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Towards a 'reformist green finance' consensus for the SDGs? Analytical insight using Philia 1.0, a new ecological macroeconomic model.

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ABSTRACT

This paper aims to shed light on effects of the so-called ‘reformist green finance’ policy agenda using *Philia 1.0,* a new stock-flow consistent ecological macroeconomic model with 321 equations. The simulations suggest that a green finance policy package based on new green prudential ratios, the evolution of the role of the state as an issuer of green bonds of last resort, and a pro-social enterprise fiscal policy could effectively enhance financial stability and trigger a rapid greening of balance sheets and economic activities. However, the effect of these policies on climate ultimately depends on the robustness of the green taxonomy, as well as on the capacity of technical progress to decrease the material and energy footprint of economic activities. Moreover, this strategy would result in an increase in securities issuance and financial income, with undesirable effects on income inequality.

KEYWORDS: SDGs, Finance, Policy, Endogenous money

JEL classification: G00

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1. Introduction

Climate change poses a serious threat to economic and financial stability (Carney, 2015; Chenet et.al, 2021) and has now triggered an irreversible decline in biological well-being (Bassino et.al, 2021; Deschênes and Greenstone 2011; Barreca et al. 2015). In response to this unprecedented context, the 17 Sustainable Development Goals outline a desirable future in which the economy would be embedded within ecosystem constraints, while ensuring shared prosperity that limits inequalities in standards of living (Jackson, 2009; Raworth, 2017; Mazzucato, 2018; Clark and Munn 1986; Folke et al. 2016, Steffen et al. 2011, Leach et al. 2012, Galaz et.al, 2015; Pope Francis, 2015). While the need to change the structure, tools, and culture of the financial system to achieve the SDGs has been now accepted (HLEG, 2018), to date there is no consensus on the appropriate macroeconomic strategies and tools to be adopted. In this context, Jäger and Schmidt (2020) recently proposed a *taxonomy of green finance* to clarify the priorities of these initiatives.

For the first strand of 'neoliberal green finance', financing the 2030 Agenda amounts to materializing the SDGs in the form of monetary profits. This approach is based on the inclusion of new Environmental, Social and Governance (ESG) criteria in investment processes, collective savings products and corporate financing. Extra-financial ratings are seen as a tool with which portfolio managers, via various financial asset evaluation models, can optimize the risk-return trade-off of asset portfolios (Baker et al., 2018; Febi et al., 2018; Hachenberg & Schiereck, 2018; Bachelet et al., 2019; Gianfrate & Peri, 2019; Zerbib, 2020; Tang & Zhang, 2020; Fatica & al., 2021; Flammer, 2021). This 'neoliberal green finance' agenda is based on two presuppositions. The first is that ESG performance will allow investors to make monetary surpluses compared to the norm observed in the markets. The second is that the presence of these excess returns in the secondary market will be sufficient to redirect investments on the required scale. In other words, this approach entails "*a financialization of ESG performance: it is no longer measured for its own sake, but for what it contributes to financial performance"* (Van Weeren, 2021).

Jäger and Schmidt (2020) contrast this 'neoliberal green finance' with 'reformist' and 'transformative' green finance. For these two strands, the relevant question is not to demonstrate or ensure the correlation between extra-financial rating and the profits of the financial sector, but to contribute to identifying, at different scales, a set of levers that would allow financial structures, rules, norms, tools, and narratives to be *re-embedded* in macro-systemic ecological and social constraints. The common underlying presupposition is that "*natural resources and balances are limited and precarious, while financial and monetary resources can and should be abundant, provided that they are used in the service of the general interest*" (Institut Rousseau, 2022, p.182). Nevertheless, the theoretical framework and the economic content differ in these two approaches.

'Transformative green finance' emphasizes the social, historical and temporary nature of accounting and monetary arrangements (Chambost, Lenglet & Tadjeddine, 2019), and acknowledges the inability of this model inherited from the 20th century to cope with the new constraints of strong sustainability. It therefore proposes new accounting models (Rambaud & Richard, 2021), new macroeconomic monitoring indicators based on biomimicry (Lagoarde-Segot & Martinez, 2021), the development of complementary local currencies (Didier, 2022; Blanc et.al, 2018) or an overhaul of the mechanisms of corporate governance (Aubert & Hollandts, 2022). Overall, the proposed measures aim to "*break with the power of capital while supporting a transformation towards post-capitalist societies"* (Jäger and Schmidt, 2021).

'Green reformist finance' considers the financing of the 2030 Agenda as a problem of macroeconomic tools. Acknowledging the apparent falsification of the fundamental principles of neoclassical finance (such as the 'efficient market hypothesis', the 'loanable funds theory',

or ‘Brownian risk’), it calls for the development of macroeconomic strategies that draw on the implications of the endogeneity of money and finance for the economic cycle (Lavoie, 2014, 2020; Ehnts, 2017; Kelton, 2020; Galvin, 2020). Proposed schemes include, for example, the introduction of new prudential regulations, the alignment of fiscal and monetary policies with the *sustainable finance gap*, extensions of the mandates of Central Banks, and the scaling up of public development banks (Scialom, 2022; Dikau & Wolz, 2021; Mazzucato, 2016, 2018; Krieger and Zipperer, 2022; Chenet et.al, 2021; Lagoarde-Segot, 2020; Institut Rousseau, 2022; Couppey-Soubeyran and Delandre, 2021; Finance Watch, 2021; Climate and Company, 2022; Client Earth, 2021; Center for European Reform, 2019).
In this paper, we contribute to a better understanding of the potential effects of these different approaches on the financing of the 2030 Agenda by introducing and using *Philia 1.0,* a new stock-flow consistent ecological macroeconomic model containing 321 equations.
Philia 1.0 seeks to contribute to the development of ecological macroeconomic modeling, as initiated by the seminal work of Dafermos et.al (2018); Jackson and Victor (2015, 2020); Carnivali et.al (2021), Bovari et.al (2018) and Monasterolo & Raberto (2018). This class of model allows for the analysis of the relationships between the financial system, macroeconomic dynamics, and climate in a rigorous framework that considers the entanglement of accounting and financial balance sheets, realistic monetary and financial mechanisms, planetary limits, and feedback effects of the natural system on the economy (Daly and Farley, 2010; Hall et.al, 2018; Dron, 2015. The full interpretation of the processes driven by different economic and climate ‘shocks’ then provides, within a simplified framework, ‘analytical intuition’ about economic and social processes.
After bringing the model to a stable stationary state, and highlighting some of its properties, we perform a number of simulations to compare and contrast the effects of economic policies resulting from the recommendations of ‘reformist green finance’ with a reference scenario consistent with the assumptions of ‘neoliberal green finance’. The modeled shocks include the introduction of new macro-prudential control ratios, a green debt rediscounting mechanism by the Central Bank, the modification of public procurement rules in favor of social enterprises, and the redefinition of the role of the State as a green bond issuer of last resort. We compare the simulated trajectory of the economy and the ecosystem block with a reference scenario in which banks gradually incorporate the cost of climate destruction in their loan offer, bond markets include a ‘*greenium*’, and the Central Bank intervenes to guarantee financial stability.
Our results suggest that economic policies inspired by the ‘reformist green finance’ strand could rapidly align the structure of the physical and financial capital stock with a specified green taxonomy target. Nevertheless, the ultimate impact of these policies on climate depends on the robustness of the green taxonomy. Moreover, these policies appear to have ambiguous effects on SDG 10 (reduced inequality), as the massive issuance of financial instruments appears to increase both income and wealth inequality over time.
The remainder of this article is structured as follows. Section 2 situates *Philia 1.0* in the literature on ecological macroeconomic models. Section 3 presents the accounting architecture and the main financial and ecological economic relationships of the model[1] . Section 4 presents the simulation results and Section 5 concludes.

2. Contributions and objectives of modeling

2.1. Methodological principles

2.1.1. Stock-flow consistent modeling

[1] The accounting matrices, variables, equations, initial parameters and steady state of Philia 1.0 are described in the technical appendix of this article.

Ecological macroeconomic models are part of a broader field of research in stock-flow consistent macroeconomic modeling (SFC). This method proposes a functional alternative to neoclassical models (DSGE/CGE) by representing the economy from a monetary and financial perspective, and based on assumptions specific to the post-Keynesian school (Godley & Lavoie, 2012; Lavoie, 2014; Ponsot et.al, 2019).
Thus, in SFC models, agents do not have a 'utility function', but adopt a procedural rationality inspired by Simon (1962) and act in such a way as to eliminate observed deviations between past values and targeted values. With the exception of financial markets, economic closure is thus achieved through stock fluctuations rather than through price adjustment - the main role of prices being to allocate income between wages and profits, rather than to allocate resources.
Moreover, money creation by the banking sector and financial oscillations play an essential systemic role in these models. The real dynamics of the economy (evolution of GDP, employment, inflation...) is thus approached from a monetary perspective, i.e. as a continuous cycle of monetary creation, circulation and destruction driven by the animal spirits of entrepreneurs and banking decisions. Thus, the representation of the economic system is not based on the general equilibrium of markets, but as a double-entry accounting circuit derived from national accounting. The behavioral equations are nested in an accounting matrix, so that each model contains a redundant equation, implied by all the others and verified at each step of the simulations. Finally, the economy is driven by demand in both the short and long run, with factor endowments acting as a restoring force (via the inflation rate).

2.1.2. Macroeconomic ecological modeling

The development of ecological SFC modeling connects this literature to the principles of ecological economics. The approach taken, in line with the seminal work of Dafermos et.al (2017, 2018) generally consists in linking the economic system to an ecosystem block following Georgescu-Roegen (1972). This integrated structure then allows for the laws of thermodynamics, the carbon cycle, material and energy resource depletion, and the costs of climate change to be considered, and the evolution of the economic system and the Earth system to be modeled as an 'organic whole'.
Ecological macroeconomic modeling can thus examine the ecosystem, real and monetary dynamics generated by financial decisions, such as Treasury operations, monetary and prudential policies, the evolution of money and capital markets (primary and secondary), banking decisions, corporate governance decisions, and the risk and term structure of interest rates.
Table 2 presents the characteristics of the main founding models of the ecological SFC literature. These models differ in terms of size, representation of the ecosystem, the functioning of firms, households, the financial sector, consideration of inflationary mechanisms and the effects of openness, and methodology. *Philia 1.0.* aims to contribute to this literature, by making it possible to analyze the impact of financial policies proposed in the context of the discussions on the 2030 Agenda.

INSERT TABLE 2 HERE

2.1.3. The analytical aim of Philia 1.0

Philia 1.0 is a mind map of the economic system that allows us to obtain an analytical intuition of how it really works (Godley and Lavoie, 2012; Oreiro & Costa-Santos, 2019; Mazier, 2020). It is a manageable tool, making it easy to identify the origin and limitations of the results, and to assess their consistency with the hypotheses put forward. Its validation lies in its accounting closure, numerical properties, consistency between simulation results and hypotheses, readability of causal sequences, and their consistency with stylized facts.

The econometric revolution of Sims (1980) has indeed considerably reduced the popularity of the macro-econometric models with simultaneous equations that were dominant in the 1970s. The essence of Sims' critique is that the estimation of a large number of variables and equations prevents from capturing the full dynamic and intertemporal relationships between variables. This induces a set of statistical biases in the analysis (non-linearity, regime shifts, stationarity, cointegration, endogeneity, reverse causality...), which considerably reduce the performance and predictive power of econometric models, even in comparison with simple autoregressive models (Lutkepöhl and Krätzig, 2004, p.86). This critique has led to the development of the VAR modeling literature[2]. However, the statistical superiority of these models presupposes to discard many dynamic causal sequences in the 'black box' of lagged dependent variables, fixed effects and residuals (Lavoie, 2014).

Analytical stock-flow consistent macroeconomic models may therefore have a role to play as a preliminary step, or as a complement to econometric modeling. They contribute to our understanding of social processes by offering analytical frameworks in which the set of causal mechanisms and adjustment sequences between different variables are made explicit (Godley and Lavoie, 2012: Mazier, 2020). They render apparent a set of complex logical sequences, building from a set of explicit assumptions and structural relationships informed by stylized facts. This modeling process necessarily discards (without ignoring) certain elements of reality. The intended contribution of Philia 1.0 is therefore to serve as a "*useful fiction*" (Setterfield, 2016) or - to paraphrase Malinvaud – to be a "*discreet servant*" of the economic policy debate.

