use, low-carbon capital is the most interesting per unit for the service sector and the consumption goods producers (the ones with the choice as to which type of capital to use). This is due to a lower usage of raw material and energy, resulting in a lower bill per unit of capital used, and lower related GHG emissions. Capital good prices p_{K_G} and p_{K_B} are set as a fixed mark-up μ_K on unit costs:

$$\forall i \in \{K_G, K_B\}, \quad p_i = (1+\mu_K) \times \frac{w_K N_i + D_i^{EN} p_{EN}}{\mathbf{q}_i} \tag{15}$$

In the financial sector, the commercial bank (BA) provides loans and keeps deposits. The commercial bank endogenously creates money (Jakab and Kumhof, 2015), meaning that it increases its balance sheet at every lending (i.e. the bank creates new deposits as it grants a new credit). This is consistent with most recent literature on endogenous money creation (McLeay et al., 2014).

The BA gives out loans to finance firms' investment plans. The bank sets sector-specific interest rates that affect firms' capital costs and NPV calculations. The commercial bank can grant credit under the condition that it complies with regulatory capital requirements (eq. 16). When this does not happen, credit is rationed and firms have to scale down their investment plan. In this situation, the commercial bank reacts by retaining part of its earnings to increase the equity base and, thus, the Capital Adequacy Ratio (CAR) and the lending capacity. Thus, the lending activity in EIRIN can be endogenously affected by the performance of the borrowers, which pay interest on loans, thus impacting on bank's profits and equity. Within this framework, policies and/or shocks which influence firms' activity and investments may be sources of financial instability.

The credit market is characterised by the level of credit and the cost of credit, which can be affected by the climate sentiments (figure 3).

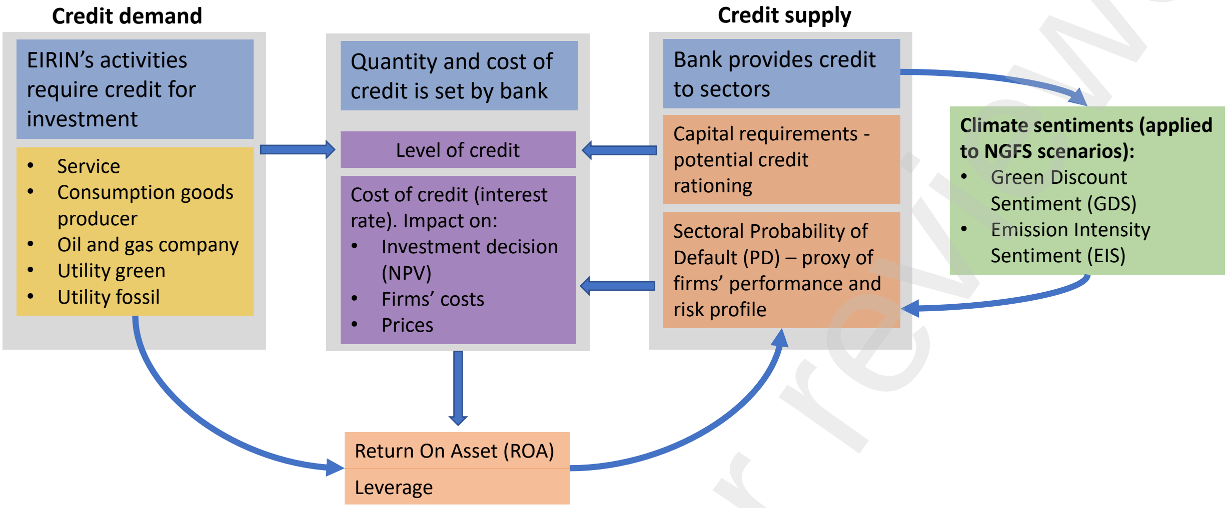

Figure 3: Credit market in EIRIN.
The figure shows the main features of the credit market implemented in EIRIN. The blue arrows mark the direction of influence. The yellow box includes the sectors which demand credit for investment purposes. The orange boxes include the determinants of the banks' credit supply, i.e. the capital requirements (which affect the level of granted credit) and the sectoral probability of default (PD, which affects the interest rate of loans). The green box includes banks' climate sentiments, which affect sectoral PDs and, thus, the cost of credit. The blue arrows highlight the connections between the components of the credit market.
Source: Authors' own elaboration.

The *level of credit* is how much the bank lends to the sectors that demand credit at a time t. The maximum credit supply of the bank is set by its equity level E_{BA} divided by the Capital Adequacy Ratio (CAR) parameter $\widetilde{\text{CAR}}$, in order to comply with banking regulation. Another relevant information is the the demand for new credit $\mathbf{D}_{BA}(t)$ and the previous credit level $\mathbf{L}(t-1)$. The additional credit that the bank can provide at each time step is given by its maximum supply, minus the amount of loans already outstanding, so that the total amount of loans makes its realised capital adequacy ratio remain above $\widetilde{\text{CAR}}$:

$$\Delta^{+}\mathbf{L} = \min\left\{\mathbf{D}_{BA}(t), E_{BA}(t-1)/\widetilde{\text{CAR}} - \mathbf{L}(t-1)\right\} \ . \tag{16}$$

The *cost of credit* is the interest rates applied to the different sectors. The interest rate is sector-specific and based on macroeconomic indicators. In addition, credit can be constrained depending on the profitability of the investment and on bank's lending capacity.

Let ν be the risk free interest rate, which is the sum of the policy rate and the bank's Net Interest Margin (NIM). Given the annualised probability of default PD_i of sector i, we seek to determine its objective loan interest rate $\hat{\kappa}_i$ granted by the bank.

We verify

$$\underbrace{\hat{\kappa}_i(t) - \nu(t)}_{\text{credit spread}} = PD_i(t) \times (1 - \mathcal{R}_i), \tag{17}$$

where $\mathcal{R}_i$ is the (constant) expected recovery rate[6] of i. The PDs themselves are computed following Alogoskoufis et al. (2021), that is $PD_i(t) = \beta_0 + \beta_1 * \Delta_{ROA\,i}(t) + \beta_2 * Lev_i(t) + \zeta_i$, where ROA stands for returns on assets, Lev represents the leverage of sector i and ζ_i is a sector specific constant.

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[6] See Hamilton and Cantor (2006) on the model itself, and Bruche and González-Aguado (2010) on the macro-economic determinants of recovery rates.

Then, in order to determine the actual rate applied, we allow for bridging only part of the distance between the previous interest rate and the objective interest rate. That means, denoting as $\kappa_i(t)$ the realised interest rate at t we have $\kappa_i(t) = \kappa_i(t-1) + \lambda \times (\hat{\kappa}_i(t) - \kappa_i(t-1))$, where $\lambda \in]0, 1]$ is the interest adjustment speed.

Each indebted sector i pays interests with rate $\kappa_i(t)$ at t on its total loans $L_i(t-1)$ of the previous period. Thus, the total interests paid are:

$$\mathsf{ID}_i(t) = \kappa_i(t) \times L_i(t-1) \tag{18}$$

The interests paid on debt are subtracted from the operating earnings of i and added to that of the banking sector. Similarly, the repayment of the debt is reduced:

$$\Delta^- L_i(t) = \chi_i \times L_i(t-1) \tag{19}$$

where χ_i is the (constant) repayment rate of i.

The central bank (CB) sets the risk free interest rate ν according to a Taylor-like rule (Taylor, 1993). The EIRIN's implementation of the Taylor rule differs from the traditional one because we do not define the potential output based on the Non-Accelerating Inflation Rate of Unemployment (NAIRU) (Ball and Mankiw, 2002). Indeed, NAIRU's theoretical underpinnings are rooted in general equilibrium theory, while EIRIN is not constrained to equilibrium solutions, focusing on the analysis of out of equilibrium dynamics. Thus, it would not be logically consistent to adopt a standard Taylor rule and NAIRU.

The interest rate in EIRIN indirectly affects households' consumption via price increase, resulting from firms that adjust their prices based on the costs of credit.The policy interest rate depends on the inflation gap $\pi - \bar{\pi}$ and output gap (measured as employment gap $u - \bar{u}$, i.e. the distance to a target level of employment $\bar{u}$):

$$\nu(t) = \omega_\pi(\pi(t) - \bar{\pi}) - \omega_u(u(t) - \bar{u}) \tag{20}$$

where π is the one-period inflation of the weighted basket of consumption goods and services (with a computation smoothed over a year, i.e. m periods):

$$\pi(t) = \frac{\mathbf{q}_{F_L}(t)}{\mathbf{q}_{F_K}(t) + \mathbf{q}_{F_L}(t)} \cdot \left(\frac{p_{F_L}(t)}{p_{F_L}(t-m)}\right)^{1/m} + \frac{\mathbf{q}_{F_K}(t)}{\mathbf{q}_{F_K}(t) + \mathbf{q}_{F_L}(t)} \cdot \left(\frac{p_{F_K}(t)}{p_{F_K}(t-m)}\right)^{1/m} - 1 \tag{21}$$

The inflation gap is computed as the distance of the actual inflation π to the pre-defined target inflation rate $\bar{\pi}$. Moreover, the central bank can provide liquidity to banks in case of shortage of liquid assets.

The foreign sector (RoW) interacts with the domestic economy through tourism import, consumption good imports and exports, raw material supply, fossil fuels imports, and potential energy export to the domestic economy.

The foreign sector's exports to the domestic economy are provided in infinite supply and at a given price to meet the internal production needs. Tourists' inflows consist in the consumption of labour-intensive consumption goods. Raw material, consumption good and intermediate good exports are a calibrated share of the country's GDP and are sold at world prices.

The government (G) is in charge of implementing fiscal policy, via tax collection and public spending, including welfare expenditures, subsidies (e.g. for households' consumption of basic commodities), public service wages and consumption.

In order to cover its regular expenses, the government raises taxes and issues sovereign bonds, which are bought by the capitalist households, by the commercial bank and by the central bank. The government pays a coupon rate c_G on its outstanding bonds n_G. Taxes are applied to labour income (wage), capital income (dividends and coupons), profits of firms, and GHG emissions. If the government's deposits are lower than a given positive threshold $\bar{M}$, i.e., $M_G < \bar{M}_G$, the government issues a new amount $\mathbf{\Delta n}_G = (\bar{M}_G - M_{Gov})/p_G^\dagger$

of bonds to cover the gap, where $p_G^\dagger$ is the endogenously determined government bond price. Government spending C_G is a fixed percentage of revenues from taxes R_G.

For a detailed description of all sectors, market interactions and behavioural equations, refer to Monasterolo and Raberto (2018, 2019); Dunz et al. (2021a) and Gourdel et al. (2022).

3. Data and calibration

Austria is a signatory of the Paris Agreement. Moreover, as part of its Nationally Determined Contribution (NDC) – and in line with EU Regulation 2018/1999 on the Governance of the Energy Union and Climate Action – Austria has pledged to reduce its CO2 emissions by 40% compared to 1990 levels by 2030 and achieve climate neutrality by 2050 (Umweltbundesamt, 2019). However, in 2019 Austria's total GHG emissions (without Land Use, Land Use Change and Forestry) amounted to 79.8 Mt CO2 equivalents, i.e. they increased by 1.8% with respect to 1990, and by 1.5% while compared to 2018 (Zechmeister, 2021; Pazdernik, 2021). Industrial production processes and the energy sector drive GHG emissions increase. Ritchie and Roser (2020) report a 10% increase in total GHG emissions and a 15% increase in GHG emissions per capita over the 1990-2019 period, as a result of industrial processes, economic growth and consumption.

We calibrate the EIRIN model to reproduce the state and evolution of the Austrian economy in the period 2014-2019. We choose this time interval to avoid taking into consideration the exceptional time of monetary instability caused by the Euro Area debt crisis before 2014 (Constancio, 2012; Guerini et al., 2018) as well as the macroeconomic demand and supply shocks caused by the COVID-19 pandemic (Barua, 2020; Juergensen et al., 2020). This choice allows us to better reproduce the long-run trends that the Austrian economy is set on and therefore perform a policy exercise which is more meaningful in the long term.
The state of the Austrian economy is captured by the macroeconomic indicators and data on energy and GHG emissions flows. The target time series presented in table 1 ensures that all the relevant aspects of the simulation process, including the macroeconomy and the energy and emissions dynamics, can be validated against the actual data. Time series data are provided by Eurostat and Statistik Austria.

After having set the target space, we proceed with the calibration of over 100 model parameters. The large number of parameters reflects the richness of the EIRIN model in terms of agents, sectors and flows. For the calibration we follow a two-step strategy. First, we estimate all parameters for which we can find correspondence in official data or previous research, and we initialize the missing parameters with standard values (Dunz et al., 2021b; Monasterolo and Raberto, 2018). However, since no model can fully reproduce the "true" data generating process of the real economy (Fagiolo et al., 2019), we complete the initialization of EIRIN with estimated parameters. This procedure produces a benchmark model far from the target time series. Then, we search for alternative parameter values via indirect inference (Gourieroux et al., 1993). Here we follow two criteria. First, we use a version of the Method of Simulated Moments (MSM) (Chen et al., 2012; Mariano et al., 2000) to identify a relevant parameters vector, use it to initialise and simulate the EIRIN model, and extrapolate the first two moments of the simulated target time-series at a given interval in the simulation periods. The simulated moments are then compared to the moments of the real time series by means of the distance function:

$$\mathcal{L} = \sum_{i=1} \left(\alpha \frac{|\bar{x_i} - \bar{y_i}|}{\bar{x_i}} + \beta \frac{|\sigma(x_i) - \sigma(y_i)|}{\sigma(x_i)} \right) (\mathbf{X}|\theta) \tag{22}$$

where θ is the parameter vector, $\mathbf{X}$ is the vector of simulated time series values and $\mathbf{Y}$ is the vector of actual time series values. The parameters $\alpha = 0.8$ and $\beta = 0.2$ represent the weights assigned respectively to the relative error of the mean for each distribution and the relative error of the standard deviation. This allows to select only those parameters vectors that produce simulated time series which are "close enough" to the real time series according to the rule

$$\mathcal{L} < \varepsilon \tag{23}$$

where ε is an arbitrarily selected threshold. With this procedure, we obtain a set of plausible parameters specifications. Given the complexity of EIRIN it is possible to obtain plausible aggregate results from several parameters soecifications. Looking only at the aggregates could hide some underlying dynamics which are better assessed qualitatively. Therefore, we review candidate parameters specifications according to our second criterium, which is the plausibility of the causal mechanisms that emerge in the simulation. This is important because it is crucial that models used to analyse policy prescription do match well the causal relationships observed in the real systems they represent (Guerini and Moneta, 2017). Our calibration addresses both aggregate macroeconomic variables and the underlying causal mechanisms in the economy. The combination of these two criteria gives us the finalised baseline model. The results of the calibration are presented in table 1.

Variable	**Model value (2019)**	**Real value (2019)**	**Model mean (2014-2019)**	**Real mean (2014-2019)**
Value Added manufacturing (% of GDP)	37,34	35,07	37,33	35,5
Value Added services (% of GDP)	52,9	54,6	52,61	54,1
Value Added capital producers (% of GDP)	10,29	10,32	10,2	10,4
International tourism (% of GDP)	4,68	5,67	4,65	5,33
Remittances (% of GDP)	0,71	0,69	0,71	0,72
Employment in manufacturing (% of tot emp.)	25,42	25,26	25,55	25,45
Employment in services (% of tot emp.)	74,58	74,74	74,45	74,55
Real GDP growth rate (%)	2,09	1,61	2,15	1,74
Inflation rate (%)	0,63	1,72	0,6	1,78
Public debt (% of GDP)	70,57	70,4	71,23	79,08
Private credit (% of GDP)	33,88	85,32	33,18	84,73
Gov consumption (% of GDP)	26,48	19,26	26,38	19,55
Unemployment (%)	6,18	4,49	5,83	5,36
Central bank's policy rate (%)	-0,77	-0,39	-0,79	-0,24
Imports (% of GDP)	41,68	52	41,44	50,47
Export (% of GDP)	49,78	55,72	49,56	54,07
Renewable energy share (%)	27,58	33,63	27,04	33,5
Carbon tax revenues (% of GDP)	0,03	0,02	0,03	0,02
Total tax revenues (% of GDP)	29,95	43,14	29,88	43,04
Energy share households (%)	19,11	23,67	19,18	23,93
Energy share manufacturing (%)	26,2	23,48	26,06	23,93
Energy share services (%)	37,71	34,96	37,73	34,97
Energy share energy production (%)	11,23	12,31	11,31	11,1
Energy share capital producers (%)	1,74	1,82	1,72	1,85
Emissions share maufacturing (%)	16,25	23,72	15,81	24,16
Emissions share services (%)	17,33	19,54	17,21	19,14
Emissions share energy producers (%)	20,59	21,81	20,72	21,1
Emissions share MINEOIL (%)	2,14	1,89	2,16	1,94
Emissions share capital producers (%)	43,69	33,04	44,1	33,66

Table 1: Calibration of EIRIN on the Austrian economy.
The variables column outlines the targets for the model calibration. The two columns reporting the 2019 values compare the real value for each variable in the Austrian economy in 2019 with the one obtained in the last period of the model calibration time span. The last two columns report the mean values of each indicator over the 2014-2019 period in Austria and the corresponding period in the model simulation.

4. Climate risks and climate scenarios

Climate transition scenarios analyse the changes in socio-economic systems that could contribute to mitigate climate change by considering the relation between the economy and the biosphere. Thus, climate transitions scenario are relevant for assessing macroeconomic and financial impacts of unmitigated climate change and the opportunities for climate policy and investments to mitigate such risks. We consider here two main channels of climate-related financial risks (Carney, 2015; NGFS, 2019):

- *Climate physical risks*, which stem from the impact of hazards (e.g. floods, droughts) on physical assets, with consequences on losses of firms' productive capacity and output, as well as on the value of the financial contracts of the hit firms. In turn, a negative adjustment in the financial value of firms can negatively affect the value of the portfolio of financial actors (e.g. banks, insurance, pension funds) who hold firms' financial contracts. For instance, a firm whose productive capital is destroyed by severe floods, and has borrowed from a bank, may not be able to repay the interests and principals of the loan, thus leading to Non Performing Loans (NPLs), which can negatively affect the bank's balance sheet. Recent research analysed investors' exposure to climate physical risks and concluded that they are significant (Dietz et al., 2016; Mercure et al., 2018; Alogoskoufis et al., 2021; Mandel et al., 2021; Jensen and Traeger, 2021). Austria is also exposed to physical risks (see Steininger et al. (2016) for an assessment of physical climate damages).
- *Climate transition risks*, related to the way in which climate policies and regulations are implemented in order to decarbonise the economy and align finance flows to the Paris Agreement targets. In particular, transition risk emerges if the transition is delayed and occurs suddenly: what is referred to as "disorderly" (Battiston et al., 2017; NGFS, 2020). A late and sudden introduction of climate policies and regulations would increase the costs of alignment for high-carbon firms, and lead to a large asset price volatility as a result of the price adjustment of carbon-intensive and low-carbon assets (respectively negative for the former, and positive for the latter), giving rise to "carbon stranded assets" (Mercure et al., 2018; Van der Ploeg and Rezai, 2020; Cahen-Fourot et al., 2021). Recent research showed that transition risk could represent a material risk for financial stability at the level of individual financial institutions, as well as for the financial system (Battiston et al., 2017; Roncoroni et al., 2021; Vermeulen et al., 2021). The Austrian banking sector is also exposed to climate transition risks (Battiston et al., 2020; Guth et al., 2021).

We build our study on the climate scenarios developed by the NGFS (NGFS, 2021) and reproduce some of them using the EIRIN Stock-Flow Consistent model (Monasterolo and Raberto, 2018; Dunz et al., 2021a; Gourdel et al., 2022).

4.1. NGFS climate transition scenarios

The NGFS is a group of over 100 central banks and financial regulators, launched after the 2017 Paris one planet summit (Banque de France, 2017). The goal of NGFS is to support investors and financial institutions in the development of climate financial risks assessment and management, including climate stress test exercises (Alogoskoufis et al., 2021). To this end, the NGFS has co-developed, in collaboration with the process-based Integrated Assessment Models (IAM) community[7], climate mitigation scenarios to inform the assessment of climate-related financial risks (NGFS, 2020, 2021). The second vintage of the NGFS scenarios, which were published in 2021, comprises six scenarios of climate transition and physical risks (figure 4).

The NGFS scenarios climate change patterns and input shocks are rovided by three IAMs: GCAM[8], MESSAGE-GLOBIOM[9], and REMIND-MagPIE[10] (Calvin et al., 2013; Kriegler et al., 2013; Rogelj et al.,

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[7] For a description of the IAM Community, see `https://www.iamconsortium.org/`

[8] The source code is open source and available at `https://github.com/JGCRI/gcam-core`

[9] The source code is open source and available at `https://github.com/iiasa/message_ix`

[10] The source codes of the models are open source and available at these URLs: `https://github.com/remindmodel/remind` ; `https://github.com/magpiemodel/magpie`

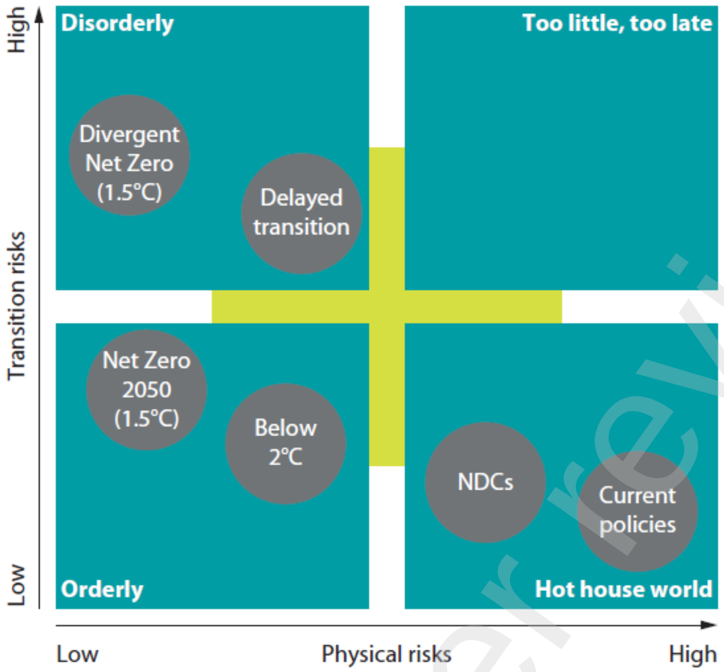

Figure 4: NGFS climate transition scenarios framework.
Positioning of each NGFS scenario based on the intensity of physical and transition risk out to 2100 in each of them.
Source: NGFS Climate Scenarios for central banks and supervisors.(2021)

2019). These are then fed to the econometric global model NiGEM (NIESR, 2021) to produce macroeconomic estimates. The scenarios are characterised by output trajectories of economic activities (e.g. electricity production out of coal or wind), following a model-specific geographic disaggregation. This feature allows us to downscale model inputs and outputs at country level - e.g. for Austria - and to integrate them in the EIRIN model. The six NGFS scenarios differ with regard to (i) global temperature targets (e.g. 1.5°C, 2°C), (ii) GHG emissions targets by 2050 (e.g. net zero), (iii) climate policy ambition (e.g. current policies, net zero 2050), (iv) timeliness of policy implementation (e.g. early or delayed implementation), and (v) availability of carbon dioxide removal technologies.

The NGFS scenarios also consider the potential trade-offs across these dimensions. For instance, implementing policies late means that they will have to be more stringent compared to earlier transitions, e.g. in the form of higher carbon price. The three IAM models used to simulate the NGFS scenarios have a similar structure. In particular, they combine macro-economic, agriculture and land-use, energy, water and climate systems into a framework that allows to analyse complex dynamics between those components. However, the IAMs differ in terms of solution concept (partial equilibrium vs. general equilibrium), agent foresight (recursive dynamic vs. perfect foresight), solution method (cost minimisation vs. welfare maximisation) and spatial dimension[11]. In order to achieve the target temperature and emissions, the IAMs rely on policies based on the increase of carbon prices, on the introduction of Carbon Capture and Storage (CCS) technologies, on changes in the energy mix, and on increases in energy efficiency (Bertram et al., 2021). The key drivers for the transition are the changes in the relative cost and availability of low-carbon and high-carbon energy generated by the increasing carbon prices. In turn, these changes affect the demand for and supply of high-carbon products (both final and intermediary), which are replaced by low-carbon alternatives. Moreover, the IAM models consider the role played by deteriorating climate conditions by including a climate damage function which correlates levels of physical damages to losses of GDP. This is modelled on the work by Kalkuhl and

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[11] For a thorough discussion of the differences between the IAM models used to simulate the NGFS scenarios, refer to the NGFS technical documentation in Bertram et al. (2021)

Wenz (2020). Each scenario's output is composed of aggregate values for key variables as well as diagnostic variables[12].

The NGFS scenarios capture complex dynamics in the interaction between different parts of the economy and the environment. However, they account neither for the role of finance nor for investors' risk expectations across the scenarios (Battiston et al., 2021b). Indeed, the IAMs do not include money, and financial actors do not make investment decisions informed by risk assessment. In addition, IAMs do not include banks that can decide to lend to a firm at a certain cost (i.e. the interest rate) depending on their financial risk assessment of the borrower. Thus, in IAMs, firms can always make an investment without financing costs. Nevertheless, real firms are subject to financing costs and potential credit constraints that can affect their investment decisions. Neglecting the role of finance has major implications on the understanding of the dynamics of the low-carbon transition across NGFS scenarios. Indeed, the banking sector can affect the realization of the NGFS scenarios, via changes in the cost and level of credit, depending on the perception and level of trust in climate policies.

4.2. Integrating the NGFS scenarios in the EIRIN model

In our analysis we consider the scenarios designed in the NGFS 2021 Report NGFS (2021). In particular, we use the structure of the REMIND-MagPie model (Hilaire and Bertram, 2020). We make this choice because the REMIND-MagPie model provides very rich input and output data, including a EU breakdown, which we downscale to extrapolate information specific to Austria. NGFS scenarios are simulated using periods lasting five years until 2050 and ten years between 2050 and 2100. The EIRIN model is calibrated here on a six months time steps thus requiring interpolation of some input data.

We consider four transition scenarios that are characterised by different policy ambitions and measures, and readiness of innovation[13]. The integration of the NGFS scenarios into the EIRIN model closely follows the methodology in Gourdel et al. (2022).

First, we consider a "Net Zero" (NZ) scenario. From the original six NGFS (2021) scenarios we merge the two NGFS scenarios reaching net zero emissions by 2050 ("Net Zero 2050" and "Divergent Net Zero") into a single scenario. This modelling choice allows us to simplify the analysis of results. Here, transition policies are introduced early and smoothly following a path that is compatible with keeping average temperature increases below 1.5°C. The government introduces an increasing tax schedule on GHG emissions. In addition, it significantly adjusts its incentives for low-carbon investment and renewable energy producers, while introducing minimum requirements for investments in low-carbon capital.

Second, we consider a "Below 2°C" (B2C) scenario. Here, the climate policies are introduced early and smoothly, but are compatible with a 67% chance of achieving a less than 2°C temperature increase (NGFS, 2021). This difference is driven by a lower carbon price increase than in the NZ scenario. Moreover, government's green incentives and investment requirements are less stringent.

Third, we consider a "Delayed Transition" (DT) scenario in which climate policies are introduced late, i.e. in 2030, rather than in 2021. Thus, the policies need to be stricter, translating into higher and quickly rising carbon prices and a stricter steering of investments towards the green sectors by the government. Nonetheless, the delay in policy introduction means that overall GHG emissions levels remain higher than in the previous scenarios.

Fourth, we consider a "Current Policy" (CP) scenario i.e. current policies. This scenario follows the baseline model of EIRIN calibration and can be considered the benchmark case against which the other

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[12] NGFS scenarios can be explored at `https://www.ngfs.net/ngfs-scenarios-portal/`

[13] We decide to not include climate damages in our design of the NGFS scenario. This choice is made for two reasons. The first is that this paper focuses on transition risks generated by climate policies. Including climate damages in the model would give a much larger role to physical risks, making it difficult to disentangle the impacts of transition risks. It would be possible to extend the analysis by including climate damages and eventually test the difference with the current application. The second reason is the availability and quality of the data. The values of climate damages to GDP reported in the NGFS database are available only for large regional groupings, the closest to Austria being the whole EU. However, simply assuming that Austria will follow the same path of the EU is too simplistic an assumption and could lead to skewed simulation results.

scenarios are analysed.[14]

We reproduce and simulate the NGFS scenarios in ERIN by (i) including features of the NGFS scenarios (e.g. carbon price, see (NGFS, 2021)), and (ii) enriching them with specific policy measures, coherently with the scenarios' targets and objectives. In particular, we consider the following transition policies:

1. A minimum low-carbon investment requirement implemented by the government
2. A subsidy to renewable energy producers introduced by the government
3. A rebate for low-carbon capital investments introduced by the government
4. Faster investment adjustments in the renewables sector

We describe the features of the measures considered to implement the NGFS scenarios into EIRIN.

4.2.1. Carbon price and tax adjustments

The main low-carbon transition policy considered in the NGFS scenarios is a gradual increase in the pricing of GHG emissions. According to the literature, carbon pricing has a high potential for the reduction of CO2 emissions (Stiglitz et al., 2017; Boyce, 2018). In Austria, the government is working on the introduction of a price on CO2 as part of the new *Ökosoziale Steuerreform* - "Socio-ecological Tax Reform", which will become effective in October 2022 (WKO, 2021; BMK, 2022).