[2] As noted by Kibala-Kuma (2018, p.6) "*the VAR model has the advantage of capturing the variation of the parameters of the model over time, and thus allows for a better restitution of the dynamics of the system, which gives credibility to the economic policy (macroeconomic forecasts) that adjusts and adapts to the variations or shocks (innovations) experienced by the socio-economic environment*". Empirical applications of SFC models have been proposed by Gimet et.al (2018) and Gaysset et.al (2018), among others. Note that macro-econometric modeling is currently undergoing a certain revival - through the development of empirical SFC models based on national accounts and allowing quantified forecasts of the future state of the economy. The objective is to guide economic policy on alternative bases to the DGSE models used by Central Banks (Kinsella, 2011; Reyes-Ortiz & Mazier, 2022; Passarella, 2019).

Table 2 Comparison of recent ecological macroeconomic models

Model	Size	Ecosystem	Companies	Households	Financial sector	Inflation	International dimension	Method	Main simulations
Dafermos et. al (2018)	140 equations	Thermodynamic laws Physical flow matrix Physical flow stock matrix Feedback on capital stock and population health	Homogeneous firms Private investment limited by factor utilization rate Financing of investments: cash, bond issue, bank loans	Homogeneous households Explicit modeling of the labor market	Endogenous currency Credit rationing Dynamic portfolio choice of households Green and brown bond market Quantitative easing	No	No	Discrete time Calibration/ reference scenario for the world economy Sensitivity analysis and Monte-Carlo simulations	Impacts of climate damage on consumption, investment, demand for financial assets, potential output indicators in a reference scenario Effects of a Green Quantitative Easing program on financial stability, the bond market, household wealth, climate change
Jackson and Victor (2020)	94 equations	Environmental load indicator	Heterogeneous firms: private sector, public sector Categorization of investments: productive, non-productive, additional, non-additional, residential and productive Financing of investments: cash, share issues and bank loans	Homogeneous households Choice of homogeneous portfolio	Endogenous currency Fixed allocation of household portfolios	Linked to the tensions in the goods market	'Rest of the world' block	Discrete time Calibration (Canadian economy) Comparison with reference scenario	Evolution and decomposition of a sustainable prosperity index under three scenarios: Reference scenario, Carbon reduction scenario (higher carbon price and investment in renewable electricity) Sustainable" scenario (higher carbon price, investments in renewable electricity, lower population, shorter working

									hours, substitution of brown capital by green capital by private companies, increased social transfers)
Carnevali et.al (2021)	228 equations	Thermodynamic laws Physical flow matrix Physical flow stock matrix Feedback on capital stock and household consumption	Homogeneous firms	Heterogeneous incomes: workers and capitalists Heterogeneous portfolio selection	Endogenous currency Dynamic allocation of international household portfolios	No	Symmetric two-country model Heterogeneous productive structure: green and brown economic areas	Discrete time Calibration on World Bank data Comparison with reference scenario	Impact of four types of shocks on the economy, society, the financial system and the ecosystem: An increase in the preference for safe financial assets; An increase in the preference for green financial assets; An increase in household preference for 'green' consumer products; Changes in tax policies (coordinated and uncoordinated)
Monasterolo and Raberto (2018)	47 equations	No	Green and brown capital Financing by bank credit	Heterogeneous households Representative agent model Labor market and price/wage loop	Endogenous currency Taylor's rule Sovereigns (green and brown)	No	Import of raw materials	Calculation of four different scenarios	Four scenarios on macroeconomic variables, capital composition and external balance: Business as usual Coercive Green (private investments in green capital) Tax incentives

									Green quantitative easing
Bovari et.al (2018)	30 equations	Climate module at Nordhaus (2014)	Homogeneous Financing choices: Modigliani-Miller theorem Price-wage loop in the labor market	Homogeneous households Passive behaviur of households	Endogenous currency	Price index converges to an exogenous long-term value	No	Continuous time	Impact of different carbon price trajectories on private debt, GDP, employment rates, emissions, and global temperatures in four scenarios: Without taking into account the effects of the climate, Consideration of the effects of climate on production, Consideration of the effects of climate on production and capital stock, Same, with more convex shape of the climatic damage
Philia 1.0	321 equations	Thermodynamic laws Physical flow matrix Physical flow stock matrix Feedback on capital stock, household preferences, general price level	Heterogeneous enterprises: public sector, financial sector, social sector Financing options based on the *pecking order theory* Financing through cash, commercial	Heterogeneous incomes: workers and capitalists Heterogeneous portfolio selection	Endogenous money Rationing of bank credit/dual access to finance Green taxonomy of physical and financial assets Dynamic portfolio selection by households,	Caused by the scarcity of natural resources	No	Discrete time Initial calibration on euro zone data Stationary state	Two scenarios: 'Neoliberal green finance scenario: greenium and lending risk for brown projects 'Reformist green finance' scenario: green financial repression, government as an

			paper, bonds, shares		banks and investment funds Bond and equity markets Financialized investment funds Quantitative easing				issuer in last resort, rediscounting of green loans, and pro-social business fiscal policy Discussion of the effects of the robustness of the green taxonomy

3. Description of the model

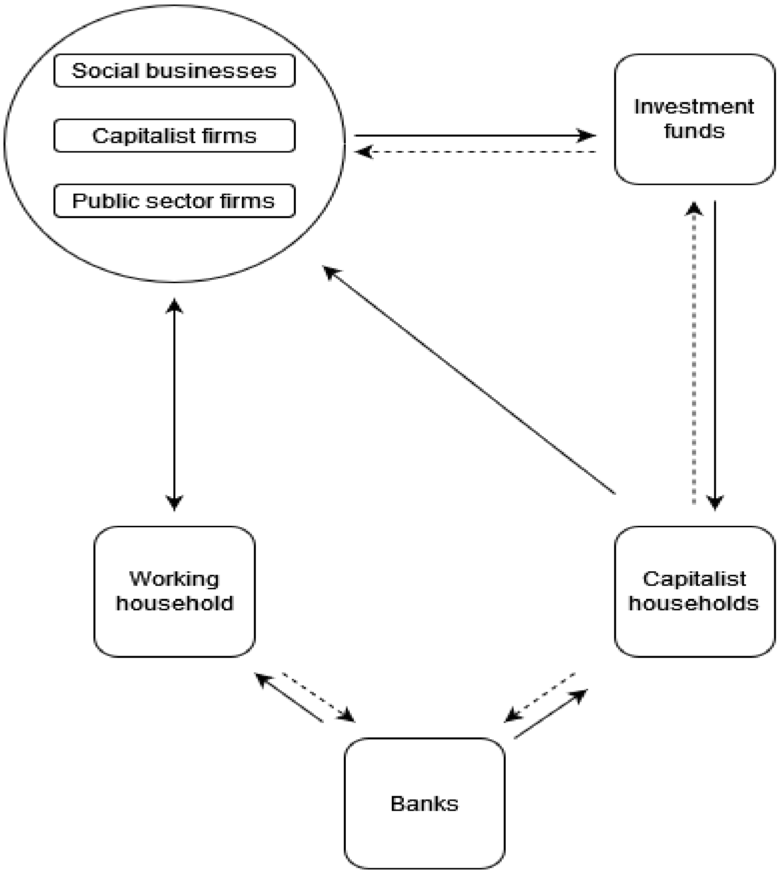
Philia 1.0 includes 321 accounting and behavioral equations, calibrated on European data. The detailed description of the accounting framework, the behavioral equations, and the steady state of the model can be found in the technical appendix. Philia 1.0 focuses on certain features of contemporary capitalism, such as the prevalence of a financialized accumulation regime (Esptein, 2000; Van der Zwan, 2014; Gimet et.al, 2019); the low inclusion of working households and social enterprises in financial markets (Chambost, Lenglet & Tadjeddine, 2019); the rise of inequalities related to wealth and the valuation of financial assets (Piketty, 215; Piketty et.al, 2019; Alstadsæter et.al, 2019); and finally the appartion of inflation caused by the scarcity of energy and material resources, as well as by extreme climate events (World Bank, 2022; Parker, 2018; Acedevo et.al, 2020).
The model includes a heterogeneous household sector (divided into 'worker' and 'capital-owner' households), a heterogeneous productive enterprise sector (divided into social enterprises, capitalist firms, and public sector enterprises). The financial sector includes a banking sector, an investment fund sector (unlisted), a central bank, and secondary markets on which investors make return expectations. Philia 1.0 also includes a 'green' taxonomy of physical capital, mirroring the taxonomy of financial instruments. These instruments include bank loans, corporate bonds, and commercial paper, equities and sovereign securities. The ecosystemic sphere of the model takes into account the laws of thermodynamics, the scarcity of material resources, the evolution of the energy mix, and is taken from Dafermos et.al (2018). The following subsections provide a graphical presentation and discussion of the principles of Philia 1.0, presenting the real sphere, the financial sphere and the ecosystem sphere. These three spheres are in constant interaction in all simulations.

3.1. The real sphere

Heterogeneous households and businesses

The real sphere of the model includes heterogeneous households and firms. Households are subdivided into worker households (whose disposable income is the sum of wages and surpluses paid out by social enterprises, net of employee contributions); and capital-owning households (whose disposable income is their financial investments, net of taxes on capital). Working households allocate their savings to bank time deposits and sight deposits.
In addition to these bank deposits, capitalist households have access to investments in investment funds. The portfolio choice of capitalist households depends on relative expected rates of return. Household consumption depends on their real and financial income and the stock of wealth inherited from the previous period. It is allocated to social, public and capitalist enterprises relative to the relative share of productive assets of each sector in the economy.
The corporate sector is subdivided into a sector of social enterprises (cooperatives with a social and ecological mission) that redistribute annual financial surpluses (net of the share of self-financing) to working households, a sector of financialized capitalist enterprises, whose equity is held by investment funds that impose an annual target for ROE, and a public sector, which is integrated into the state budget.

Figure 1 Households and businesses



Note: A solid arrow indicates an income stream. A dotted arrow indicates a purchase of financial assets.

Investment by private firms

The investment demand of private firms is modeled according to the partial accelerator principle. For both categories of firms, the target value of the capital stock depends positively on the rate of surplus (or profits) and negatively on the past debt ratio, and on heterogeneous expectations. In the case of social enterprises, public sector demand plays a dominant role in expectations. In the case of capitalist enterprises, expectations depend (negatively) on the rate of financial profitability. This reflects the cannibalization of productive investments by financial activities (such as mergers and acquisitions).

In each period, the enterprises inherit a stock of ‘green’ and ‘brown’ physical capital assets, which they depreciate according to heterogeneous principles. Social enterprises accelerate the depreciation of their stock of ‘brown’ capital, which they substitute for ‘green’ capital in proportion to the observed climate damage. Capitalist enterprises, on the other hand, depreciate ‘green’ and ‘brown’ capital according to a homogeneous rate of obsolescence.