For the implementation of the scenarios in EIRIN, we consider the carbon price trajectories of each NGFS scenario, provided by REMIND-MagPie. We use linear interpolation to obtain semestral values. The NGFS carbon price inputs are expressed in terms of price per tonne of CO2, while GHG taxes in EIRIN are levied as a percentage of sectoral GHG emissions[15]. Thus, we introduce a conversion factor to transform NGFS carbon price values into carbon taxes in EIRIN. The conversion factor is calibrated so that the baseline model in EIRIN matches the current carbon tax revenues in Austria (see section 3). We couple the increase in carbon prices with an increased flexibility in fiscal policy for which the government, after the beginning of the transition, can modify other components of its tax policy. The decision depends on the government's current fiscal performance regarding debt to GDP and deficit to GDP levels, and contributes to smooth the impacts of an increase in carbon prices.

The increase in carbon prices leads to increases in the cost of high-carbon capital and high-carbon capital-based consumption goods, relatively to the low-carbon alternatives. Higher costs lead to a decrease in profitability of high-carbon capital producers and capital-intensive firms and their ability to pay interest on the loans received from the banking sector. In contrast, low-carbon capital and energy producers become relatively more efficient and are thus able to earn a bigger market share. Therefore, final and intermediary producers' choice of capital and energy input factors partially shifts in favour of low-carbon inputs. Figure 5a presents the carbon prices trajectories conditioned to each NGFS scenarios.

4.2.2. Green investments weight

A key component in our implementation of the NGFS scenarios is how the government introduces incentives for low-carbon capital investments by the consumption goods producers (F_K) and services producers (F_L). Both firms use capital in their production process and can choose between investing in low or high-carbon capital. The investment decision depends on the Net Present Values (NPV) of the two types of capital investments (see eq. 12 and 13). The NPV of low-carbon capital increases with the gradual increase in carbon tax. Nonetheless, this increase might not be enough for the NPV of low-carbon investments to become higher than the NPV of high-carbon investments due to structural conditions and cost of capital (which is still higher for low-carbon investments). In order to counteract the effect of this dynamics, we assume that the government requires a minimum low-carbon capital investment ratio, which has to be fulfilled by the F_K

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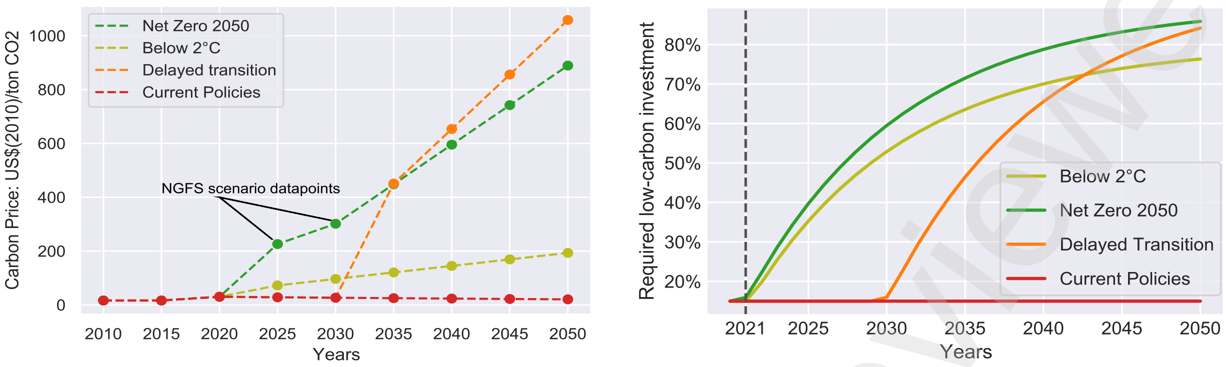
[14] We do not include a NDC scenario, regardless of its presence in the NGFS analysis (NGFS, 2021), because emissions reduction to which Austria has pledged (NDC Registry, 2020) are ambitious and would theoretically generate a low emissions outcome. However, the necessary policies have yet to be implemented and the overall level of emissions in Austria are largely above the declared 2020 targets (UNFCCC, 2020).

[15] In this application of EIRIN, GHG emission do not represent a physical quantity, even though they can be scaled to tonnes



(a) Carbon price trajectories

(b) Required green investment

Figure 5: Key fiscal policies indicators for the low-carbon transition.
Left panel: carbon price trajectories by NGFS scenarios. The x axis displays the years, the y axis reports the carbon price in units of 2010 US$ per ton of CO2 emitted. The dots represent the values in the NGFS (2021) scenarios application in REMIND-MAgPIE (available at `https://data.ene.iiasa.ac.at/ngfs`). The linear interpolation lines are the result of the author's own work.
Right panel: green investment requirements. The x axis displays the simulation years, the y axis reports the minimum low-carbon investment by goods required from the goods and services producers (F_K and F_L) by the government, whenever the NPV of low-carbon investments is positive.

and F_L firms as long as the NPV of low-carbon investments remains positive. We call this minimum ratio the "green investment weight".

We calibrate a baseline ratio to match the GHG emissions data in Austria during the reference period 2014-2019. Then, we let the ratio vary across NGFS scenarios depending on the GHG emissions target. Figure 5b shows the schedule of green investment weights across our implementation of the NGFS scenarios.

4.2.3. Renewable energy subsidies

Another channel through which the government can foster the decarbonisation of the economy is by subsidizing the renewable energy producers. The subsidy is implemented as a price discount to buy low-carbon capital. The parameter in the EIRIN model is ψ_S and represents the percentage of total capital cost covered by the government. This policy thus stimulates low-carbon investments by renewable energy producers because it increases the their NPV by diminishing the liquidity constraints. Green subsidies allow the producers of renewable energy to boost their production capacity once the transition starts. The values taken by the parameter across scenarios are available in table 2.

4.2.4. Rebates for low-carbon investments

In order to partially compensate the F_K and F_L sectors for the relative losses due to forced low-carbon investment, the government in EIRIN provides a rebate to these sectors, which is directly dependent on their investment in low-carbon capital. At every period, the rebate is given by:

$$Gov_{Rebi} = w_{Gi} * (NPV_i^{\text{high}} - NPV_i^{\text{low}}) * \rho_G \tag{24}$$

where Gov_{Rebi} is the government's rebate to sector i, w_{Gi} is the minimum required ratio of low-carbon capital investment by sector i, while $NPV_i^{\text{high}} - NPV_i^{\text{low}}$ is the difference in the NPV of high-carbon and low-carbon capital investment. The parameter ρ_G determines how much of the relative losses the government will cover. We set ρ_G to different levels for each scenario depending on the smoothness of the transition as reported in table 2.

4.2.5. Investments of the renewable energy producers

The increase in renewable energy production and use is crucial to achieve lower GHG emissions (Gielen et al., 2021). For simplicity's sake, we assume that productive activities first use all available renewable energy at each period, and cover the rest of their demand by using fossil fuels-generated energy. We assume that after the transition starts, the renewable energy producer will start investing at a higher rate to cover the gap between renewable energy currently produced and total energy demand. This gap is given by $D_{EN}(t-1) - S_{EN_G}(t-1)$. Given a predetermined capital efficiency γ_{EN_G}, the new investment the renewable sector will undertake each period is given by:

$$\Delta K_{EN_G}(t) = \frac{\lambda_{EN_G}}{\gamma_{En_G}} \left(D_{EN}(t-1) - S_{EN_G}(t-1) \right) \tag{25}$$

Note that this is only one aspect of the investment decision of the renewables sector, which also needs to repay loans taken and replace depleted and damaged capital. The parameter λ_{EN_G} represents the speed at which the renewables sector invests to close the energy gap given the efficiency of capital. in table 2 we report the values of the smoothing parameter in each scenario.

Policy Parameters	**Net Zero 2050 (NZ)**	**Below 2°C (B2C)**	**Delayed Transition (DT)**	**Current Policy (CP)**
ψ_S: Energy Subsidy	0.2	0.15	0.3	0
ρ_G: Low-carbon Rebates	1	0.7	1.1	0
λ_{EnG}: Renewables Investment Smoothing	0.105	0.07	0.08	0.04
$\Delta\tau_{Lab}$: Labour Tax Delta (%)	$15 * 10^{-2}$	$15 * 10^{-2}$	$15 * 10^{-2}$	0
$\Delta\tau_{Div}$: Dividend Tax Delta (%)	$15 * 10^{-2}$	$15 * 10^{-2}$	$15 * 10^{-2}$	0
$\Delta\tau_{Corp}$: Corporate Tax Delta (%)	$15 * 10^{-2}$	$15 * 10^{-2}$	$15 * 10^{-2}$	0

Table 2: Transition scenarios' policy parameters.
The first three parameters do not have a unit of measure. They are thoroughly explained in the corresponding sections. The tax adjustment parameters report by how many percentage points the government can change the tax schedule at each period. The government will use this measure only if it is not meeting its fiscal budget goals.
Source: Authors' own elaboration.

5. Banks' climate sentiments and the low-carbon transition

We also analyse the implications of banks' climate sentiment on adjustments in lending conditions(Briere and Ramelli, 2021; Dunz et al., 2021b). In particular, we consider the adjustment in banking sector's lending based on a backward- looking dimension, i.e. the sectors' GHG intensity of production, named Emission Intensity Sentiment (EIS) (section 5.2), and on a forward-looking dimension, i.e. the sectors' rates of low-carbon investment, named Green Discount Sentiment (GDS) (section 5.1). The differences between the two sentiments stand in the scope and time horizon of bank's expectations. The GDS is forward-looking in that it rewards sectors based on the decarbonisation efforts they make now, in the form of low-carbon investments. The bank trusts that low-carbon investments will lead to better economic performance, regardless of the current intensity of emissions. The EIS, on the contrary, is backward-looking, in that it penalises or reward sectors based on their GHG emissions intensity as reported by firms. The bank considers GHG emissions intensity as the key parameter to predict future performance, regardless of each sector's investment mix.

To assess the effects of banks' climate sentiments, we introduce the banks' climate sentiments on top of the NGFS Net Zero scenario. Then, we investigate individual effects and complementarity of the two types of climate sentiments. Table 3 sums up the main characteristics of banks' climate sentiments.

Climate sentiment's name	**Type of interest rate adjustment**	**Sectoral variable observed by the bank**	**Magnitude of interest rate adjustment**	**Target GHG emission intensity of earnings**
Green Discount Sentiment (GDS)	Discount	Share of low-carbon investments	Low, medium, high	Not considered
Emission Intensity Sentiment (EIS)	Penalty or discount	GHG emission intensity of earnings	Low, medium, high	Low, medium high

Table 3: Climate sentiments summary, considering the type of interest rate adjustment.
The table presents the key characteristics of the climate sentiments introduced in this paper. The magnitude of the interest rate adjustment and the target GHG intensity determine the quantitative impact of each climate sentiment.
Source: Authors' own elaboration.

5.1. *Forward-looking sentiment*

We introduce a discount on loans' interest rate charged by the banking sector to firms, based on the quantity of low-carbon investment that each sector is planning to undertake, i.e. a Green Discount Sentiment (GDS). The rationale for this behavioural change is that the bank expects firms that engage in low-carbon investments to perform better in future periods. We hypothesize that the commercial bank (BA) would start calculating an adjusted PD for each sector, based on the share of low-carbon investments they undertake as:

$$PD_{GDS_i}(t) = (\beta_0 + \beta_1 * \Delta_{ROAi}(t) + \beta_2 * Lev_i(t) + \zeta_i)^{(1+\chi_g * Share_{g_i}(t))} \tag{26}$$

where the $PD_{GDS_i}(t)$ is the PD of sector i at time t adjusted for the GDS climate sentiment. The power component introduces the GDS parameter χ_g, which multiplies the share of low-carbon investments undertaken by sector i: $Share_{g_i}(t)$. This adjusted PD is then used in the calculation of the interest rate on loans applied to each sector (see eq. 17). Therefore, the higher the GDS parameter, the more low-carbon investments will be discounted on average across all sectors. In addition, the banking sector will start to provide loans at lower interest rates to firms that plan larger shares of low-carbon investment. By reducing the cost of shifting to low-carbon capital, the GDS could facilitate the transition to a low-carbon economy.

5.2. *Backward-looking sentiment*

We assess the impact of a second channel for banking sector's climate sentiments, which we call Emission Intensity Sentiment (EIS). Here, we assume that the bank predicts better economic performances for firms which are *currently* less GHG-intensive, as a consequence of the new carbon pricing policy. We introduce the EIS in the EIRIN model by adding a discount or penalty to the bank's calculation of each sector's PD, based on the GHG emissions intensity of production of each sector. The rule is implemented as follows:

$$PD_{EIS_i}(t) = (\beta_0 + \beta_1 * \Delta_{ROAi}(t) + \beta_2 * Lev_i(t) + \zeta_i) + \theta_B^1 * \left(\frac{GHG_i(t-1)}{Earn_i(t-1)} - \theta_B^2\right) \tag{27}$$

where the $PD_{EIS_i}(t)$ is the PD of sector i at time t adjusted for the EIS climate sentiment. $GHG_i(t-1)$ is the total GHG emissions' volume produced by sector i in the previous period and $Earn_i(t-1)$ are its operating earnings in the previous period. The last component of the formula includes parameters θ_B^1 and θ_B^2, which increase or decrease the PD based on the sector's ratio of GHG emissions to operating earnings. θ_B^2 represents the target GHG emissions intensity of earnings for the commercial bank. The idea is that the banking sector reacts to the transition and predicts that sectors with high GHG emissions intensities will perform worse than previously expected. Thus, the banking sector tries to protect itself by setting an arbitrary GHG emissions target and adjusting their lending behaviour based on the distance between their target and sectors' performance. Sectors with GHG intensities of earnings higher (lower) than the target will face higher (lower) interest rates than they did before the EIS was introduced. θ_B^1 is a weight parameter that determines the magnitude of the interest rate adjustment. The commercial bank's EIS climate sentiment penalises high-carbon production by increasing the running costs of high-carbon sectors. Therefore, EIS could favour a transition towards a low-carbon economy by rewarding low-emitters and penalising high-emitters.

5.3. Credit restrictions

Finally, we analyse the effects of a restriction on the amount of credit that the private bank is willing to allocate to low-carbon investment projects. In this scenario, banks adjust both the price of credit and the quantity. The rationale for testing this scenario stands in the existing global "green investment gap"[16] (McCollum et al., 2013; Buchner et al., 2019; Wildauer and Leitch, 2022). There are several reasons for which banks may decide to restrict credit to low-carbon investment projects (Campiglio, 2016), including a "paradox of thrift" (Zenghelis, 2012) and a perception of higher risks associated with low-carbon investments (Schmidt, 2014). Private banks could decide not to provide credit if they do not trust the climate policies implemented by the government.