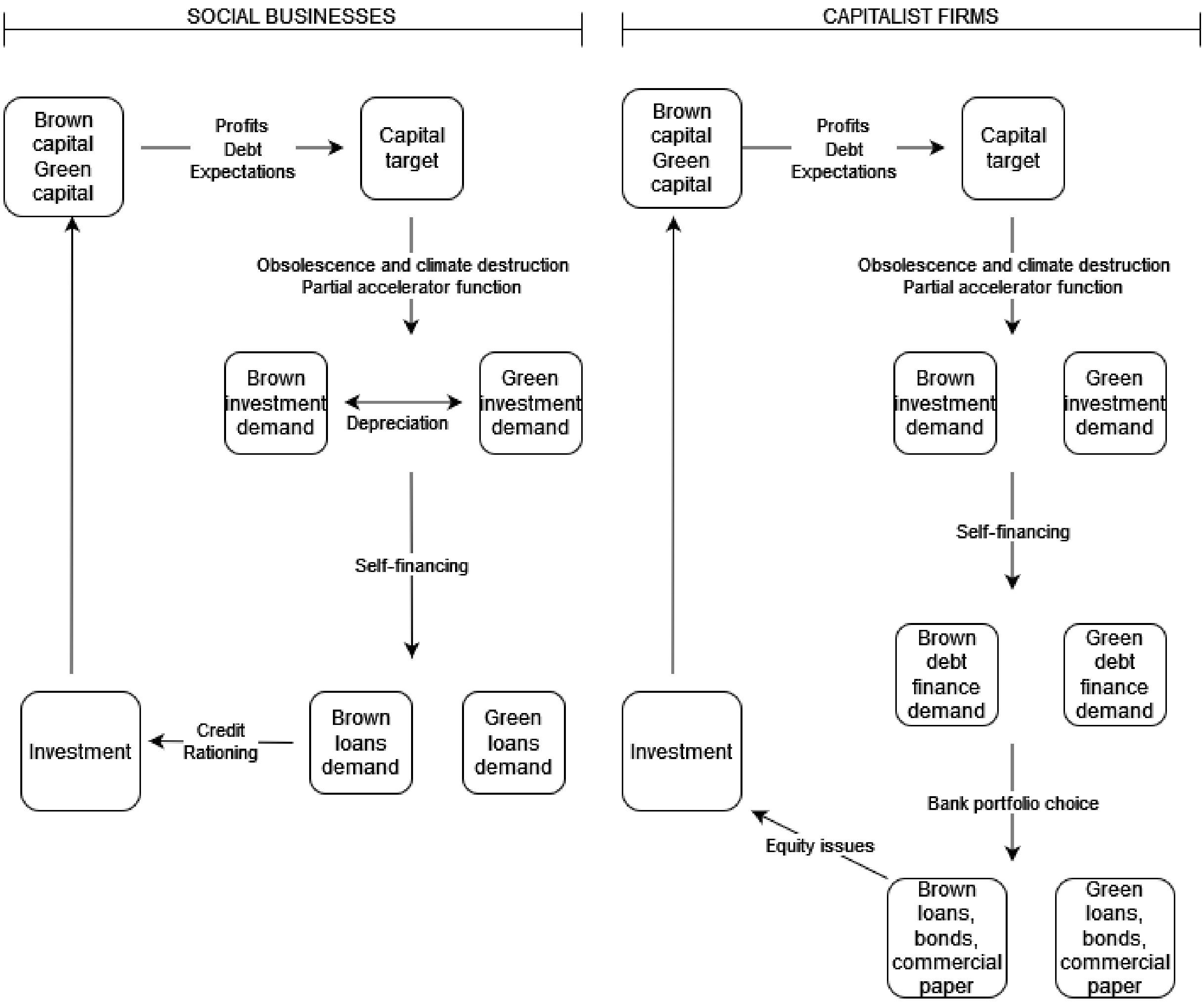
Total business investment demand is broken down into a ‘green’ and a ‘brown’ segment. The demand for ‘green’ capital assets depends on the capital depreciation terms, the climate destruction, the relative financing cost, and the technological opportunities opened by public sector firms’ investments (such as fundamental research).

The financing choice of companies

The financial structure of firms is modeled according to the pecking order theory: firms preferably draw on their retained earnings to finance their investments. They then issue a debt request to banks, which then determine the amount and structure of private debt. Finally, the issuance of new shares makes it possible to fill the gap between financing needs, self-financing and debt. Social enterprises, however, have access neither to the bond market nor to the share market, and are exposed to credit rationing if the loan offer made to them by the banks is lower than their debt demand.

The governance of capitalist companies is financialized. These companies determine the dividends paid to their shareholders by taking into account the difference between the annual capital gain and the ROE target imposed by their shareholders (investment funds). The remaining profits are then allocated to finance investments. If retained profits are insufficient to cover investment needs, these companies resort to debt finance (bank loans, the money market, the bond market) and, as a last resort, issue shares that are acquired by the investment funds on behalf of capitalist households.

Figure 2 Private sector investment decisions



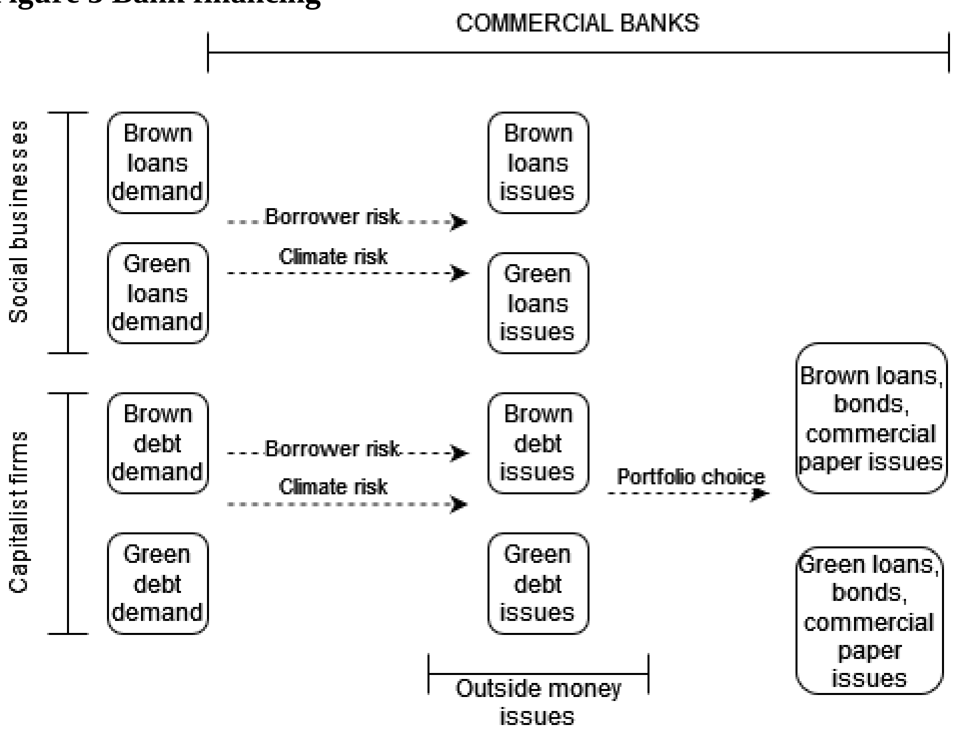
3.2. The financial sphere

The financial sphere of Philia 1.0 describes in a simplified way the relationships between the Central Bank, the Treasury, an investment fund industry, commercial banks, money and interbank markets, and a secondary market where securitized loans, bonds, commercial paper, and equities are exchanged.

Bank financing

The banking sector is modeled according to the principles of the endogenous money theory. Banks create domestic money, provide households with liquidity and deposits on demand, and have continuous access to refinancing from the central bank.
Banks receive a demand for 'green' and 'brown' financing from the corporate sector, and provide financing equal to the demand, reduced by a heterogeneous factor related to the credit risk assessment specific to each category of borrower and each category of project.
Credit risk thus depends on the rate of economic growth and the rate of refinancing with the Central Bank, and on the debt ratio observed in each sector. The 'brown' credit risk increases with climate damage. This means that banks internalize part of the contribution of their 'brown' investments to the rise in systemic climate risk.
In the case of social enterprises, bank financing takes the form of bank loans only. In the case of capitalist enterprises, the banks break down the financing granted into long-term loans, commercial paper and bonds according to the expected returns on each asset class.
The overall volume of financing granted annually by banks corresponds to the annual creation of inside credit money, held in the form of deposits by households and convertible into central bank money. The financial instruments issued in this way are traded on secondary markets. Price movements in these markets affect the total return on securities and the portfolio choices of banks and investors.

Figure 3 Bank financing



Note: A solid arrow indicates an income stream. A dotted arrow indicates a decision function.

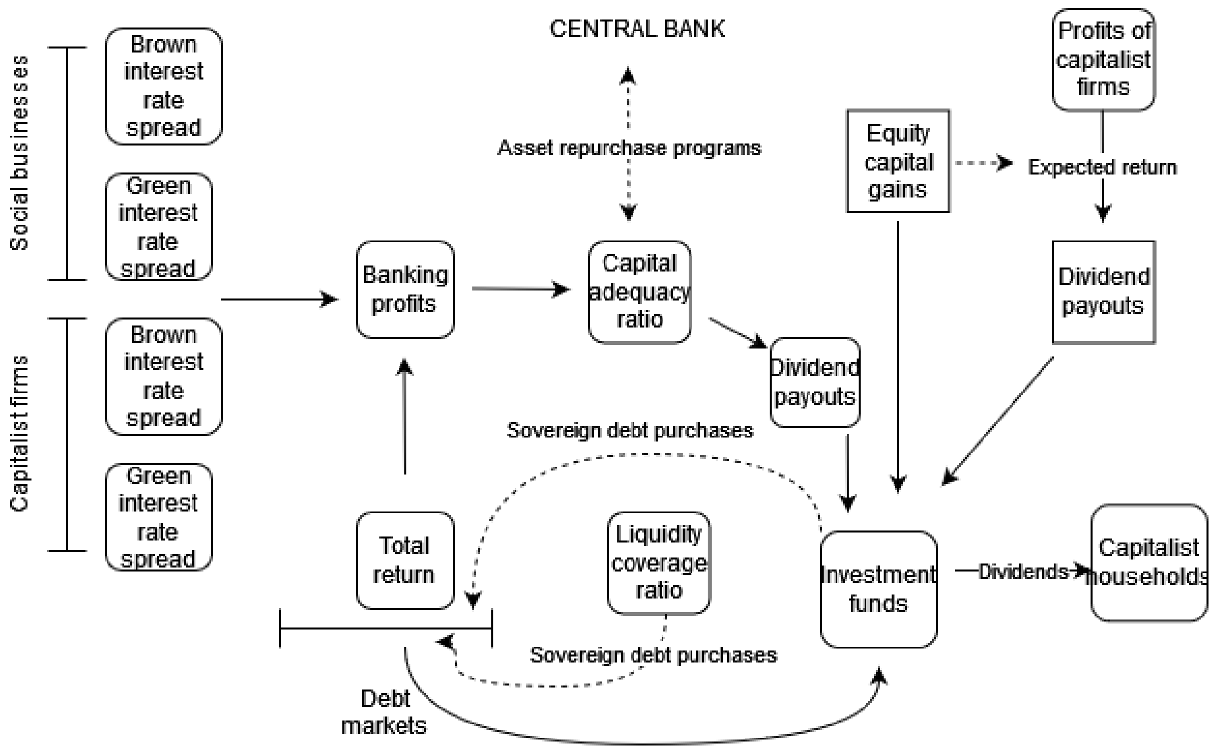
Bank governance

Banks primarily use their annual profits to shore up their capital base in order to maintain capital adequacy ratios at the regulatory target. If the ratio exceeds the regulatory target, banks distribute excess profits to their shareholders, which are the investment funds issuing shares to capitalist households. Banks also adjust their demand for sovereign securities to meet the liquidity coverage ratio target.
If banks fail to meet their prudential targets, the Central Bank intervenes by buying risky debt portfolios from the banking sector on the secondary market through asset purchase programs. In accordance with the principle of 'market neutrality' in force in the euro zone, these asset purchases reflect the green structure of the assets held by the banks. They bring the capital adequacy ratio in line with its regulatory target.

Investment funds

The investment fund industry brings together unlisted intermediaries (institutional investors, asset management companies, insurance companies). Funds issue shares in response to the portfolio demand of capitalist households. They use these savings to acquire portfolios of shares issued by capitalist companies and term bonds. They are represented on the boards of capitalist firms and set a target for total return on equity (dividend and capital gains).
Investment funds display a preference for risky assets and will dump their sovereign portfolios to acquire equity portfolios if they see profit opportunities. In addition, investment funds hold all the equity of the banking sector, which pays them its annual profits in the form of dividends. These dividends are added to the annual profits of the funds, which are then returned to capitalist households.

Figure 4 Bank governance and capital income



Note: A solid arrow indicates an income stream. A dotted arrow indicates a purchase of financial assets.

The Central Bank

The behavior of the Central Bank is motivated by a single objective: financial stability. The Central Bank guarantees the banking sector continued access to the reserves required to meet the regulatory target (expressed as a proportion of deposits), through the main refinancing operations. It also provides a deposit facility where banks can deposit their excess reserves. In addition, the Central Bank also ensures the equilibrium of the sovereign securities market, where it acts as a buyer of last resort.

Monetary policy is based on the 'floor' system used in the eurozone. This system aligns the prime rate target with the deposit facility rate, through the issuance of excess reserves in the context of asset purchase programs. The deposit facility rate is an off-market rate independent of the size of the monetary base.

The Central Bank finances the asset purchases through net issuance of reserve money. These operations increase the size of its balance sheet and the volume of excess reserves held by the banking sector and deposited at the deposit facility. These operations establish the volume of the monetary base (M0), which in no way determines the creation of bank deposits. The Central Bank's annual income statement is used to determine the value of its equity. This value is a statistical residual (BIS, 2019); the Central Bank being independent, its profits and losses are not redistributed to the Treasury.

The structure of interest rates

The model respects the risk and term structure of interest rates. The coupon rate on Treasury bonds corresponds to the deposit facility rate plus a liquidity premium that is lower than that applied to private borrowers (given the absence of solvency or liquidity risk for government borrowing in the domestic currency).

The interest rates charged to each category of private borrower (social enterprises and capitalists) depend on the prime rate, plus a specific liquidity premium, and a premium related to the green taxonomy and the maturity of the loan.

Private bonds are perpetuities that sell at par. Their coupon rate is therefore equal to the yield rate. The latter is the difference between the interest rate on the loans and the expected capital gain on the bond market. The model thus takes into account the interest rate risk: investors will ask for a higher coupon if they anticipate a price decrease, and vice versa. Finally, the structure of coupon rates incorporate a '*greenium*' observed on the green segment of the bond markets. This '*greenium*' increases with the observed climate damage.

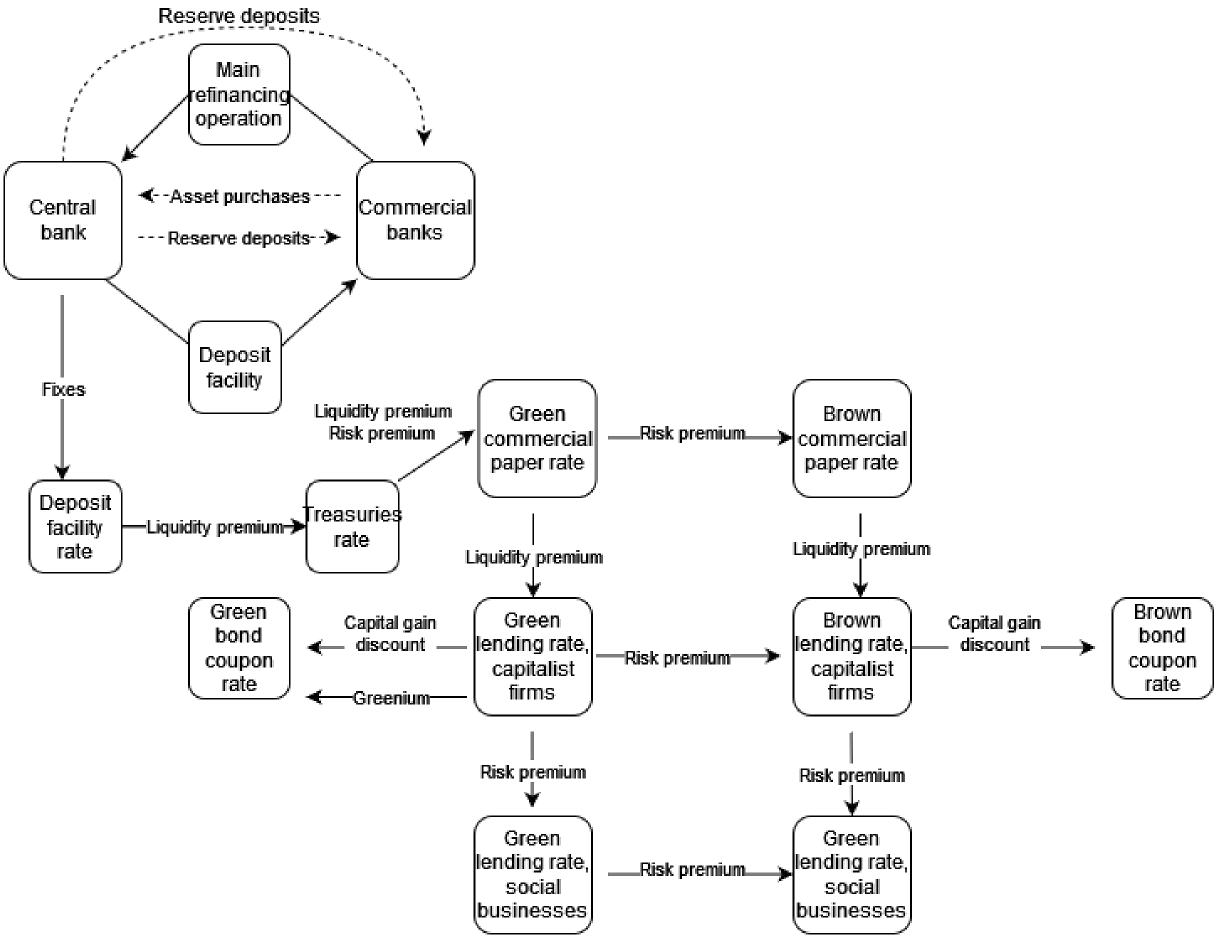
Secondary markets

Total annual return on corporate bonds, OATs, and loan portfolios is equal to the sum of the coupon rate and the capital gain made in the previous period. Total annual return on equities is defined by the standard imposed by investment funds. Financial asset prices are assumed to be stationary at equilibrium. Capital gain expectations are adaptive and depend on their value in the previous period, plus an error correction mechanism on past expectations. The actual capital gains depend on both volumes and the evolution of market prices.

Public sector and closure of the model

Public sector firms operate in a similar way to other firms. However, their capital account is integrated into the government budget constraint, and their target for 'green' and 'brown' capital stock does not depend on market factors but on public policy choices. The government budget constraint is used to calculate the annual issuance of sovereign debt. The closure of the model is ensured by checking the equality between the supply of reserve money (appearing on the Central Bank's balance sheet) and the demand for reserve money (appearing on the banking sector's balance sheet).

Figure 5 Interbank sector and term structure of interest rates



3.3. The ecological sphere

Material footprint, energy footprint, CO2 and climate

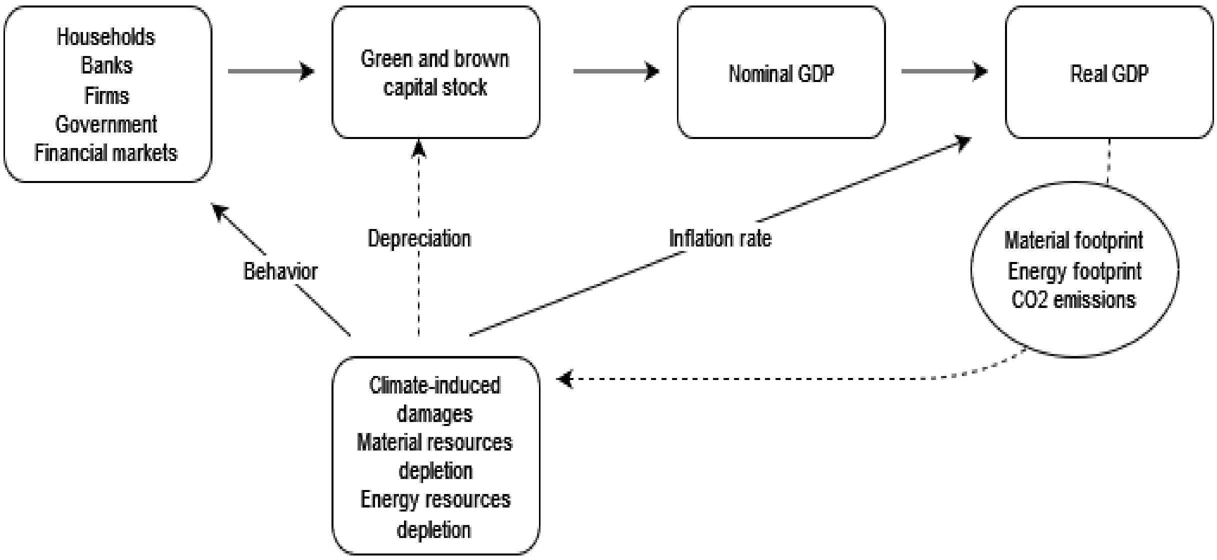
The positive impact of material production on GDP is modulated by a material intensity coefficient that decreases with the share of 'green capital' in total productive assets. The annual extraction of matter from the Earth system corresponds to the sum of material production net of the recycled socio-economic stock. This stock is expressed as a proportion of the discarded socio-economic stock due to the obsolescence of physical capital. The difference between the discarded socio-economic stock and the recycled socio-economic stock gives the annual waste emissions. Material production increases the stock of durable goods that is added to the socio-economic stock (net of the discarded stock each year).

The conversion of natural resources into material reserves and the production of material goods decreases the stock of material reserves available for production.

The energy required for production is broken down into renewable and non-renewable energy. The energy used in each period dissipates into the atmosphere according to the second law of thermodynamics. The stock of energy reserves increases with the conversion of energy resources into reserves; net of the dissipated energy. The stock of available energy resources decreases in proportion to its conversion into energy reserve. These mechanisms allow us to obtain depletion ratios of material and energy reserves measured by the ratio of material and energy extraction to their respective reserves.

Finally, annual CO2 emissions increase with industrial emissions related to the use of non-renewable energy. These emissions increase the atmospheric concentration of CO2 which, given the radiative forcing of CO2, increases atmospheric and oceanic temperature.

Figure 6 The ecosystem block and feedback effects



Note: A solid line indicates an economic relationship. A dotted line indicates a physical relationship.

Feedback effects

The depletion of material and energy resources and the evolution of the climate depend on four factors: the rate of economic growth, energy intensity, carbon intensity and the share of renewable energies in the energy mix. These variables are defined as averages of the energy (and carbon) intensity of brown capital and green capital, weighted by their respective weights in the total stock of productive capital.

In the model, climate shocks entail two types of risks: physical risks (through the destruction of the physical capital stock) and transitional risks (through changes in household behavior, the general price level and financial stability).

Extreme weather events are represented by a destruction coefficient determined by variations in atmospheric temperature. This coefficient affects the obsolescence of capital for all firms. It also contributes to modifying the inflation rate and household consumption demand, which is expressed in real terms. The multiplication of climatic events reduces the propensity to consume of households, which build up precautionary savings.

Climate disasters also increase the liquidity preference of capital-owner households. Climate damage and inflation feedback on consumption, portfolio choices, bank financing decisions, investment choices, and impacts the term structure of interest rates. All portfolio choices are based on nominal variables.

4. Simulations

We first loosely calibrate initial stock values using Eurozone level data and set all the models parameter values with reference to the literature[3]. We then solve the model using Broyden's algorithm and use numerical simulations to bring the macroeconomic system to a credible stationary steady state (described in the technical appendix). We then explore the model's response to several macroeconomic and financial shocks[4] (Reyes-Ortiz, 2020; Carnevali et.al, 2021). Then, we introduce the climate block to inspect the effect of climate shocks on the economy. Finally, we use this scenario as a baseline and change some relationships and parameters, in order to analyze the potential impact of economic policy proposals. Following Godley and Lavoie (2012) the range of the simulations reported here varies between 75 and 80 'period-years'.

In what follows, we first model a collapse of the price of 'brown' financial assets without activating the ecosystem block in order to examine the properties of the macroeconomic and financial block. Then, we introduce shocks related to the evolution of the ecosystem in a 'neoliberal green finance' and a 'reformist green finance' scenario and we draw implications from the observed causal sequences.