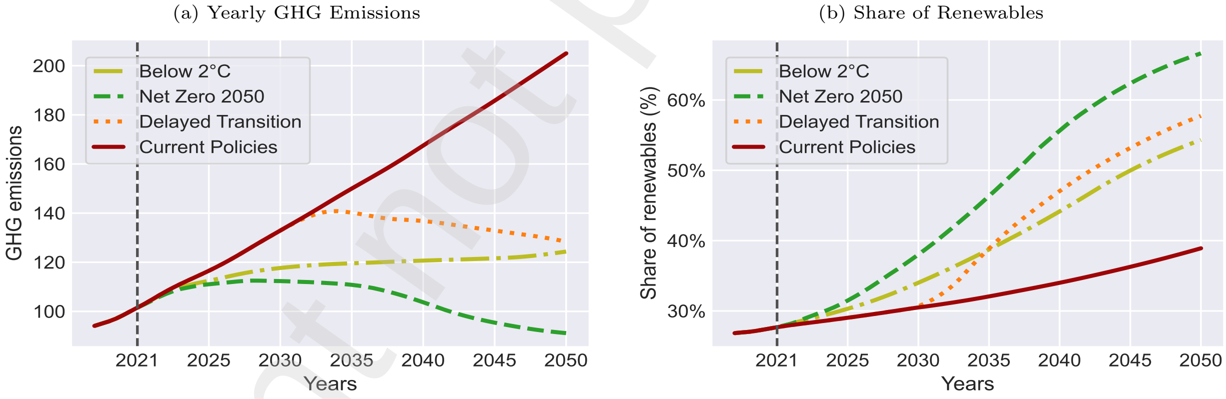
We operationalise this mechanism by introducing an exogenous parameter which governs the restriction on the amount of credit that the EIRIN commercial bank is willing to provide for low-carbon investments. In turn, productive sectors which demand credit internalise the expected credit restriction in their calculation of investment allocation between high- and low-carbon capital. We conduct a sensitivity analysis by introducing the credit restriction on the NGFS Net Zero scenario at different intensities.

6. Results

First, we discuss the macroeconomic and financial outcomes of the NGFS scenarios implemented in EIRIN and compare them with the results obtained using the current policies scenario. Then, we analyse the effects of banking sector's climate sentiments on the transition scenarios, analysing complementarities and trade-offs between the two types of climate sentiments. Finally, we test the outcomes of transition scenarios assuming bank's credit restrictions on low-carbon investments.

6.1. EIRIN-NGFS scenarios

6.1.1. Decarbonization of the economy


(a) Yearly GHG Emissions

(b) Share of Renewables

Figure 6: Impact of NGFS transition policies on GHG emissions and energy mix.
Left panel: the y axis displays the simulation time, the y axis report the yearly GHG emissions, normalised to the emissions volume in 2021. Right panel: the x axis displays the simulation time, the y axis report the ratio of renewables in the economy-wide energy mix, in percentage points.

From figure 6a it emerges that the transition scenarios achieve better outcomes than the CP scenario in terms of GHG emissions, due to climate policies. However, differences between transition scenarios exist. The NZ shows a reduction in GHG emissions of around 10% from policy implementation. This is less than half the

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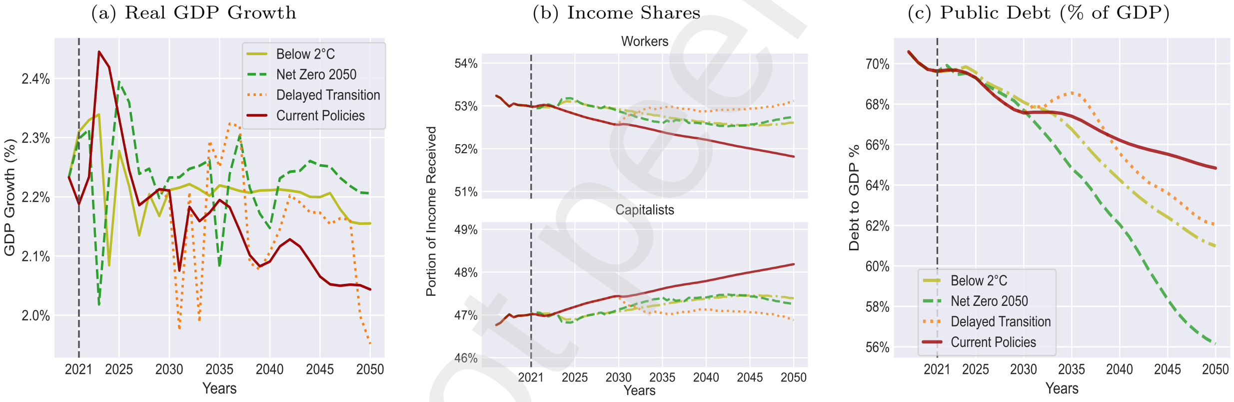
[16] The green investment gap is the difference between the amount of investment needed to reach a certain decarbonisation goal and actual investment in low-carbon technologies.

emissions obtained under the CP scenario. The DT scenario also achieves a fast reduction in emissions (−8% from policy implementation) due to the relatively higher carbon tax and larger fiscal policies. However, in DT, the transition starts too late to achieve decarbonization results that are comparable to the NZ scenarios, with GHG emissions levels in 2050 being 22% higher than in 2021, and 35% higher than the result achieved by NZ. The emissions reduction is achieved through a rapid transition to low-carbon capital and renewable energy utilisation[17].

Concerning the share of renewable energy in the energy mix, Figure 6b shows that climate policies are able to steer the economy towards a higher use of renewable energy. The share of renewables exceeds 65% of the energy mix in the NZ scenario, while it remains around 55% for both B2C and DT scenarios. This result is due both to the carbon tax coupled with the government incentives for low-carbon investments and the improvements in the renewable energy sector's productive capacity. In particular, more ambitious climate policies (NZ and DT scenarios) lead to a faster increase with respect to B2C.

Nevertheless, the late implementation of climate policies in DT leads to a lower uptake of renewables. The CP scenario presents a limited improvement in the ratio of renewable energy due to the increasing productive capacity of the renewable energy sectors and the global price of oil increasing. Yet, the improvement achieved is rather low when confronted with the other scenarios' outcomes.

6.1.2. Macroeconomic indicators and distributive effects


(a) Real GDP Growth

(b) Income Shares

(c) Public Debt (% of GDP)

Figure 7: Impact of NGFS transition policies on key macroeconomic indicators. Left panel: the x axis displays the simulation time, the y axis displays the yearly GDP growth rates over the entire simulation time. Central panel: the x axis displays the simulation time, the y axis displays the total shares of national income accrued by workers' households (top sub-panel) and capitalist households (bottom sub-panel). Right panel: the x axis displays the simulation time, the y axis displays the level of public debt to GDP over the entire simulation time.

Figure 7a shows the yearly growth rate of GDP across the scenarios. The introduction of the climate policies results in a short-term reduction of economic growth, followed by a mid- and long-run robust recovery, showing significant co-benefits of the transition. Stronger policy interventions lead to larger fluctuations along the pattern. The initial fall of GDP growth is explained by the increases in the cost of production of both capital and final goods producers due to the introduction of the carbon tax. However, in the mid-term period, growth rates across all scenarios become less volativle because of overall adjustment to the new competitive advantages. By the end of simulation the orderly transition scenarios shows GDP growth rates

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[17] It is worth noting that total accumulated GHG emissions still increase for all scenarios. This is due to the fact that we do not consider endogenous technological change in the short term. Thus, the energy intensity and carbon intensity of production for the same capital and energy mix are fixed. Emissions reductions are obtained by substituting high with low-carbon capital. This is different from the NGFS implementation and most climate-economy IAMs, which include some level of CCS take up and decrease in the energy intensity of production.

more 0.1% higher than the CP and the DT scenarios. [18]. The NZ and B2C scenarios report a real GDP growth rates which are respectively 1.5 and 1 percentage points higher than the CP scenario. Moreover, the early transition scenarios (NZ and B2C) show less volatility in growth rates than the DT scenario. The DT scenario shows a rapid drop in GDP growth towards the end of the simulation, suggesting that it could pose risks for economic and financial stability. This reflects the fact that the smoother investment stimulus and financing conditions of the orderly transition are easier for the economy to bear and adapt to.

Figure 7b shows the income share of the worker and capitalist households across scenarios. In all transition scenarios, workers' households receive a relatively larger share of income than in the benchmark simulation. The trend in the CP scenario shows worsening conditions for workers households, while this is reversed in all transition scenarios. The causal channels explaining the trends are twofold:

1. In the transition scenarios there is a relative larger employment rate driven by higher investments, which increases the wages according to the wage-setting rule (see section 2.1).
2. Larger carbon taxes reduce the profit rate of firms and increase the government's budget, which largely redistributes in favour of workers through public employment, unemployment compensation and lump sum transfers for redistributive purposes.

Another consequence of the short- term drop in GDP can be observed in the public debt to GDP ratio, which slightly increases after the transition with respect to the benchmark (figure 7c). The increase in debt to GDP ratio is mostly driven by the relative decrease in GDP and by the higher public spending connected to the policies and measure applied in the transition scenarios. Indeed, the ratio of debt to GDP increases regardless of the increase in nominal and relative incomes accrued by the government thanks to the implementation of the GHG taxes and the relatively smaller budget deficits.

Results also show that the increase in government spending to finance the transition policies is more than sustainable for the government's budget. The ratio of debt to GDP across all transition scenarios is lower than in the CP scenario.Therefore, the negative effects of higher government spending under the transition scenarios is offset in the medium and long run. The NZ scenario reports a debt to GDP ratio 9 percentage points lower than the CP scenario, while the B2C and DT scenarios show reductions of 3 and 4 percentage points respectively. Moreover, scenarios characterised by higher carbon taxes (NZ and DT) show faster reduction in the level of government debt. This result can be explained by the higher GHG taxes revenues and higher GDP. The DT scenario shows a larger initial increase in debt ratio, which again signals the potential instability triggered by a disorderly transition.

6.1.3. Banking and credit

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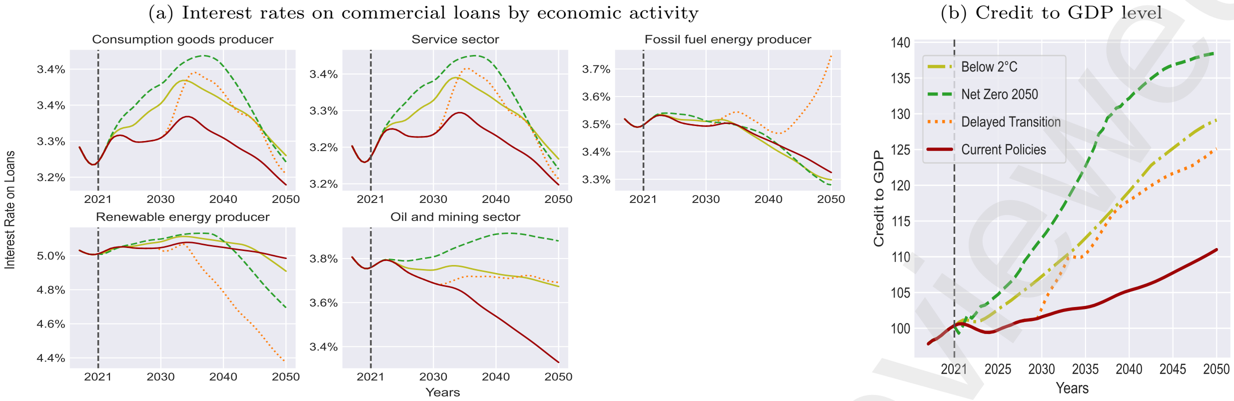
[18] It is worth recalling that we are not including climate physical damages in our analysis, which would affect the productive capacity of all economic sectors, see (Gourdel et al., 2022). The damages would be especially higher in the DT and CP scenario. Therefore, growth rates in the absence of transition policies would be more impaired than it is captured in our simulation.


(a) Interest rates on commercial loans by economic activity

(b) Credit to GDP level

Figure 8: Impact of NGFS transition policies on the credit market. Left figures: the x axis displays the simulation time, the y axis reports the interest rate on loans requested by the commercial bank for each productive sector, in percentage points. Right figure: the x axis displays the simulation time, the y axis reports the total volume of credit over GDP circulating in the economy each year.

To assess the interactions between climate policies and financial markets, in figure 8a we plot the sectoral interest rate on loans set by the commercial bank. In EIRIN, the interest rate depends on the base lending rate of the central bank and on the PD of each sector (see eq. 17). Interest rates increase across all transition scenarios after the introduction of transition policies can be explained by two synergic mechanisms:

1. The higher low-carbon capital investment requirements cause the productive sectors to take up larger debts and thus increase their leverage. Additionally, all sectors face a reduction in their ROA because of the larger taxation and a general decrease of high-carbon capital and energy. In turn, leverage and ROA affect sectors' PD, as explained in section 2.2.
2. More expensive production translates into higher costs and, thus, prices, increasing inflation and leading the central bank to review the baseline interest rate upward according to the Taylor Rule (see section 2).

The case of the fossil fuel energy producer is less trivial because the decreasing demand that it faces then translates into a decrease in its investments and thus in debt. This deleveraging can balance out with the decrease in ROA depending on the sharpness of the transition policies.

Another important financial dynamic is the growth of credit in the economy, shown in figure 8b. The NZ scenario shows a steady increase in credit to GDP level, with the 2050 value being 27% higher than the CP scenario. B2C and DT show end-of-simulations values which a respectively 18% and 14% higher than CP scenario. The increase is driven by higher investments in the transition scenarios, and by the relatively higher nominal cost of low-carbon capital, which sectors start purchasing at higher rates. The growth in credit is a symptom of the importance of access to loans for a transition in production activities to happen. The increase in production costs and transition to low-carbon capital require relatively higher liquidity levels, which firms acquire through loan financing. This dynamic signals that attention should be paid to the state of the financial system in the decarbonisation of the economy.

6.2. Green discount sentiment

In this section, we test the effects of the banking sector's adjustment in lending behaviour, by introducing an interest rate discount based on the quantity of low-carbon investments undertaken by each sector (see eq. 27). We assume that the commercial bank adopts a forward-looking approach in adjusting its lending conditions for low-carbon sectors. This behavioural change is introduced after the announcement of the transition policies of the NZ scenario. We show that the introduction of climate sentiments leads to large changes in the outcome of the NGFS scenarios. Thus, taking into account the role of financial institutions is fundamental for properly understanding and fostering the decarbonisation of the economy.

Figure 9: Interest rates on commercial loans conditioned on bank's Green Discount Sentiments, Net Zero scenario. The x axis displays the simulation time, the y axis reports the interest rates applied by the commercial bank on loans to the sectors of the economy. Each scenario is characterised by a different Green Discount Sentiment strength.

The most immediate effect of the introduction of the GDS (see section 5.1) can be observed in loans' interest rates (figure 9). The renewable energy producer, whose investments are entirely low-carbon, receives the highest reduction in interest rates, which brings it to face up to 1.1 percentage points lower interest rates for the high GDS scenario. Such discount allows the renewable energy producer to offer lower prices because of the lower cost of servicing debt, thus decreasing the overall price of energy[19]. The energy price mechanism causes a decrease in the ROA of the high-carbon energy producer, as well as an increase in its leverage. These combined effects endogenously increase the high-carbon energy producer's PD and consequently drive up their loans' interest rate. In the high GDS scenario, fossil fuel energy producers face loan interest rates up to 0.4 percentage points higher than the baseline NZ scenario.