4.1 Effect of a collapse in the price of stranded assets

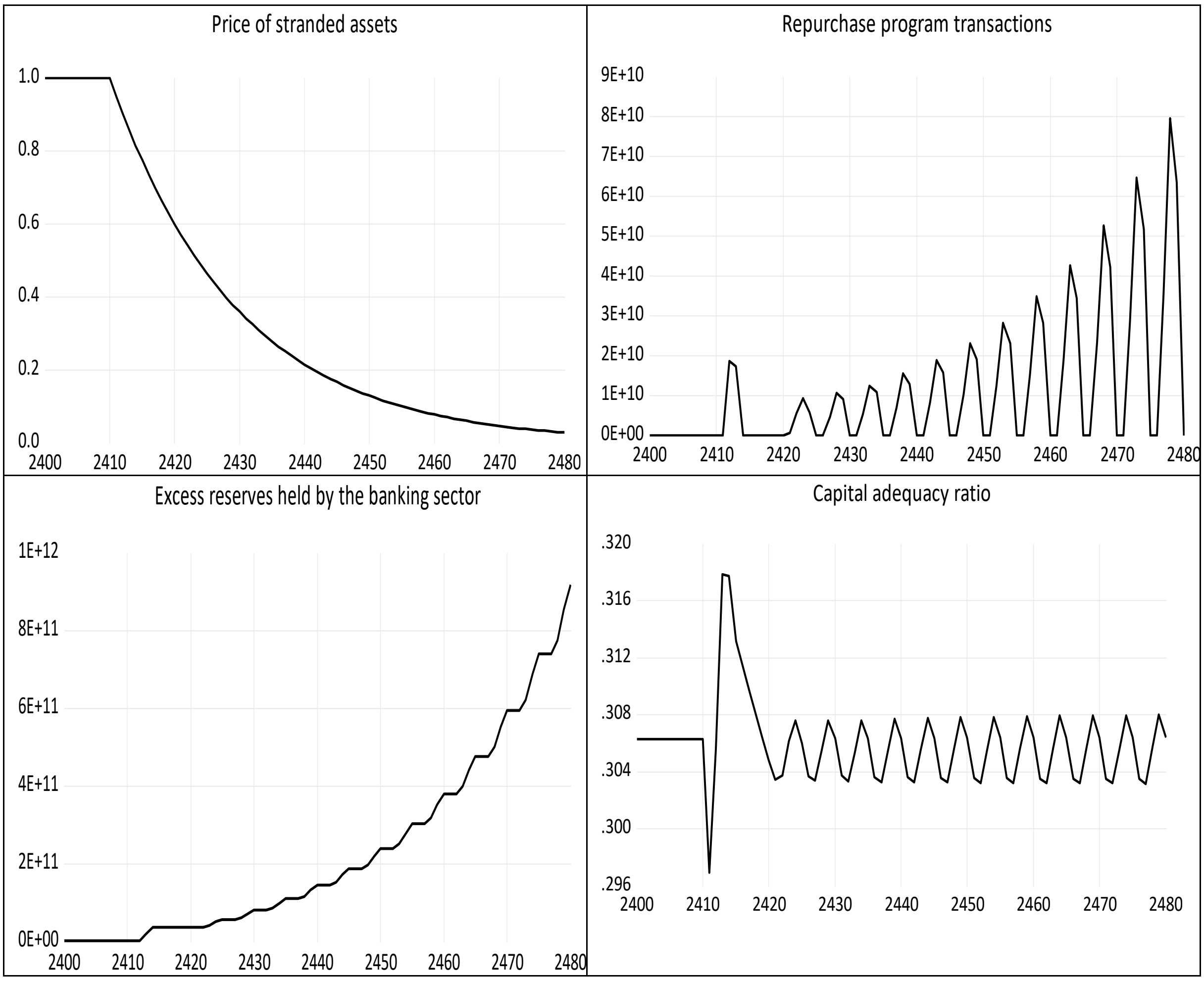
The 4th report of the Commission for the Economy and Climate (2018) estimates that $12,000 billion worth of fossil fuel-backed assets could be wiped out by 2035. The sharp depreciation of assets backed by high-carbon activities would be caused by new climate policies, technological disruption, changes in consumer behavior, or financial market expectations. Examples of affected assets include fossil fuel extraction and transportation infrastructure, as well as fossil fuel intensive activities (such as the automotive, aeronautics and plastics industries) (Scialom, 2022).

From the steady state, we introduce a shock related to the collapse of the price of commercial paper and 'brown' loan portfolios in the secondary market, from the steady state, by 10% per year, and inspect the system's response to the rise in systemic financial risk (Carney, 2015; Chenet et.al, 2021; Scialom 2022).

As shown in the northwest quadrant of figure 2, the Central Bank then immediately intervenes to maintain banking stability. Faced with a declining capital adequacy ratio, the Central Bank issues excess reserves, which it exchanges for 'stranded assets' on bank balance sheets. This increase in the size of the Central Bank's balance sheet then brings the capital adequacy ratio back to its regulatory target.

[3] Starting values and parameters are not shown for space-saving purposes but can be found in the code.
[4] This state is defined as a state where the stock and flow variables remain in a constant relationship to each other.

Figure 2 The financial crisis and the response of the Central Bank



The southwest quadrant of figure 2 shows the evolution of excess reserves held by the banking sector at the central bank (and remunerated at the deposit facility rate). Of course, these reserves can circulate between banks in the interbank market. Nevertheless, these operations leave the amount recorded on the liabilities side of the Central Bank's balance sheet (and shown in this graph) unchanged. The southeast quadrant of figure 2 shows that this operation stabilizes the capital adequacy ratio. After an initial drop, the ratio is rising again and is rapidly converging towards its regulatory target.

The response of the financial sector to this shock is therefore similar to the scenario observed during the COVID-19 pandemic, in which the interventions of the Central Banks prevented bank solvency crises. It is also consistent with the *de facto* evolution of the Central Banks' mandates over the last decade. They now adopt a financial stabilization objective that does not require any change in the prime rate - since monetary policy is based on the 'floor system' and an adjustment in the size of their balance sheet. The Central Bank is reacting to the financial crisis in the same way as the major Central Banks did during the COVID-19 crisis in 2020, similar to the asset purchase programs implemented by the ECB (such as the CSPP or the APP).

Figure 3 Effects on the financing of the economy

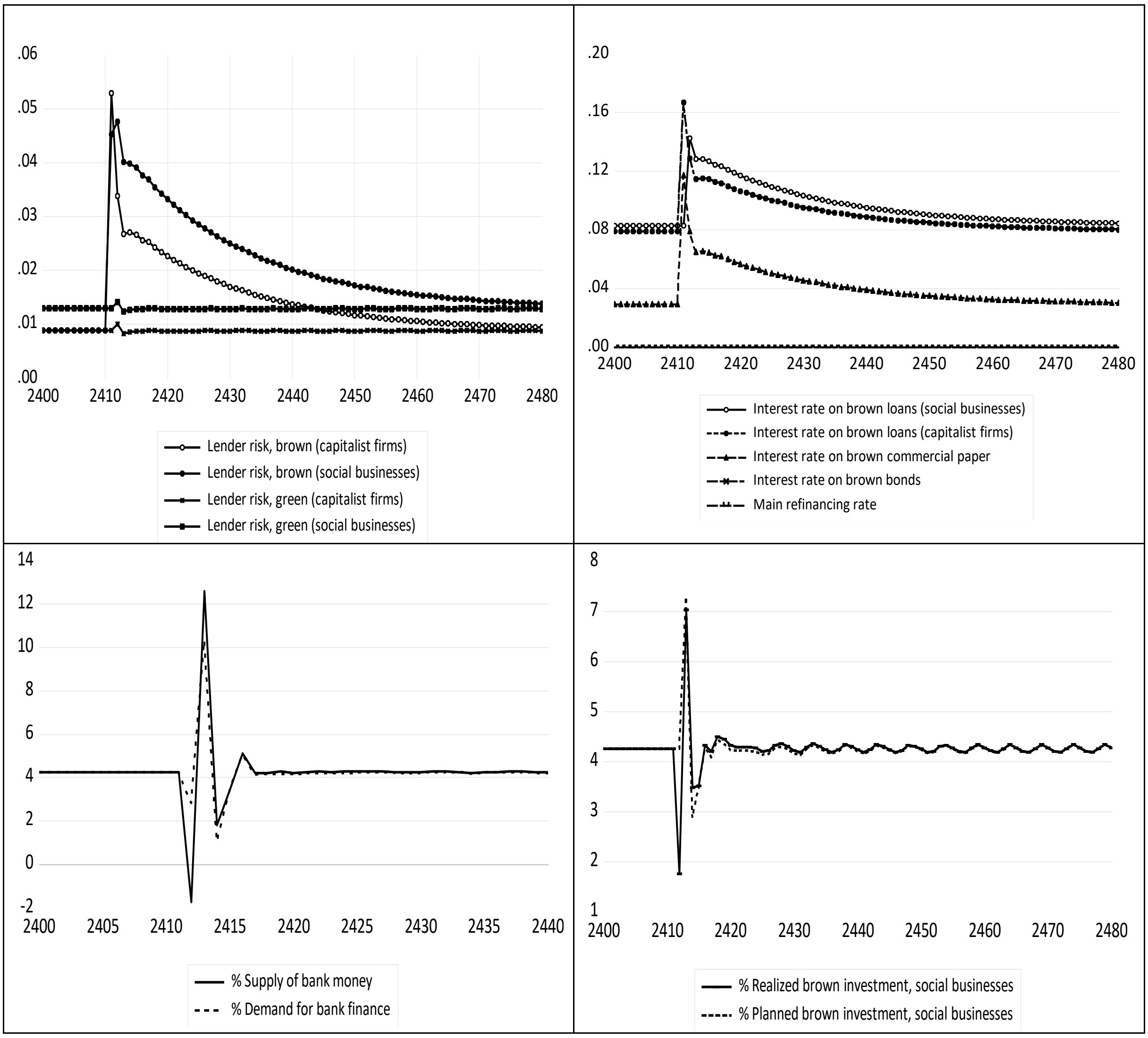


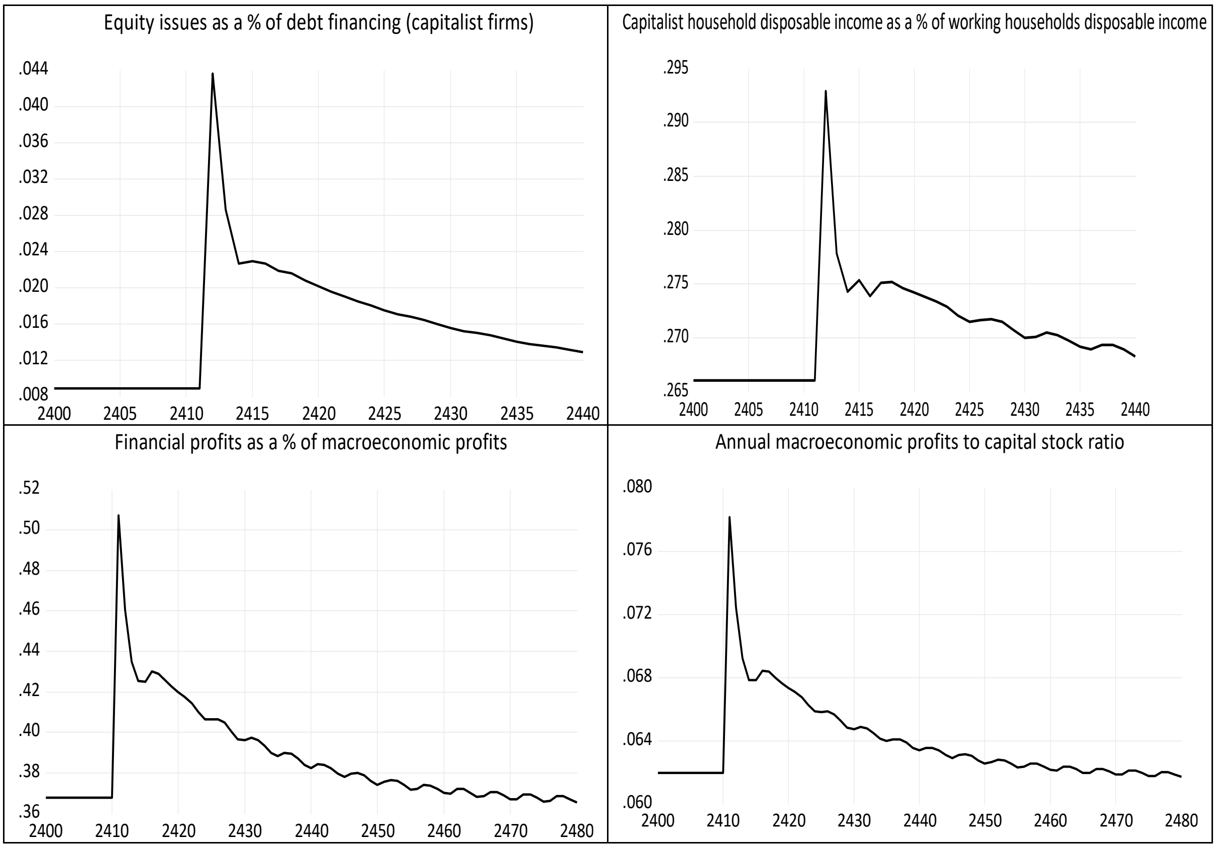
Figure 3 shows the implications of this sequence for financing conditions for real sector firms (variables are expressed as growth rates). As shown in the northwest quadrant of figure 3, banks respond to the collapse in brown asset prices by increasing the credit risk assessment for ‘brown’ investments carried by all private actors.