This result is particularly relevant because the increase in interest rate for fossil fuel energy producer is not a direct result of the GDS but it emerges endogenously from agents and sectors' behaviors and interactions. The oil and mining sector is not subject to the same dynamic because it faces no direct competition. Therefore, it is able to benefit from the initial reduction in overall level of interest rates. The consumption goods and services producers take advantage of the increasingly lower interest rates determined by their large take up of low-carbon capital. All these effects are magnified for higher GDS. Under a sufficiently large GDS adjustment parameter, the PD of the fossil fuel energy producer starts to rapidly increase, followed by their interest rate.

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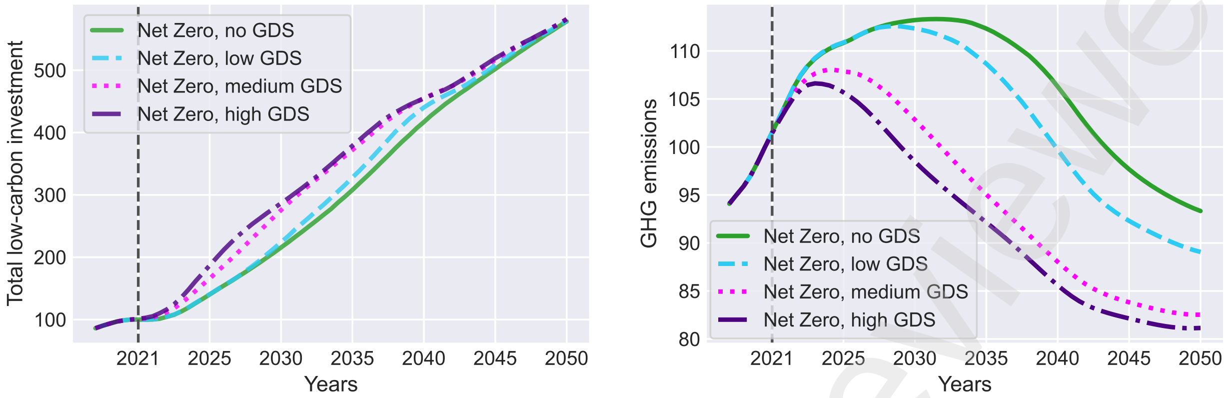
[19] In the current specification of EIRIN, the price of energy is common to both producers. It depends on production costs, a common markup rate, and an exogenous competition parameter which regulates adjustment speed.


(a) Investment in low-carbon capital

(b) Yearly GHG Emissions

Figure 10: Low-carbon investment and GHG emissions conditioned on bank's Green Discount Sentiments, Net Zero scenario.
Left panel: the x axis displays the simulation time, the y axis presents the total volume of investment in low-carbon capital across all sectors, normalised to the 2021 value.
Right panel: the x axis displays the simulation time, the y axis presents the yearly GHG emissions volumes, normalised to the 2021 value.

The new interest rate dynamics result in larger investments in low-carbon capital across all sectors, especially in the early transition years, as shown by figure 10a. This occurs because the new interest rate setting rule gives a discount associated to low-carbon investments' shares, thus endogenously increasing the NPV of low-carbon investments. These mechanisms act simultaneously to those set in motion by the fiscal policy for the Net Zero scenario, which makes low-carbon investments more competitive than high-carbon capital ones. By 2030, the amount of low-carbon investment achieved in the medium and high GDS scenarios is 3 times larger than the pre-transition level, while the NZ scenario without climate sentiments only achivese a 2 times increase over the same period.

Therefore, the main effect of the introduction of the GDS is to anticipate the growth in low-carbon investments, as displayed in figure 10a. In particular, the larger the value of the GDS, the swifter the increase of low-carbon investments. This result is due to the financial effect of the GDS on the NPVs of low- and high-carbon investments, which supports the real-economy shift in favour of low-carbon capital-based production caused by the green fiscal policies.

An earlier and broader adoption of low-carbon capital translates into faster and larger reductions of yearly GHG emissions, as from in figure 10b. The reduction obtained by the "large GDS" scenario is substantially more significant than the reduction obtained under the baseline Net Zero scenario. This suggests a high potential for the GDS climate sentiment to reduce overall GHG emissions. The reduction does not come at the expense of economic growth, which remains higher than the Current Policy scenario for all sentiments scenarios.

6.3. *Emission intensity sentiment*

In this section, we test the effects of a different adjustment in banking sector's lending behaviour. In particular, we consider the adjustment in the internal calculation of each sector's PD based on the sectors' ratio of GHG emissions to operating earnings (see section 5.2). This choice considers the past and present production history of each sector. This behavioural change is introduced after the implementation of the transition policies of the NGFS Net Zero scenario. We discuss results through three climate sentiments' scenarios, where we apply three GHG emissions intensity targets, namely "low", "medium", and "high", to the Net Zero NGFS scenario.

At the implementation of the climate policies aimed to reach the Net Zero target, the bank starts to penalise the sectors that have a higher GHG emission intensity of earnings than their internal target (see section 5.2). This happens because the commercial bank revises the computation of each sector's PD based

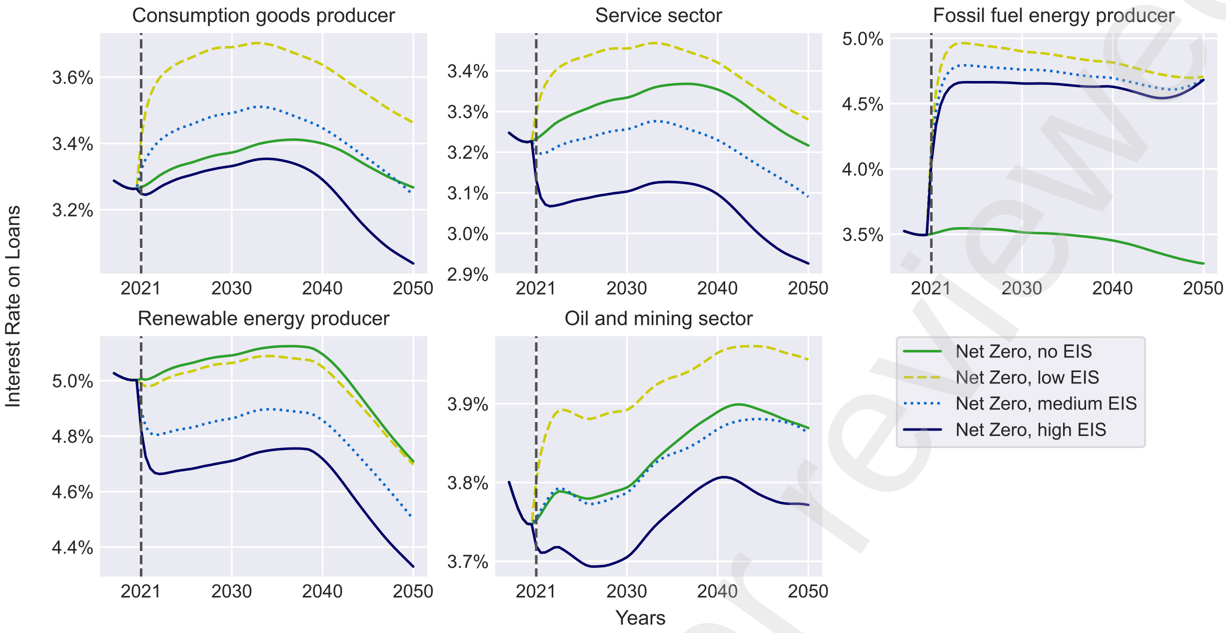


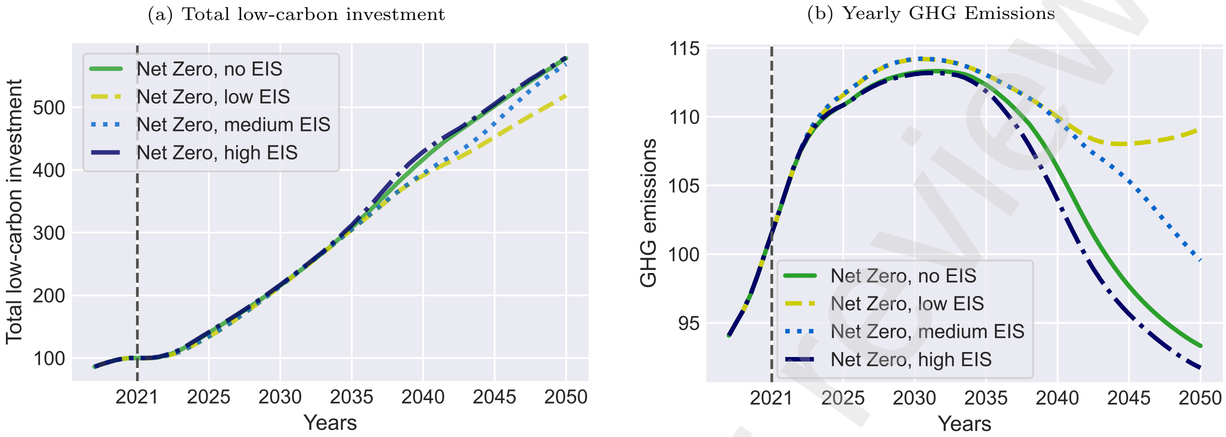
Figure 11: Interest rates on commercial loans conditioned on bank's Emission Intensity Sentiments, Net Zero scenario. The x axis displays the simulation time, the y axis reports the interest rates applied by the commercial bank on loans to the sectors of the economy. Each scenario is characterised by a different EIS strength.

on their ratio of GHG emissions to operative earnings. Thus, large emitters are charged with relatively higher interest rates, while low emitters benefit from interest rates' reductions.

Therefore, what matters for the adjustment are sectors' past low- carbon investments and the current energy use. In our calibration, all the sectors but the renewable energy producer show rather high GHG-intensity of earnings ratios at the start of the transition. This results in an increase of interest rates with respect to the Net Zero scenario without EIS for the scenarios with low and medium targets, as shown in figure 11. The scenario with a high target shows overall reductions of interest rate, apart from the fossil fuel energy producer, which remains penalised. For example, compared to the NZ scenario without EIS, the consumption goods producers faces interest rates of 0.2 percentage points higher in the low EIS target scenario and 0.3 percentage point lower in the high EIS target scenario. It is worth noting that the renewable energy producer can access lower interest rates under the high EIS than the low EIS scenario because the discount is calculated as a fixed proportion of the distance between realised intensity of emissions and the bank's target. In the low EIS scenario, the target is lower, giving rise to a smaller difference with the renewable energy producers' GHG intensity of earnings, and thus a lower discount.

Figure 12b shows that lower EIS targets lead GHG emissions to decrease at slower rates. The high and medium EIS scenarios respectively show a 9% increase and no change with respect to the beginning of the transition. The high EIS scenario shows a reduction 2% larger than the NZ scenario without EIS. The key dynamic is that, at the beginning of the transition, the final goods and services producers have large emissions intensity of earnings. Therefore, they get penalised through higher interest rates, which in turn hinder their possibility to invest, both in high and low-carbon capital. Indeed, if these sectors' GHG intensity of earnings were to fall below the banks target they would benefit from an interest rate discount, but it doesn't apply to the consumption good producers, and only later on for the services producers.

Higher interest rates also affect the NPV of both low-carbon and high-carbon investments, preventing the low-carbon NPV to rise with respect to the high-carbon NPV. Lower bank's EIS targets induce slower take up of low-carbon capital as shown in figure 12a. The high target EIS scenario, on the contrary, presents an increase in low-carbon investments and a reduction in GHG emissions, albeit small. This is caused by the increased ease of investments in low-carbon capital lead by the interest rate reduction, similarly to the mechanism triggered by the GDS climate sentiment. Also similarly, the adjustments do not come at the expense of economic growth, which remains higher than the Current Policy scenario for all sentiments scenarios, with lower EIS scenarios presenting better performances.


(a) Total low-carbon investment

(b) Yearly GHG Emissions

Figure 12: Low-carbon investment and GHG emissions conditioned on bank's Emission Intensity Sentiments, Net Zero scenario. lLeft panel: the x axis displays the simulation time, the y axis presents the total volume of investment in low-carbon capital across all sectors, normalised to the 2021 value. Right panel: the x axis displays the simulation time, the y axis presents the yearly GHG emissions volumes, normalised to the 2021 value.

The EIS climate sentiment could have either hampering or enabling effect for a low-carbon transition. The introduction of bank's climate sentiments can be thought of as a reaction of the banking sector targeted at discouraging investment in high-carbon capital goods, with the aim to foster a decarbonisation of the economy. However, they can also impair the transition to low-carbon production if the banking sector's reaction is too abrupt.

6.4. The complementarity of bank's climate sentiments

In this section, we analyse the interaction of the two climate sentiments. We design two illustrative scenarios, which add respectively "enabling" and "hampering" climate sentiments to the policies for the NGFS Net Zero transition. The "enabling" scenario is characterised by high GDS and high EIS sentiments; the "hampering" scenario is characterised by low GDS and low EIS sentiments. This allows us to gauge the complementarity of the two sentiments and the potential interaction effects of climate sentiments and NGFS transition policies.

We show that climate sentiments matter for the effectiveness of climate policies: given the same set of policies implemented by the government, climate sentiments in the banking sector influence the portfolio of investment undertaken by the productive sectors and consequently the quantity of GHG emissions generated. We find that the availability of credit at favourable economic conditions is crucial for the take up of low-carbon capital. Furthermore, an abrupt adjustment in expectations by the banks to the green transition could be detrimental for the realisation of the decarbonisation goals.