As shown in the northeast quarter, this increase is reflected in the maturity structure of ‘brown’ interest rates (loans, bonds and commercial paper). Green interest rates are also rising: the increase in systemic risk is causing banks to hedge against the risk of default by raising rates across the board. On the other hand, the refinancing rate set by the Central Bank remains unchanged.

The consequences for the financing of the economy can be seen at the bottom of figure 3: first, the credit money issued by banks is less than the demand for financing from the business sector (and includes loans, bonds and commercial paper) (southwest quadrant). In addition, credit rationing reduces investment by social enterprises, which have no other external financing channel (southeast quadrant). The intervention of the Central Bank, however, quickly brings financing conditions back to a level close to that observed in the stationary state.

For many authors, the stabilizing intervention of the Central Bank and the injection of liquidity in the financial markets would have led to a reinforcement of the financialization of the economy and of income inequalities (Braun, 2020; Szymborska, 2022). This is reflected in the model as follows: in the face of tightening bank credit conditions, capitalist firms apply the pecking order theory and make greater use of the equity market to finance their investments. As shown in the northwest quadrant, their financial structure thus evolves to include more equity[5] .

Figure 4 The financialized regime of accumulation



This evolution is not neutral with respect to income inequality. First, it increases inequality between working and capitalist households. Indeed, stock purchases are only accessible to capitalist households that delegate portfolio decisions to investment funds. The dividends paid therefore increase the income of these households.

Second, the share of financial profits (made by banks and investment funds that hold the shares issued by firms) in total macroeconomic profits is increasing (southwest quadrant); just as the share of total macroeconomic profits relative to the stock of physical capital is increasing (southeast quadrant). These two observations suggest that the successive interventions of central banks since the 2008 crisis have not rolled back the financialized mode of regulation, but have contributed to its durability, and even to its reinforcement.

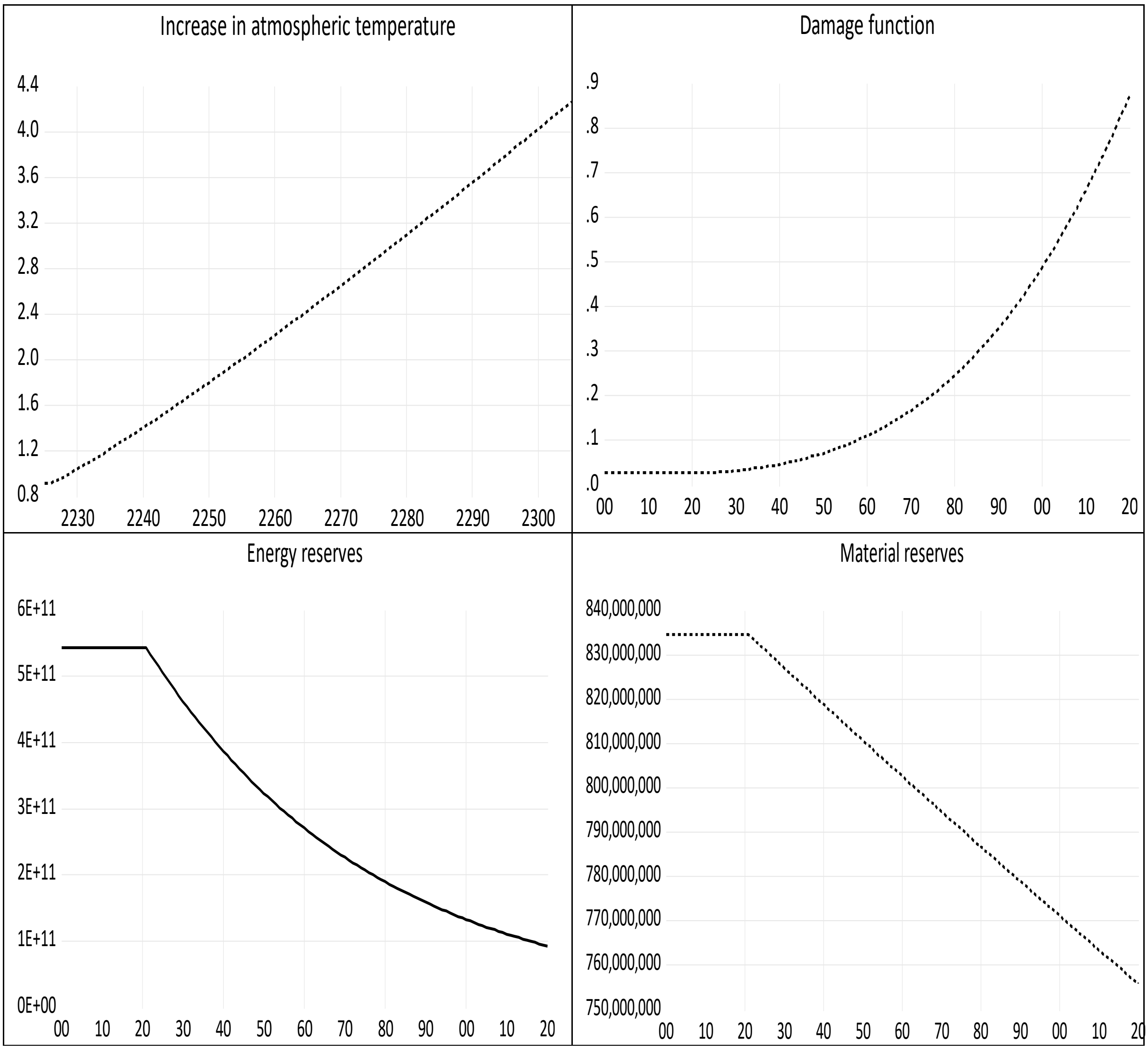
5.2.2. Ecosystem effect in the 'neoliberal green finance' scenario

We return to the initial steady state-without a financial shock-and activate the climate block of the model, in a '*neoliberal green finance*' scenario, with no change in other model parameters. As shown in Figure 5, temperature increases by about 4 degrees over 80 periods, consistent

[5] At the macroeconomic level, the possibilities of financing by issuing shares are limited by the loanable funds available to investment funds. In the model, this is the savings of capitalist households. Nevertheless, in the simulations carried out, the shares issued find takers and the primary market is in equilibrium.

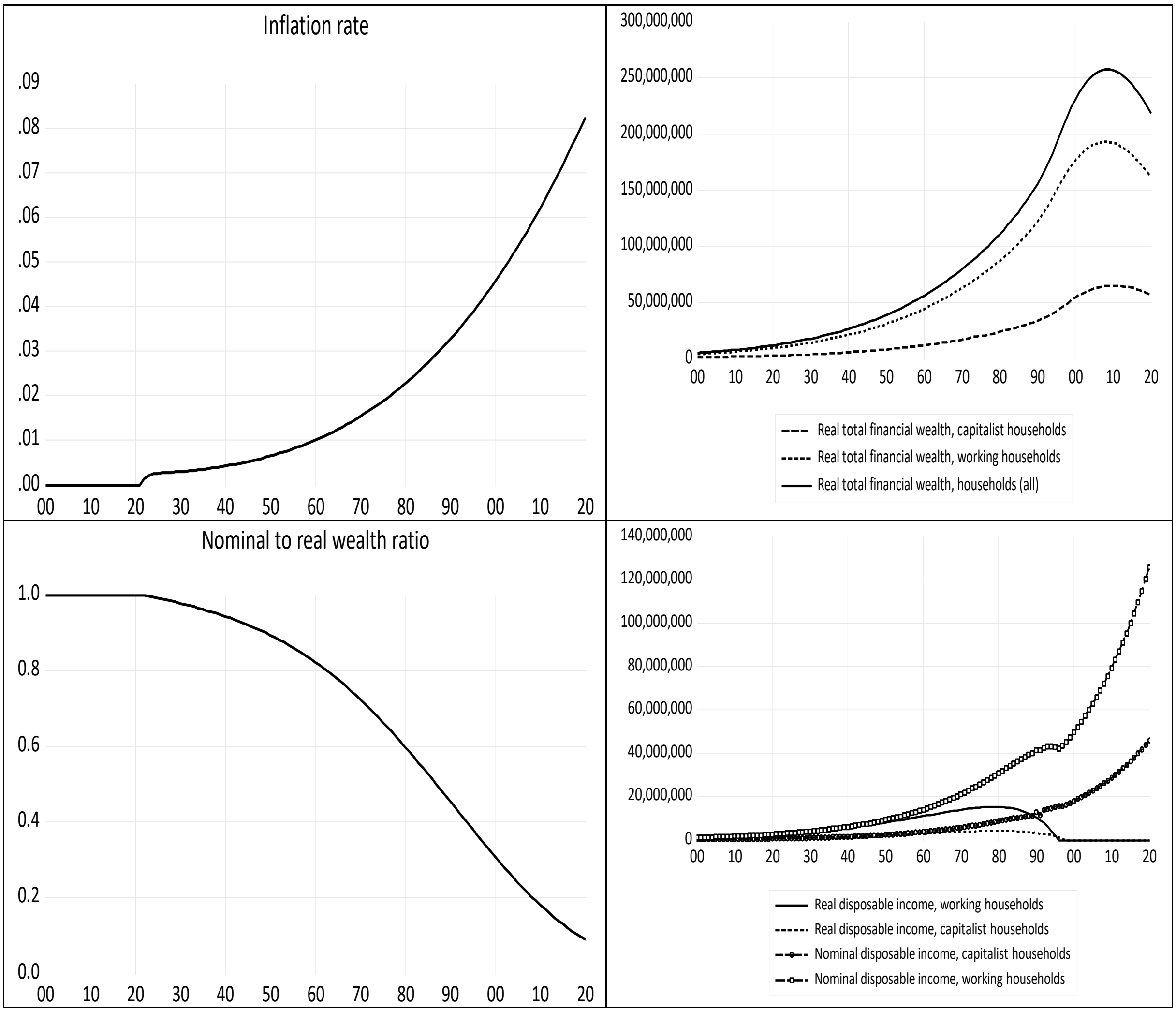
with the median ‘*shared socioeconomic pathway*’ (SSP4) scenario for terrestrial temperature (Tollefson, 2020; O'Neill et al., 2017)) (northwest quadrant). The climate damage function increases to an extreme value of 1 at the end of the simulation (northeast quadrant). Material reserves and energy reserves shrink with humanity's ecosystem footprint (GDP function) (south quadrant).

Figure 5 Ecosystem dynamics



As shown in figure 6, these shocks have an impact on the inflation rate, which increases throughout the period to reach 10% per year at the end of the simulation (northwest quadrant). Inflation affects the real value of household financial assets, which increases in trend (northeast quadrant) but more slowly than in nominal terms (southwest quadrant). Similarly, nominal incomes continue to rise, but real incomes fall after a number of periods. Energy-linked inflation is thus a binding constraint: ‘money tokens’ can grow indefinitely, but their convertibility into real resources is limited by the carrying capacity of the Earth system (Daly and Farley, 2010).