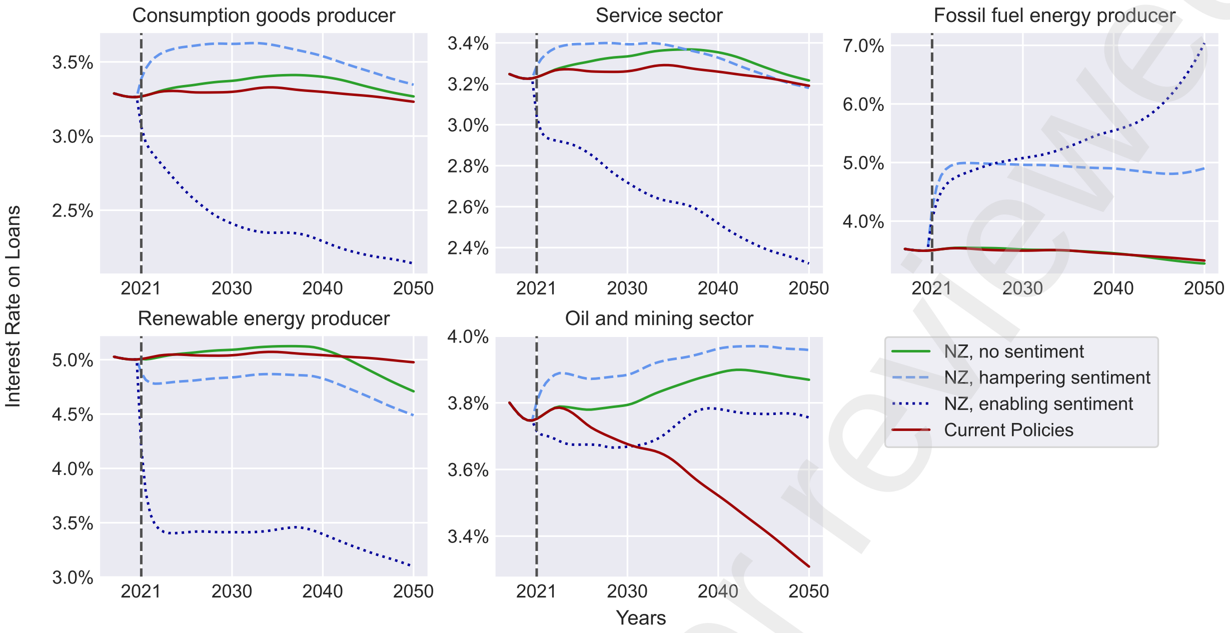
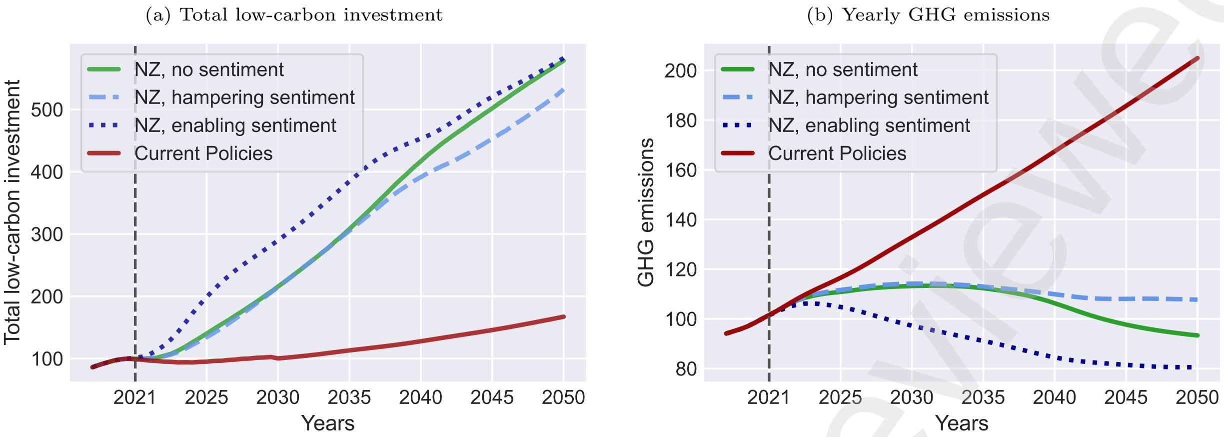


Figure 13: Interest rates on commercial loans conditioned on bank's climate sentiments combinations, Net Zero scenario. The x axis displays the simulation time, the y axis reports the interest rates applied by the commercial bank on loans to the sectors of the economy. The "hampering" scenario is characterised by low Green Discount Sentiment and low Emission Intensity Sentiment. The "enabling" scenario is characterised by high Green Discount Sentiment and high Emission Intensity Sentiment.

Figure 13 shows the interest rates' adjustments obtained by the combined presence of both climate sentiments' channels. In the "enabling" scenario, the bank provides high discounts for the low-carbon investments' share (GDS channel) and sets relaxed GHG emissions targets. It results in a large discount on interest rates for consumption goods and services producers, and for the renewable energy producer, leading to a large increase in interest rates for the fossil fuel energy producer 6.2.

In contrast, the "hampering" scenario focuses on the EIS channel, by setting lower GHG emission intensity targets and small discounts for low-carbon investments' shares. This leads to an increase in interest rates across all sectors with the exception of the renewable energy producer.

The interest rate dynamics result in a slower uptake of low-carbon investment in the "hampering" scenario in comparison with the Net Zero scenario without climate sentiments, see figure 14a. In contrast, in the "enabling" scenario a faster and consistently higher take-up of low-carbon investments occurs across the whole simulation time span, in particular in the first decade after transition policies are introduced. The main mechanism which drives those results is the NPV (see eq. 13 and 12). The "enabling" combination of climate sentiments triggers a faster increase in the NPV of low-carbon investments (see section 6.2). While the "hampering" and "enabling" scenarios show different patterns of low-carbon investments, the levels of total investments remain almost unvaried. Figure 14b shows the implications on a faster reduction in GHG emissions for the "enabling" scenario, in which emissions levels in 2050 are 20% lower than before the transition, while the "hampering" scenario fails to reduce GHG emissions, with the end-of-simulation GHG emissions level being 9% higher than at the introduction of transition policies. Both "hampering" and "enabling" scenarios show GDP growth rates consistently higher than the Current Policy scenario.


(a) Total low-carbon investment

(b) Yearly GHG emissions

Figure 14: Low-carbon investment and GHG emissions conditioned on climate sentiments combinations, Net Zero scenario. Left panel: the x axis displays the simulation time, the y axis presents the total volume of investment in low-carbon capital across all sectors, normalised to the 2021 value. Right panel: the x axis displays the simulation time, the y axis presents the yearly GHG emissions volumes, normalised to the 2021 value.

To further explore the importance of climate sentiments for the effectiveness of climate policies, we simulate the remaining NGFS transition scenarios (B2C and DT) coupled with the “enabling” mixture of climate sentiments. Figure 15 shows that the B2C scenario with “enabling” sentiments performs better than the Net Zero scenario without climate sentiments in terms of speed of reduction of GHG emissions. By 2030, in the B2C scenario with “enabling” climate sentiments, the total volume of GHG emissions stops growing and already starts to decrease. In the same period, in the NZ scenario without sentiments, the absolute quantity of GHG emissions is still 16% higher than before the transition.

Summing up, results highlight that:

- Climate sentiments can foster the decarbonisation of the economy, even in presence of less ambitious climate policies.
- A faster transition towards low-carbon capital across sector leads ot an earlier decarbonisation of the economy. However, in the long-term the NZ scenario still performs better than B2C on low-carbon investment rates. This result is influenced by the important policy package (e.g. higher carbon taxes and green subsidies) implemented in NZ that introduces long-term comparative advantages for low-carbon production practices and thus more sustained economic growth.

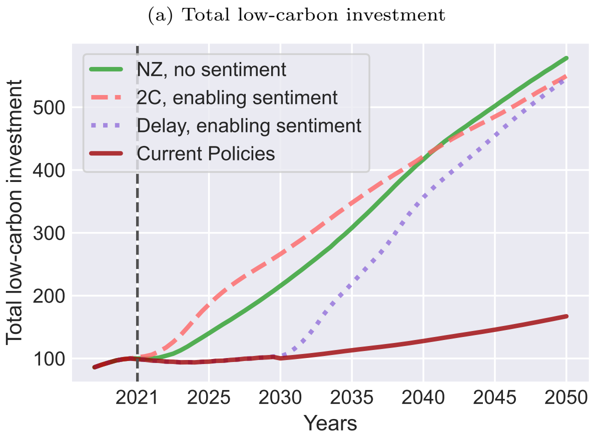


Figure 15: Impact of enabling climate sentiments on low-carbon investment and GHG emissions across transition scenarios Left panel: the x axis displays the simulation time, the y axis presents the total volume of investment in low-carbon capital across all sectors, normalised to the 2021 value. Right panel: the x axis displays the simulation time, the y axis presents the yearly GHG emissions volumes, normalised to the 2021 value.

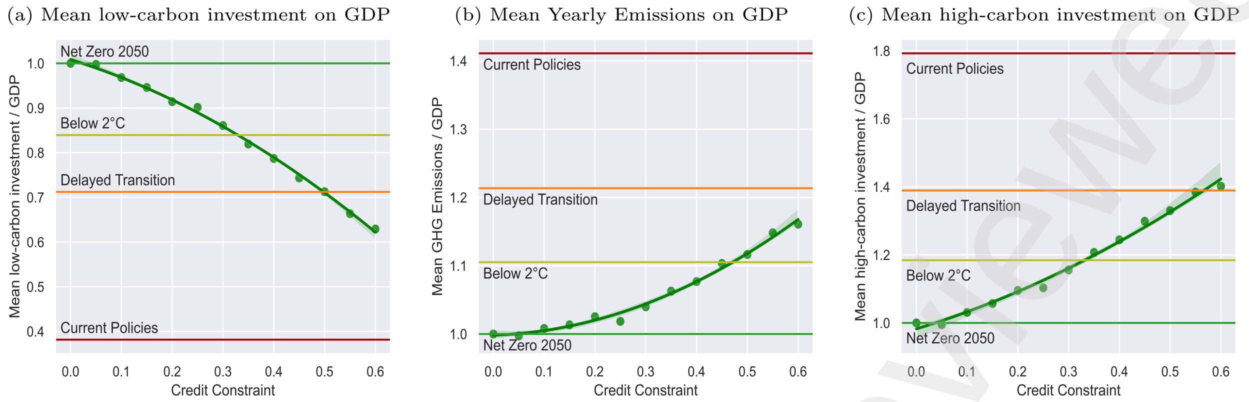
6.5. *Credit restrictions*

The introduction of credit restriction on low-carbon investments has two main consequences. First, it prevents low-carbon capital producer to exploit the competitiveness advantage that would have arrived with the climate policies. Second, it increases in relative terms the demand of high-carbon capital from the final production sectors. These two effects combine to generate relatively higher levels of high-carbon investment, as shown in figure 16c.

Figure 16 shows results from the sensitivity analysis of the magnitude of the credit constraints. First, the introduction of a credit constraint on low-carbon investments leads to a proportional reduction in average low-carbon investments, as shown in figure 16a. If the credit restriction is high enough, the quantity of low-carbon investment to GDP can decrease to a level below that achieved under the Below 2°C and Delayed Transition NGFS scenarios. For example, with 50% of low-carbon investment requests being restricted, the mean quantity of low carbon investment to GDP results 30% smaller than it would be in the NZ scenario. This result is interesting because GDP also decreases for higher credit constraints. Therefore, the reduction in low-carbon investment is relatively larger than that in GDP. The lower levels of low-carbon investment directly translate into a weaker transition towards low-carbon production processes and therefore higher GHG emissions per unit of GDP, as shown in figure 16b.

Second, for high levels of credit restrictions, the decarbonisation results achieved with the Net Zero policies can be worse than the results obtained by B2C policies without credit restrictions. For example, with 50% of low-carbon investment requests being restricted, the mean yearly GHG emissions to GDP result 11% higher than the level achieved by the NZ scenario without credit constraint. This is larger than the level obtained by the B2C scenario without credit constraints.

Results show that the introduction of credit restrictions on low-carbon investment can reduce the overall volume of investment, and adjust the quality of the capital mix demanded towards a “dirtier” mix. With 50% of low-carbon investment requests being restricted, the mean high-carbon investment to GDP results 33% higher than in the NZ scenario without constraints. These results contribute to show the importance of the role played by the finance sector in the decarbonisation of the economy.


(a) Mean low-carbon investment on GDP

(b) Mean Yearly Emissions on GDP

(c) Mean high-carbon investment on GDP

Figure 16: Decarbonisation of the economy conditioned on credit constraints on low-carbon investment, Net Zero scenario. Left panel: the x axis displays the values of the credit constraint parameter, the y axis displays the mean quantity of low-carbon investment to GDP during the simulation period (2021-2050). The horizontal lines report the values obtained for the NGFS scenarios previously simulated. Central panel: the x axis displays the values of the credit constraint parameter, the y axis displays the mean quantity of GHG emissions to GDP during the simulation period (2021-2050). The horizontal lines report the values obtained for the NGFS scenarios previously simulated. Right panel: the x axis displays the values of the credit constraint parameter, the y axis displays the mean quantity of high-carbon investment to GDP during the simulation period (2021-2050). The horizontal lines report the values obtained for the NGFS scenarios previously simulated.

7. Conclusions

In this paper we study how banks' climate sentiments, i.e. their expectations about climate policy credibility and firms' performance in the low-carbon transition, affect economic decarbonization and the realization of climate mitigation scenarios. To this aim, we tailored the EIRIN macro-financial model by embedding an enhanced credit market and the NGFS climate scenarios. We considered two ways in which banks can form expectations, i.e. backward-looking and forward-looking climate sentiments. We then analysed the effects of both sentiments on the adjustment in the cost of capital, on firms' endogenous investment decision, and on the realization of the NGFS scenarios. We calibrated EIRIN on the Austrian economy.

Our results confirm the importance for policy makers to commit early and credibly to carbon taxes and other climate fiscal policy measures in order to achieve an orderly low-carbon transition and decrease the risk of carbon stranded assets. In addition, banks' expectations play a crucial role in making or failing an orderly transition because they affect the adjustment in risk assessment and thus in lending conditions, including potential credit constraints.

First, we find that climate policy credibility (i.e. an orderly introduction of climate policies aligned with the Paris Agreement temperature targets) has important co-benefits by 2050, in particular in the Net Zero scenario, including higher GDP than the current policy scenario; -8% GHG emissions than in 2021; substantial benefits in terms of government's fiscal stability and income distribution. Second, banks' climate sentiments can reinforce the impact of transition policies on decarbonization (-20% GHG emissions in comparison to the Current Policies scenario), and the co-benefits of an orderly carbon tax introduction on avoided GDP losses. However, banks' climate sentiments can also counteract the impact of the climate policies, depending on how expectations affect the revision of lending conditions for high- and low-carbon investments. On the one hand, banks' forward-looking sentiments foster firms' low-carbon investments due to the discount in the cost of capital associated to low-carbon investments' shares, thus endogenously increasing the Net Present Value (NPV) of low-carbon investments. On the other hand, banks' backward-looking sentiments can either promote or hamper low-carbon investments, since banks reward or penalize sectors by adjusting loans' interest rates based on firms' GHG emissions intensity. Third, we show that credit constraints on low-carbon investments can have a significant detrimental effects on decarbonization and overall economic performance.

Our findings are relevant not only for academics, but also for professionals in the banking and finance industry, for central bankers and financial regulators that engage in climate financial risk assessment and management. In particular, our results highlight the importance for financial supervisors to consider the interplay between banks' expectations and climate policy credibility in their macro-financial models, in order to correctly assess the potential costs and co-benefits of the transition, and the implications for banks. This point, in turn, is crucial to inform the discussion about the role (if any) and design of green financial and macro-prudential policies aimed to mitigate climate-related financial risks. Future research on the role of the banking sector in the realization of the climate scenarios would benefit from the availability of more detailed information about banks' assessment and management of climate risks.