Figure 6 Climate inflation, wealth and income



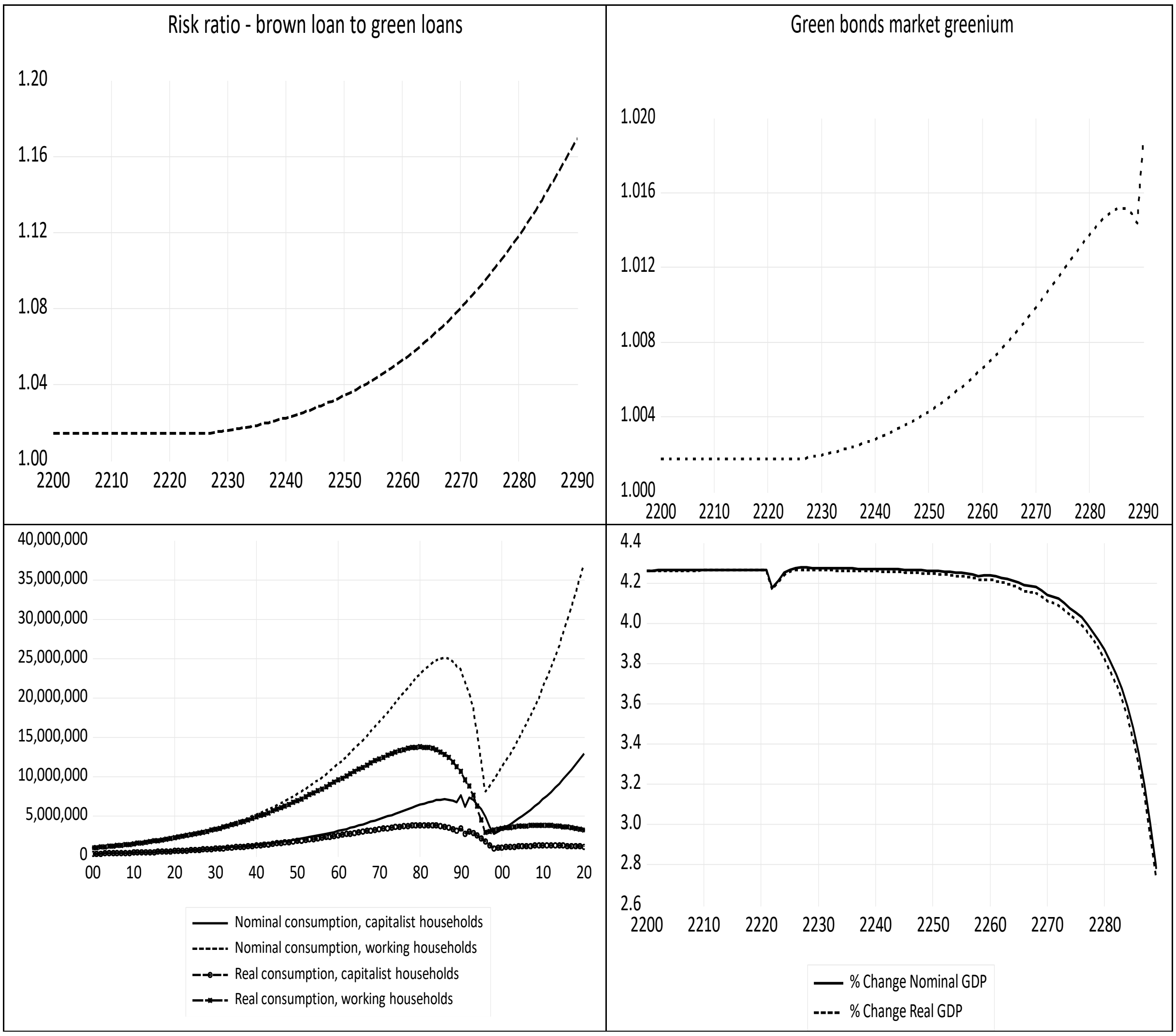
As shown in Figure 7, the market mechanisms predicted by neoclassical finance come into play: banks respond to the climate shock by incorporating climate risk into their lending decisions. Indeed, credit rationing is about 20% higher for ‘brown’ loans than for ‘green’ loans at the end of the simulation (northwest quadrant). Similarly, coupons on green bonds decrease relative to brown bonds as a result of a ‘greenium’ (northeast quadrant).

This gradual consideration of climate risk by suppliers of capital does not, on its own, generate an ecological bifurcation. The reason is that from the entrepreneur’s perspective, the change in financing conditions affects the relative nominal discount rate, but not the expected income flows associated with each category of projects (which depend on the expected demand). The impact of variations on the cost of green and brown debt on the relative value of investment project selection metrics (NPV, IRR, payout ratio) is therefore uncertain. In the real world, the impact of interest rate on the cost of capital is mitigated by possible opposite variations in the cost of equity and the capital structure (the relevant cost of capital being the WACC). Overall, a change in the relative cost of debt finance is unlikely to trigger a massive reorientation of ‘brown’ investment towards ‘green’ projects, and to induce private agents to sufficiently increase the net additional demand for green investment to tackle climate change[6].

Indeed, as shown in the southwest quadrant, in this scenario household consumption decreases in real terms, but also in nominal terms. This is explained by the fact that the propensity to consume decreases: climate risk generates income losses; households try to protect themselves by building up precautionary savings (expressed in nominal terms). As the same graph shows, consumption decreases even more in real terms as inflation increases over the period. Finally, the growth rate of nominal and real GDP falls sharply, by half.

One must remember that these results are parameter dependent and not predictive. They highlight a logical sequence of events which, if the hypotheses and structural relationships put forward have any validity, must be considered as a plausible scenario and should lead to strengthen policy decisions.

Figure 7 Macroeconomic effect of climate shocks



[6] One should acknowledge that the results reported here are contingent on the parameters chosen. As discussed in section 2, the objective of modeling is to highlight a possible logical stream of causal sequences. Similar results to those presented here are obtained using different values for the parameters related to greenium and the consideration of climate risk by banks. The simulations are available from the authors.

5.3. A ‘reformist green finance’ scenario

Much like US macroeconomic policy during World War II, many economists recommend activating extraordinary tools to face an existential peril (US Federal Reserve, 1942). A frequently proposed strategy is thus to rely on an environmental taxonomy of assets and new macroeconomic tools to channel finance to the ‘green’ sector, at the expense of the ‘brown’ sector - from which financial actors would be forced to gradually withdraw (Bezemer et.al, 2018; McCollum et.al, 2013; Lagoarde-Segot, 2020; Galvin, 2020; SDSN, 2018).
As Table 1 shows, the proposed measures include, for example, the introduction of new prudential regulations, the modification of refinancing conditions by the Central Bank, the use of the government budget to close the *sustainable finance gap* (with or without the issuance of helicopter money by the Central Bank), the modification of public procurement rules, and the adoption of an ecological tax. This reform agenda seems to be shared by a part of the academic literature (Scialom (2022); Dikau & Wolz (2021); Mazzucato (2015); Mazzucato and Semeniuc (2018); Krieger and Zipperer (2022); Chenet et.al (2021); Lagoarde-Segot (2020); Lagoarde-Segot & Dupré (2021)) and in the grey literature (Institut Rousseau, 2022; Couppey-Soubeyran and Delandre, 2021; Finance Watch, 2021; Climate and Company (2022); Client Earth (2021); Center for European Reform (2020)). It could outline the contours of a new macroeconomic climate consensus in support of the 2030 Agenda.

Table 1 Proposals of the "green finance reform" movement

Monetary and prudential policy	References	Budgetary policy	References
"Financial repression" and ecological credit policy	Lagoarde-Segot (2020); Lagoarde-Segot & Dupré (2021); Bezemer et.al (2018); Le Quang & Scialom (2021)	Stop subsidies to the brown sector/taxation of polluting activities	Climate and Company (2022); Client Earth (2021); Center for European Reform (2020); Institut Rousseau (2022)
Changes to prudential rules and refinancing conditions	Rousseau Institute (2022); Veblen Institute (2022); Reclaim Finance (2020); Finance Watch (2020); Scialom (2022); Dikau & Wolz (2021)	Direct public sector investment to close the *sustainable finance gap*	Climate and Company (2022); Rousseau Institute (2022); Mazzucato (2016, 2018)
"Helicopter money": central bank money issue for households and states targeted at the ecological transition	Institut Rousseau (2022); Institut Veblen & Finanzwende (2020), (2020); Positive Money (2020) Dufrêne, Grandjean & Giraud (2021); "manifesto of the 150 economists" (2021)	Reform of public procurement rules with green public procurement	Finance Watch (2020) Rousseau Institute (2022); Krieger and Zipperer (2022)

We analyze the extent to which such macroeconomic strategies could contribute to mitigating the effects of climate disruption. To do so, we use the ‘*neoliberal green finance’* scenario as a baseline, introduce several policy measures and inspect the trajectory of key variables.

New prudential ratios

The first shock consists of a modernization and reactivation of so-called ‘financial repression’ policies in order to meet the 2030 Agenda. We assume that to maintain their operating license, banks must maintain the share of green assets held on their balance sheet $\frac{D_{d,g}}{D_{d,b}}$ (Lagoarde-Segot (2020) and Lagoarde-Segot and Dupré (2021)) at the level of a regulatory target, set ad-hoc by the regulator (here it is set at 2)[7] . These credit control policies are used in several developing and emerging countries (Lagoarde-Segot, 2020), as part of China's green policy (Chenet et.al, 2021), and have been used in recent economic history to align investment decisions with higher national objectives (Federal Reserve, 1942).

Rediscounting of green receivables

The second shock consists of a change in the rules for refinancing the banking sector. In order to reduce the risks of toxic claims linked to the accumulation of green claims and the depreciation of brown assets, banks can directly rediscount up to 5% of green claims with the Central Bank. Rediscounting was used by the US Federal Reserve to finance the Second World War, and by the French Treasury in the immediate post-WWII aftermath, and is among the proposals of the European Green Deal platform (2019) and the Institut Rousseau (2022)[8] .

From a banking perspective, the convertibility of green claims into reserve money reduces the credit risk of ‘green loans’ to zero - regardless of the risk category of issuer (social enterprises or capitalist enterprises). This has the effect of reducing the cost of credit and the volumes of financing granted to the green sector, and of reducing credit rationing for social enterprises (which, unlike capitalist enterprises, do not have access to the financing possibilities of the equity, bond and money markets)[9] .

The state as the green bond issuer of last resort

However, there is no a *priori* guarantee that the annual flows of ‘green’ debt issued by the private sector (the demand for green debt) will be sufficient to allow the banking sector to meet the regulatory target. The government must therefore play the role of ‘green’ bond issuer of last resort to ensure financial stability.

This requires that the net public expenditure in the green sector be adjusted in order to guarantee the required liquidity on the green debt market. As the banking sector is then forced to acquire these securities through the new prudential regulations, the risk of an attack on sovereign bonds (and a surge in interest rates) is eliminated from the outset. In addition to its impact on financial stability, this fiscal rule may have an industrial benefit: giving the government the role of green bond issuer of last resort under this new prudential policy may facilitate public investments in infrastructure and fundamental research required to close the sustainable finance gap (Climate and Company (2022); Institut Rousseau (2022); Mazzucato (2016, 2018).

[7] It is possible that at the end of the year, some banks will exceed this target and others will fail to meet it. To guarantee the functioning of the system, this policy can be complemented by the opening of an interbank market for loan certificates organized by the Central Bank (as is the case in India, for example) (Lagoarde-Segot, 2020). This regulatory ratio is achieved at the level of the consolidated banking sector balance sheet.

[8] These think tanks recommend that the European Investment Bank issue long-term green bonds, which would then be bought back by the European Central Bank as part of its asset purchase program.

[9] In addition, this mechanism gives monetary policy an additional degree of freedom. Indeed, banks can obtain regulatory reserve money via rediscount operations, which reduces the need for main refinancing operations. The Central Bank could then raise these refinancing rates - for example to limit inflationary pressures, or to limit the decline in its own funds (see below) - without creating any risk for the stability of the payment system. See Lagoarde-Segot & Revelli (2022).

More favourable public procurement rules for social enterprises

Finally, in the perspective of SDGs 8, 10 and 11, many authors recommend a change in the rules of public procurement to make it more favorable to SMEs and social enterprises (Rousseau Institute, 2022; Krieger and Zipperer, 2022). We therefore assume that the external money created by these 'green emission of last resort' operations is shared evenly between social enterprises and capitalist enterprises (50% each).