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Appendix A. Balance sheets and accounting equations

Appendix A.1. Balance sheet matrices

To provide a detailed description of agents' and sectors' stocks and flows, we complement section 2 by presenting a set of three matrices. Table A.4 includes the balance sheet matrix, which shows all the assets and liabilities for each agent and sector at each simulation step, thus representing a snapshot of the EIRIN economy.

In table A.4, rows show assets and claims of assets among sectors, and generally it sum up to 0. Exceptions are given by tangible capital and inventories, which are accumulated by firms, and stock shares owned by the capitalist households and banks. In fact, since stock shares are traded in the financial market, the market price and book value of equity shares can be different.

Table A.5 is called transaction flow matrix, and shows all the stock and monetary flows among agents and sectors. It highlights how cash flows among agents and sectors need to cancel out (see the zeros in the last column) and the determinants of the liquidity changes for each sector. The top part describes the flows of revenues (no sign) and payments (minus sign) that each agent and sector make or receive. The result of agents and sectors transaction is the Net Cash Flow (NCF). The bottom part of the table shows the changes in cash flow due to the variation in real, monetary and financial assets or liabilities.

Finally, table A.6 is called net worth change matrix and reports the variation in the net worth of each agent and sector due capital depreciation, change in inventories and price change of real and financial assets.

	H_W	H_K	F_K	F_L	K_B	K_G	EN_B	EN_G	MO	BA	CB	G	RoW	Total
Tangible capital														
- high-carbon			$p_{K_B}K_{K_B}^{F_K}$	$p_{K_B}K_{K_B}^{F_L}$			$p_{K_B}K_{K_B}^{EN_B}$		$p_{K_B}K_{K_B}^{MO}$					$p_{K_B}K_{K_B}$
- green			$p_{K_G}K_{K_G}^{F_K}$	$p_{K_G}K_{K_G}^{F_L}$				$p_{K_G}K_{K_G}^{EN_G}$						$p_{K_G}K_{K_G}$
- Inventories			$p_{F_K}IN_{F_K}$											$p_{F_K}IN_{F_K}$
Gold in the vault											M_{CB}			M_{CB}
Gov bonds		$p^\dagger_G n_G^{H_K}$								$p^\dagger_G n_G^{BA}$	$p^\dagger_G n_G^{CB}$	- $p^\dagger_G n_G$		0
Bank's loans			$-L_{F_K}$	$-L_{F_L}$			$-L_{EN_B}$	$-L_{EN_G}$	$-L_{MO}$	L_{BA}				0
CB's loan										$-L_{CB}$	L_{CB}			0
Bank's deposits	M_{H_W}	M_{H_K}	M_{F_K}	M_{F_L}	M_{K_B}	M_{K_G}	M_{EN_B}	M_{EN_G}	M_{MO}	$-D_{BA}$		M_G		0
CB's reserves										M_{BA}	$-M_{\text{fiat}}$		M_{RoW}	0
Traded stock shares		$p^\dagger_{F_K} n_{F_K}^{H_K}$	$-E_{F_K}$							$p^\dagger_{F_K} n_{F_K}^{BA}$				$p^\dagger_{F_K} n_{F_K} - E_{F_K}$
		$p^\dagger_{F_L} n_{F_L}^{H_K}$		$-E_{F_L}$						$p^\dagger_{F_L} n_{F_L}^{BA}$				$p^\dagger_{F_L} n_{F_L} - E_{F_K L}$
		$p^\dagger_{K_B} n_{K_B}^{H_K}$			$-E_{K_B}$					$p^\dagger_{K_B} n_{K_B}^{BA}$				$p^\dagger_{K_B} n_{K_B} - E_{K_B}$
		$p^\dagger_{K_G} n_{K_G}^{H_K}$				$-E_{K_G}$				$p^\dagger_{K_G} n_{K_G}^{BA}$				$p^\dagger_{K_G} n_{K_G} - E_{K_G}$
		$p^\dagger_{EN_B} n_{EN_B}^{H_K}$					$-E_{EN_B}$			$p^\dagger_{EN_B} n_{EN_B}^{BA}$				$p^\dagger_{EN_B} n_{EN_B} - E_{EN_B}$
		$p^\dagger_{EN_G} n_{EN_G}^{H_K}$						$-E_{EN_G}$		$p^\dagger_{EN_G} n_{EN_G}^{BA}$				$p^\dagger_{EN_G} n_{EN_G} - E_{EN_G}$
		$p^\dagger_{MO} n_{MO}^{H_K}$							$-E_{MO}$	$p^\dagger_{MO} n_{MO}^{BA}$				$p^\dagger_{MO} n_{MO} - E_{MO}$
		$p^\dagger_{BA} n_{BA}^{H_K}$								$p^\dagger_{BA} n_{BA}^{BA} - E_{BA}$				$p^\dagger_{BA} n_{BA} - E_{BA}$
Equity (net worth)	$-E_{H_W}$	$-E_{H_K}$									$-E_{CB}$	$-E_G$	$-E_{RoW}$	$-E_{\text{EIRIN}}$
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table A.4: Balance sheet matrix of the EIRIN economy. Each column represents the balance sheet of an agent or sector. Assets are reported with no sign and liabilities with a negative sign. Each column always sums to zero to highlight the definition of equity (or net worth). Except for real assets, the table rows also sum to zero in most cases to highlight the financial interlinkages among sectors, i.e. that what is a financial asset for a sector is a liability for another sector. In the case of traded stocks the difference between assets and their counterparts is different from zero to highlight that market value of equity is generally different from its book value.

Cash flows from:	H_W	H_K	F_K	F_L	K_B	K_G	EN_B	EN_G	MO	BA	CB	G	RoW	$\sum$
Consumption of:														
- goods	$-p_{F_K}q_{F_K}^{H_W}$	$-p_{F_K}q_{F_K}^{H_K}$	$p_{F_K}q_{F_K}$									$-p_{F_K}q_{F_K}^{G}$		0
- services	$-p_{F_L}q_{H_W}^{F_L}$	$-p_{F_L}q_{H_K}^{F_L}$		$p_{F_L}q_{F_L}$								$-p_{F_L}q_{F_L}^{G}$		0
- energy	$-p_{EN}q_{EN}^{H_W}$	$-p_{EN}q_{EN}^{H_K}$	$-p_{EN}q_{EN}^{F_K}$	$-p_{EN}q_{EN}^{F_L}$	$-p_{EN}q_{EN}^{K_B}$	$-p_{EN}q_{EN}^{K_G}$	$p_{EN_B}q_{EN_B}$	$p_{EN}q_{EN_G}$						0
- oil							$-p_O q_{EN_B}$		$p_O q_{MO}$					0
Imports	$-p_{R_c}q_{H_W}^{I_c}$	$-p_{R_c}q_{H_K}^{I_c}$	$-p_R q_{F_K}^{I_p}$	$-p_R q_{F_L}^{I_p}$									$p_{R_c}q_{RoW}^{I_c} + p_R q_{RoW}^{I_p}$	0
Exports			$p_{F_K}q_{F_K}^{E}$	$p_{F_L}q_{F_L}^{E}$					$p_O q_{MO}^{E}$				$-p_{F_K}q_{RoW}^{E}$ $-p_{F_L}q_{RoW}^{E}$ $-p_O q_{Row}^{E}$	0
Remittances	R_{H_W}	R_{H_K}											$-R_{RoW}$	0
Wages	Y_{H_W}		$-N_{F_K}w_{high}$	$-N_{F_L}w_{low}$	$-N_{K_B}w_{high}$	$-N_{K_G}w_{high}$						$-N_G w_{high}$		0
Interests:														0
- bonds' coupons		$c_G n_G^{H_K}$								$c_G n_G^{BA}$	$c_G n_G^{CB}$	$-c_G n_G$		0
- bank's loans			$-k_{F_K}L_{F_K}$	$-k_{F_L}L_{F_L}$			$-k_{EN_B}L_{EN_B}$	$-k_{EN_G}L_{EN_G}$	$-k_{MO}L_{MO}$	Y_{BA}				0
- CB's loan										$-\nu_{CB}L_{BA}$	$\nu_{CB}L_{CB}$			0
Income tax	$-T_{H_W}$	$-T_{H_K}$	$-T_{F_K}$	$-T_{F_L}$	$-T_{K_B}$	$-T_{K_G}$	$-T_{EN_B}$	$-T_{EN_G}$	$-T_{MO}$	$-T_{BA}$		T_G		0
Dividend payout		Y_{H_K}	$-d_{F_K}$	$-d_{F_L}$	$-d_{K_B}$	$-d_{K_G}$	$-d_{EN_B}$	$-d_{EN_G}$	$-d_{EN_G}$	$-d_{BA}$				0
Seignorage											$-S_{CB}$	S_G		0
	=	=	=	=	=	=	=	=	=	=	=	=	=	
(Net Cash flow)	$+NCF_{H_W}$	$+NCF_{H_K}$	$+NCF_{F_K}$	$+NCF_{F_L}$	$+NCF_{K_B}$	$+NCF_{K_G}$	$+NCF_{EN_B}$	$+NCF_{EN_G}$	$+NCF_{MO}$	$+NCF_{BA}$	$+NCF_{CB}$	$+NCF_G$	$+NCF_{ROW}$	0
	+	+	+	+	+	+	+	+	+	+	+	+	+	
Investment in:														
- high-carbon capital			$-p_{K_B}q_{K_B}^{F_K}$	$-p_{K_B}q_{K_B}^{F_L}$	$p_{K_B}q_{K_B}$		$-p_{K_B}q_{K_B}^{EN_B}$		$-p_{K_B}q_{K_B}^{MO}$					0
- low-carbon capital			$-p_{K_G}q_{K_G}^{F_K}$	$-p_{K_G}q_{K_G}^{F_L}$		$p_{K_G}q_{K_G}$		$-p_{K_G}q_{K_G}^{EN_G}$						0
Δ Loans			ΔL_{F_K}	ΔL_{F_L}			ΔL_{EN_B}	ΔL_{EN_G}	ΔL_{MO}	$-\Delta L_{BA} + \Delta L_{CB}$	$-\Delta L_{CB}$			0
bond issues		$-p_G^{\dagger}\Delta n_{H_K}$								$-p_G^{\dagger}\Delta n_{BA}$	$-p_G^{\dagger}\Delta n_{CB}$	$p_G^{\dagger}\Delta n_G$		0
Δ bank's deposits	$-\Delta M_{H_W}$	$-\Delta M_{H_K}$	$-\Delta M_{F_K}$	$-\Delta M_{F_L}$	$-\Delta M_{K_B}$	$-\Delta M_{K_G}$	$-\Delta M_{EN_B}$	$-\Delta M_{EN_G}$	$-\Delta M_{MO}$	ΔD_{BA}		$-\Delta M_G$		0
Δ CB's reserves										$-\Delta M_{BA}$	ΔM_{fiat}		$-\Delta M_{ROW}$	0
$\sum$	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table A.5: Cash flow matrix of agents and sectors in the EIRIN economy. The matrix is divided into two sections. The first section refers to cash receipts or outlays of operating activities with an impact on net worth. The second section refers to cash flows generated by variations in real, financial and monetary assets or liabilities.

	H_W	H_K	F_K	F_L	K_B	K_G	EN_B	EN_G	MO	BA	CB	G	RoW
(Net cash flows table A.5)	$+NCF_{H_W}$	$+NCF_{H_K}$	$+NCF_{F_K}$	$+NCF_{F_L}$	$+NCF_{K_B}$	$+NCF_{K_G}$	$+NCF_{EN_B}$	$+NCF_{EN_G}$	$+NCF_{MO}$	$+NCF_{BA}$	$+NCF_{CB}$	$+NCF_G$	$+NCF_{ROW}$
Capital depreciation			$-\delta_K K_{F_K}$	$-\delta_K K_{F_L}$			$-\delta_K K_{EN_B}$	$-\delta_K K_{EN_G}$	$-\delta_K K_{MO}$				
Change of inventories			$p_{F_K} \Delta IN_{F_K}$										
Price change of:													
-tangible capital			$\Delta p_K K_{F_K}$	$\Delta p_K K_{F_L}$			$\Delta p_K K_{EN_B}$	$\Delta p_K K_{EN_G}$	$\Delta p_K K_{MO}$				
-inventories			$\Delta p_{F_K} IN_{F_K}$										
-bonds		$p_G^\dagger n_G^{H_K}$								$p_G^\dagger n_G^{BA}$	$p_G^\dagger n_G^{CB}$	$-p_G^\dagger n_G$	
-stock shares		$\sum_{i \neq G} \Delta p_i^\dagger n_i^{H_K}$								$\sum_{i \neq G} \Delta p_i^\dagger n_i^{BA}$			
	$-\Delta E_{H_W}$	$-\Delta E_{H_K}$	$-\Delta E_{F_K}$	$-\Delta E_{F_L}$	$-\Delta E_{K_B}$	$-\Delta E_{K_G}$	$-\Delta E_{EN_B}$	$-\Delta E_{EN_G}$	$-\Delta E_{MO}$	$-\Delta E_{BA}$	$-\Delta E_{CB}$	$-\Delta E_G$	$-\Delta E_{RoW}$
$\sum$	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A.6: Net Worth Change Matrix. The matrix shows how sectors' net worth changes due to net cash flow, capital depreciation, change in inventories and the price changes of real and financial assets.

Appendix A.2. Accounting equations

In this section, we present some main accounting equations related to the balance sheets' assets and liabilities of key agents and sectors. In particular, we show how assets and liabilities change following the flows of income and expenses, based on behavioral rules highlighted in section 2.

Appendix A.2.1. Households (H), divided into worker (H_W) and capitalist (H_K)

- Worker (H_W) (receiving wage as income)

  Changes in assets:

$$\Delta\ M_{H_W} = Y^{net}_{H_W} - p_{F_L}\ D^{F_L}_{H_W} - p_{F_K}\ D^{F_K}_{H_w} - IM_{H_W} \tag{A.1}$$

  where IM_{H_W} represents the imported consumption goods. $Y^{net}_{H_W}$ is the disposable labour income, net of energy expenses $p_{EN}\ q^{H_W}_{EN}$ and income tax payments,
  i.e., $Y^{net}_{H_W} = (1 - \tau_{H_W})\,(N_{high}\ w_{high}\ +\ N_{low}\ w_{low}\ ) - p_{EN}\ q^{H_W}_{EN} + R_{H_W}$, where R_{H_W} are remittances, τ_{H_W} is the rate of income tax and N_{high} is the share of the labour force employed in the capital intensive consumption goods sector, in public sector and in capital goods producer sector, while N_{low} represent the share of labour force employed in labour intensive sector,
  i.e. $N_{high} = N_{Gov}\ +\ N_{F_K}\ +\ N_K$ and $N_{low} = N_{F_L}$.

  Changes in equity:

$$\Delta E_{H_W} = \Delta M_{H_W} \tag{A.2}$$

  where changes in worker's equity ΔE_{H_W} are all reflected in worker's changes in deposits being the only way workers accumulate wealth.

- Capitalist (H_K) (receiving dividends and bonds' coupons as income)

  Changes in assets:

$$\Delta M_{H_K} = Y^{net}_{H_K} - p_{F_L}\ D^{F_L}_{H_K} - p_{F_K}\ D^{F_K}_{H_K}\ -\ p^{\dagger}_G\ \Delta n^{H_K}_G - \sum_{i \neq G} p^{\dagger}_i \Delta n^{H_K}_i - IM_{H_K} \tag{A.3}$$

  where IM_{H_K} is capitalist household consumption good imports, while i represents the index of the sector whose stock shares have been bought (or sold) by the capitalist household in the financial market (see table A.4). $Y^{net}_{H_K}$ is the net disposable income, net of energy expenses $p_{EN}\ q^{H_K}_{EN}$ and capital income tax payments,
  i.e. $Y^{net}_{H_K} = (1 - \tau_{H_K})\left(d_{F_L}\ +\ d_{F_K}\ +\ d_K\ +\ d_{EN}\ +\ + d_{BA}\ +\ n^{H_K}_G\ c_G\right) - p_{EN}\ q^{H_K}_{EN} + R_{H_K}$, where R_{H_K} are remittances, τ is the tax rate applied to the dividends payout and bonds coupons.

  Changes in equity:

$$\Delta E_{H_K} = \Delta M_{H_K}\ +\ \Delta n^{H_K}_G\ p^{\dagger}_G + n^{H_K}_G\ \Delta p^{\dagger}_G\ + \sum_{i \neq G} p^{\dagger}_i \Delta n^{H_K}_i\ + \sum_{i \neq G} \Delta p^{\dagger}_i n^{H_K}_i \tag{A.4}$$

  where $p^{\dagger}_G\ \Delta n^{H_K}_G$ and $\sum_{i \neq G} p^{\dagger}_i \Delta n^{H_K}_i$ represent the change in number of government bonds and stock shares owned by the capitalist household, respectively. $\Delta p^{\dagger}_G\ n^{H_K}_G$ and $\sum_{i \neq G} \Delta p^{\dagger}_i n^{H_K}_i$ show the change in price of government bonds and stock shares.

Appendix A.2.2. Consumption good and service producers (F), divided into consumption goods producer (F_K) and service firm (F_L), with $j \in \{F_L, F_K\}$.

Changes in assets:

$$\Delta M_j = \Pi_j - d_j - p_K \, I_j + \Delta L_j \tag{A.5}$$

where I_j represents the investment, Π_j is the net operating profit, i.e. $\Pi_j = p_j \, \left(D^j_{H_W} + D^j_{H_K}\right) + G_j + p_j q^E_j - w_x \, N_j - p_R \, q_R - p_{EN} \, q^{EN}_j - k_j \, L_j - T_j$, with $x = high, low$. T_j is the corporate tax, G_j is the government spending, $p_j q^E_j$ are consumption good and service exports, L_j are new loans and d_j is the total dividends payout which is set equal to the net operating profits realised at the previous time step, if positive.

$$\Delta K_j = -\, \delta_j \, K_j \; - \; \xi_j \, K_j + I_j \tag{A.6}$$

where the change in capital stock K_j is influenced by the investments I_j, the capital depreciation rate δ_j and the possible capital stock destruction due to natural hazards ξ_j.

$$\Delta \, IN_{F_K} = q_{F_K} - D^{F_K}_{H_W} - D^{F_K}_{H_W} \tag{A.7}$$

where q_{F_K} represents the consumption goods produced in a certain period, which add up to inventories IN_{F_K} if unsold.

Changes in equity:

$$\Delta E_j = \Delta M_j + \Delta \left(p_j \, IN_j\right) + \Delta(p_K \, K_j) - \Delta L_j \tag{A.8}$$

Changes in equity of consumption good and service firms consist of deposit changes ΔM_j, changes in inventory valuation (which are assumed to exist only for F_K, where $\Delta \left(p_{F_K} \, IN_{F_K}\right) = \Delta p_{F_K} \, IN_{F_K} + p_{F_K} \, \Delta IN_{F_K}$), changes in employed capital $\Delta(p_K \, K_j) = \Delta p_K \, K_j + p_K \, \Delta K_j$ as well as changes in liabilities, given by loans ΔL_j.

Appendix A.2.3. Capital goods firms (K), divided into high-carbon (K_B) and low-carbon (K_G) capital producer, with $j \in \{K_B, K_G\}$

Changes in assets:

$$\Delta M_j = \Pi_j - d_j \tag{A.9}$$

where Π_j is the net operating profit, i.e. $\Pi_j = p_j \; I_j - w_{high} \; N_K - p_{EN} \; q^j_{EN} - T_j$, and we have $I_{K_B} = I^{F_K}_{K_B} + I^{F_L}_{K_B} + I^{MO}_{K_B} + I^{EN_B}_{K_B}$ and $I_{K_G} = I^{F_K}_{K_G} + I^{F_L}_{K_G} + I^{EN_G}_{K_G}$. d_j is the total dividend payout set equal to the net operating profit, if positive, realised at the previous time-step.

Changes in equity:

$$\Delta E_j = \Delta M_j \tag{A.10}$$

Appendix A.2.4. Energy firms (EN), divided into high-carbon (EN_B) and low-carbon (EN_G) energy producers, with $j \in \{EN_B, EN_G\}$

Changes in assets:

$$\Delta M_j = \Pi_j - d_j - p_K \, I_j + \Delta \, L_j \tag{A.11}$$

where Π_j is the net operating profit, i.e $\Pi_j = p_j q^{EN} - p_O \, q^j_{MO} - k_j L_j - T_j$, where $p_O \, q^j_{MO}$ is the oil sold by MO and, therefore, is positive only for EN_B (see section 2). d_j is the total dividend payout set equal to the net operating profit, if positive, realised at the previous time step.

$$\Delta K_j = -\delta_j K_j - \xi_j K_j + I_j \tag{A.12}$$

where the change in capital stock K_j is influenced by the investments I_j, the capital depreciation rate δ_j and the possible capital stock destruction due to natural hazards ξ_j.

Changes in equity:

$$\Delta E_j = \Delta M_j + \Delta p_j K_j + p_j \Delta K_j - \Delta L_j \tag{A.13}$$

Appendix A.2.5. Oil and mining company (MO)

Changes in assets:

$$\Delta M_{MO} = \Pi_{MO} - d_{MO} - p_{K_B} I_{MO} + \Delta L_{MO} \tag{A.14}$$

where Π_{MO} is the net operating profit, i.e $\Pi_{MO} = p_O q_{MO} - k_{MO} L_{MO} - T_{MO}$, where $p_O \, q_{MO}$ is the oil sold by EN_B. d_{MO} is the total dividend payout set equal to the net operating profit, if positive, realised at the previous time step.

$$\Delta K_{MO} = -\delta_{MO} K_{MO} - \xi_{MO} K_{MO} + I_{MO} \tag{A.15}$$

where the change in capital stock K_{MO} is influenced by the investments I_{MO}, the capital depreciation rate δ_{MO} and the possible capital stock destruction due to natural hazards ξ_{MO}.

Changes in equity:

$$\Delta E_{MO} = \Delta M_{MO} + \Delta p_{K_B} K_{MO} + p_{K_B} \Delta K_{MO} - \Delta L_{MO} \tag{A.16}$$

Appendix A.2.6. Commercial bank (BA)

Changes in assets:

$$\Delta M_{BA} = \Pi_{BA} + \sum_n \Delta D_n + \Delta n_G^{BA} p_G - \sum_n \Delta L_n - p_G^{\dagger} \Delta n_G^{BA} - \sum_{i \neq G} p_i^{\dagger} \Delta n_i^{BA} \tag{A.17}$$

where Π_{BA} is the operating profit, i.e. $\Pi_{BA} = k_n \left(\sum_n L_n\right) - \nu_{CB} L_{CB} + n_G^{BA} c_G$, with $n \in \{F_L, F_K, EN_B, EN_G, MO\}$, while i represents the index of the sector whose stock shares have been bought (or sold) by the banking sector in the financial market (see table A.4). D_n are deposits and d_{BA} is the total dividend payout set equal to the operating profit, if positive, realised at the previous time step, and if the bank fulfils a capital requirement rule, i.e. its equity capital is higher than a given percentage of total outstanding loans.

Changes in liabilities and equity:

$$\Delta D_{BA} = \Delta M_{H_w} + \Delta M_{H_k} + \Delta M_{F_K} + \Delta M_{F_L} + \Delta M_{EN} + \Delta M_K + \Delta M_{Gov} \tag{A.18}$$

$$\Delta E_{BA} = \Delta M_{BA} + \sum_n \Delta L_n + \Delta n_G^{BA} p_G + n_G^{BA} \Delta p_G + \sum_{i \neq G} p_i^{\dagger} \Delta n_i^{BA} + \sum_{i \neq G} \Delta p_i^{\dagger} n_i^{BA} - \sum_n \Delta D_n - \Delta L_{CB} \tag{A.19}$$

where $p_G^{\dagger} \, \Delta n_G^{BA}$ and $\sum_{i \neq G} p_i^{\dagger} \Delta n_i^{BA}$ represent the change in number of government bonds and stock shares owned by the banking sector, respectively. $\Delta p_G^{\dagger} \, n_G^{BA}$ and $\sum_{i \neq G} \Delta p_i^{\dagger} n_i^{BA}$ show the change in price of government bonds and stock shares owned by the banking sector.

Appendix A.2.7. Government (G)

Changes in assets:

$$\Delta M_G = T_{H_W} + T_{H_K} + T_{F_K} + T_{F_L} + T_K + T_{EN} + S_G - n_G\, c_G - G + \Delta n_G\, p_G \tag{A.20}$$

where G is the government spending, S_G represents seignorage and $\Delta n_G\, p_G$ shows the issuance of new bonds. The different tax proceedings are computed as a $\tau\%$ of the labour income, capital income and operating profits realised at the previous time step. For the sake of simplicity, we assume that the operating profits of the bank are not subject to taxation.

Changes in equity:

$$\Delta\, E_G = \Delta M_G - \Delta n_G\, p_G + n_G \Delta p_G \tag{A.21}$$

Appendix A.3. Central Bank (CB)

Changes in assets:

$$\Delta\, M_{CB} = \nu_{CB}\, L_{CB} - S_G - \Delta\, L_{CB} \tag{A.22}$$

where Seignorage S_G is set equal to the value of $\nu_{CB}\, L_{CB}$ at the previous time step.

Changes in liabilities and equity:

$$\Delta\, D_{CB} = \Delta\, M_{BA} \tag{A.23}$$

$$\Delta\, FL_{CB} = \Delta\, M_{RoW} \tag{A.24}$$

$$\Delta\, E_{CB} = \Delta\, M_{CB} + \Delta\, L_{CB} - \Delta\, D_{CB} - \Delta\, FL_{CB} \tag{A.25}$$

where FL_{CB} represent foreign liabilities.

Appendix A.3.1. Foreign Sector (RoW)

Changes in assets:

$$\Delta M_{ROW} = p_{R_c}\, q^{I_c}_{RoW} + p_R\, q^{I_p}_{RoW} - R_{H_W} - R_{H_K} - p_{F_K} q^E_{Row} - p_{F_L} q^E_{Row} - p_O q^E_{Row} - \Delta\, L_{ROW} \tag{A.26}$$

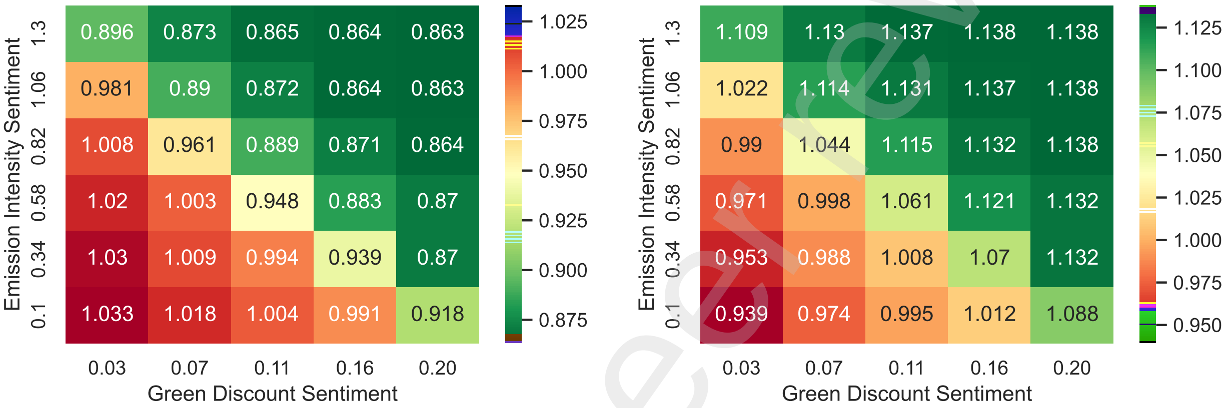
where $p_{R_c}\, q^{I_c}_{RoW}$ and $p_R\, q^{I_p}_{RoW}$ represent imports of households and firms, respectively. R_{H_W} and R_{H_K} are remittances, while $p_{F_K} q^E_{RoW}$, $p_{F_L} q^E_{Row}$ and $p_O q^E_{RoW}$ represent firms' exports.

Changes in liabilities:

$$\Delta\, E_{RoW} = \Delta\, M_{RoW} \tag{A.27}$$

Appendix B. Sensitivity analysis

To further explore different combinations of climate sentiments, we conduct a sensitivity analysis for several parametrizations of the two climate sentiments' channels combined. Figure B.17 presents the results for the GHG emissions' levels achieved and quantities of low-carbon investment as a ratio of GDP during the simulation time span[20]. Figure B.17a shows how the best results for the decarbonisation of the economy are obtained under high values of the GDS parameter, which means higher discounts for the same shares of low-carbon investment, and high GHG emissions intensity targets. On the contrary, harsher EIS targets hamper the decarbonisation achievements.



(a) Mean GHG emissions (2021-2050,% of GDP)

(b) Mean low-carbon investment (2021-2050, % of GDP)

Figure B.17: Sensitivity analysis of the effects of Green Discount Sentiment and Emission Intensity Sentiment on GHG emissions and low-carbon investment.
For both panels, each square (x, y) reports the results of running the Net Zero scenario coupled with a GDS parameter $\chi_g = x$, and EIS targeting a GHG intensity of earnings y. The values are normalised to the result obtained by running the Net Zero NGFS scenario without climate sentiments. Left panel: the heatmap reports the average value of yearly GHG emissions throughout the whole simulation period (2021-2050).
Right panel: the heatmap reports the average quantity of low-carbon investment over the whole simulation period (2021-2050).

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[20] All values are normalised to the value obtained with the NGFS scenario without climate sentiments