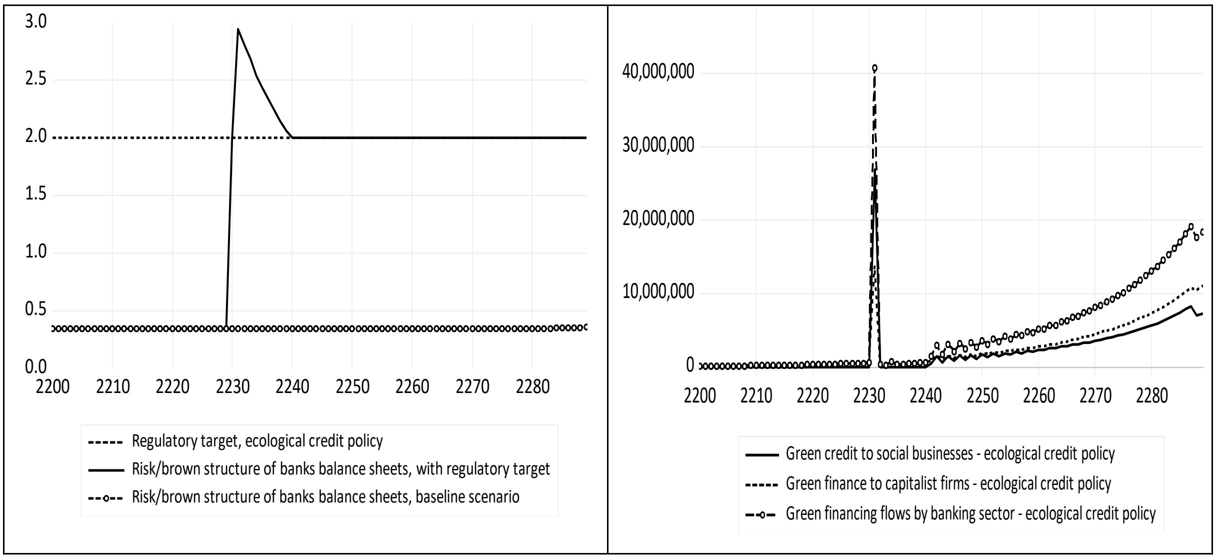
5.3.2. Simulations

Figure 8 describes the effects of these shocks on bank balance sheets and funding flows. As shown in the northwest quadrant, the structure of bank balance sheets adjusts rapidly toward the new regulatory target: banks hold twice as many 'green' assets as 'brown' assets over the course of the simulation.

This stockpiling reflects the shift in financing flows to the private sector: inspection of the northeast quadrant reveals a rapid increase in 'green' financing volumes to social enterprises (in the form of loans) and to capitalist enterprises (in the form of loans, bond purchases, and commercial paper).

Nevertheless, as shown in the southeast quadrant, demand for green debt from the private sector is insufficient for banks to meet their prudential targets. The government is therefore forced to intervene as a green bond issuer of last resort. Green sovereign issuance first increases rapidly at the beginning of the simulation in order to fill the imbalance with respect to the target; then it slows down and maintains a positive pace during the simulation. The counterpart of these issues is a continuous increase in the stock of green sovereign securities accumulated by the banks and allowing them to reach the required target. These securities are included in the liabilities of the Treasury, and their counterpart is a new asset held by the private sector. It is therefore an external money creation operation.

Figure 8 The greening of financial players' balance sheets



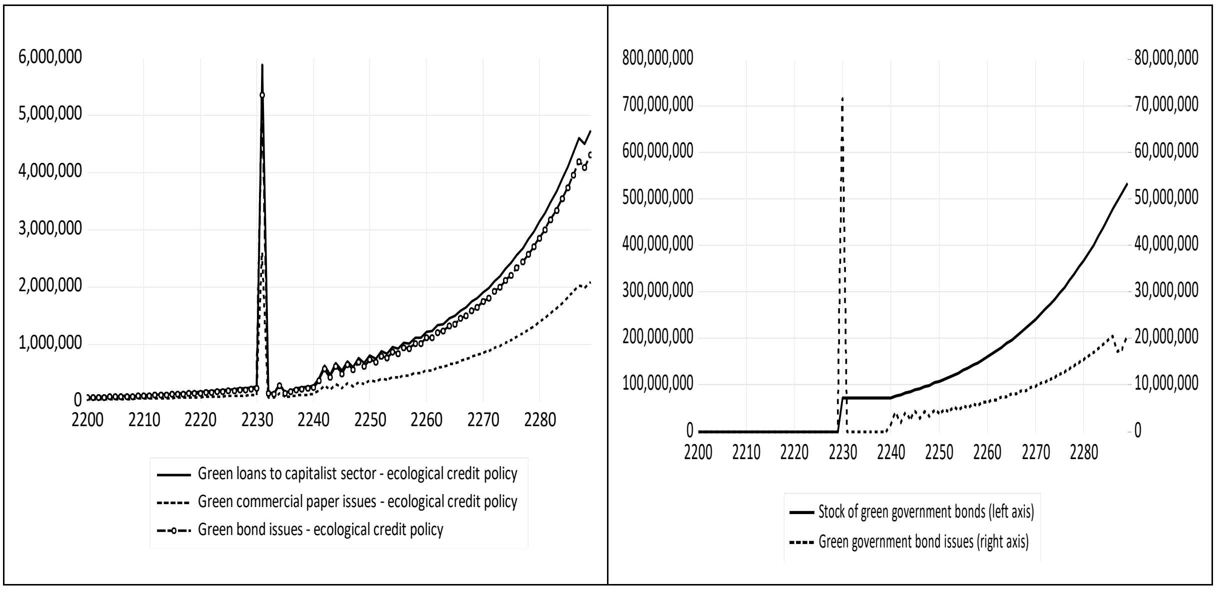
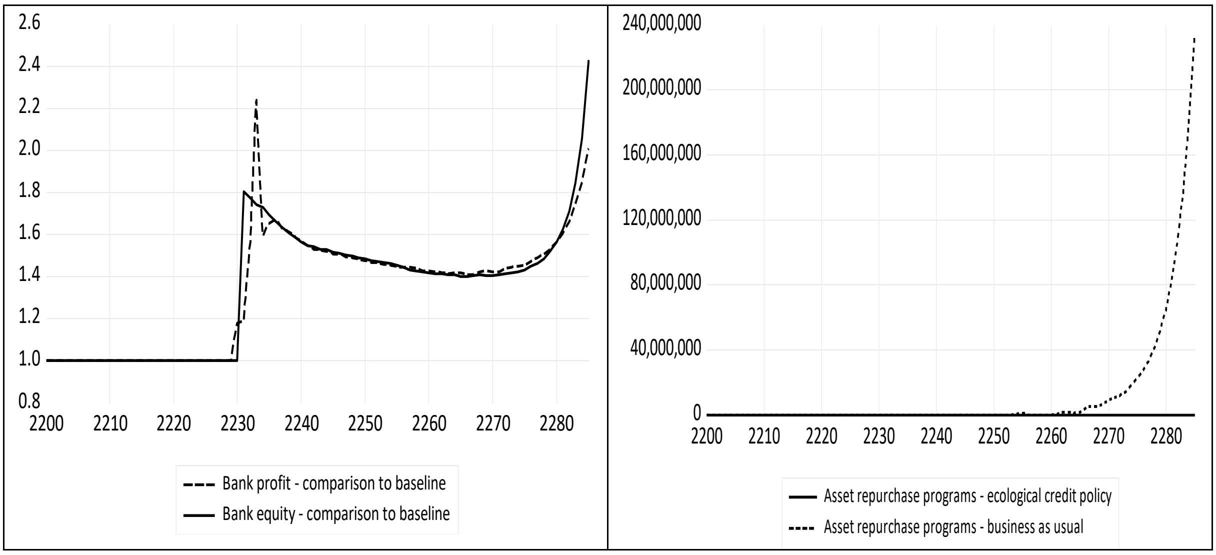


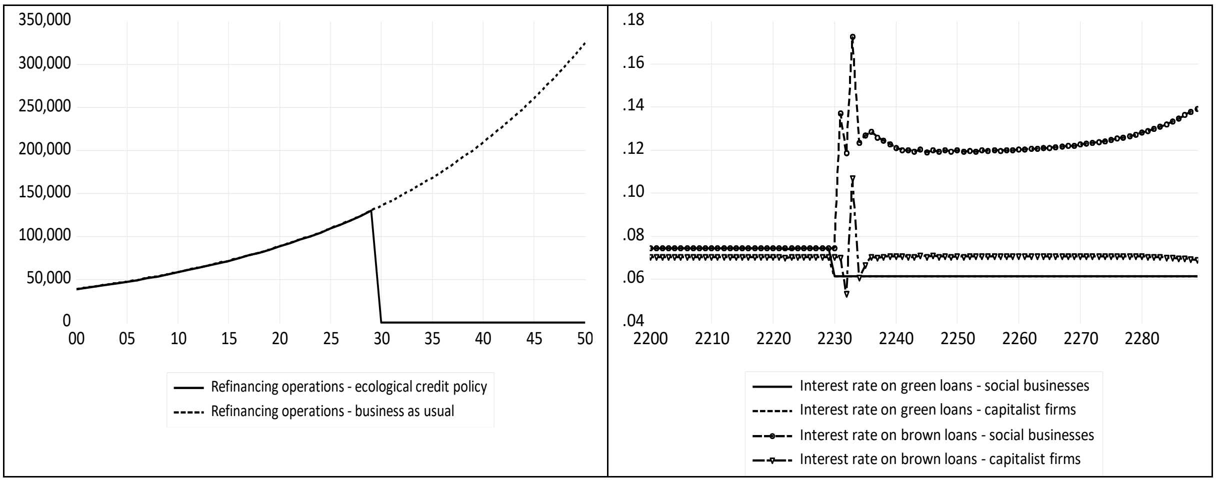
Figure 9 shows the effects of this credit policy on the banking sector, compared to the '*neoliberal green finance*' scenario.

These graphs suggest that the 'reformist green finance' agenda is beneficial to the banking sector. Indeed, the northwest quadrant shows that the accumulation of new risk-free debt by banks leads to an increase in their profits and capital. The greater liquidity of bank balance sheets makes central bank intervention unnecessary compared to the 'neo-liberal green finance' scenario (northeast quadrant).

Through the rediscounting of green loans, banks obtain sufficient reserve requirements to no longer resort to refinancing operations (southwest quadrant). This improvement in the banks' situation is accompanied by a greening of credit conditions: interest rates for 'green' projects are falling significantly under the effect of this policy, while those for 'brown' projects are rising - under the effect of the climate risk (southeast quadrant)**.**

Figure 9 Effects on the banking sector





Finally, Figure 10 describes the effects of this strategy on the real sphere and the ecosystem. The results obtained here call for moderate optimism.

Inspection of the northwest quadrant reveals that economic policy has the desired effects on the productive structure: the 'green' to brown productive capital stock ratio increases sharply relative to the 'neoliberal green finance' scenario.

Nevertheless, the northeast quadrant indicates that the ultimate impact of these policies on the climate depends on the stringency of the green taxonomy and on chosen assumptions regarding the ability of technological change to decouple GDP growth from material and energy use. As underlined in Jackson (2018), decoupling is a fundamental issue which must not be overlooked if we are to take resilience seriously, in the face of climate change[10].

This graph shows the impact of the reformist green finance scenario on temperature and climate destruction using two different taxonomies: a weak taxonomy in which material intensity, energy intensity, and carbon intensity are stable throughout the simulation; and a strong taxonomy in which these intensities decrease each year by a rate of 5% thanks to technological progress. This graph suggests that 'greening the economy's balance sheets' would only be effective the green taxonomy is sufficiently constraining (e.g., if it excludes fossil resources and allows for a major technological disruption such as the development of fusion energy[11]). The southwest quadrant complements these results by showing that the reformist green finance strategy will successfully limit inflationary pressures only if such assumptions are met.

Finally, the southeast quadrant highlights a mechanism which to the best of our knowledge has never been put forth in the 'reformist green finance' literature. In the short run, the real annual disposable income of capital-owner households increases sharply relative to that of worker households. The real financial wealth of capitalist households also increases relative to that of working households over the entire simulation. The reason is that the strategy relies on large-scale issuance of financial securities, which give rise to income payments (interest, coupons and capital gains) segmented by social category. In the model these stream of payments benefit

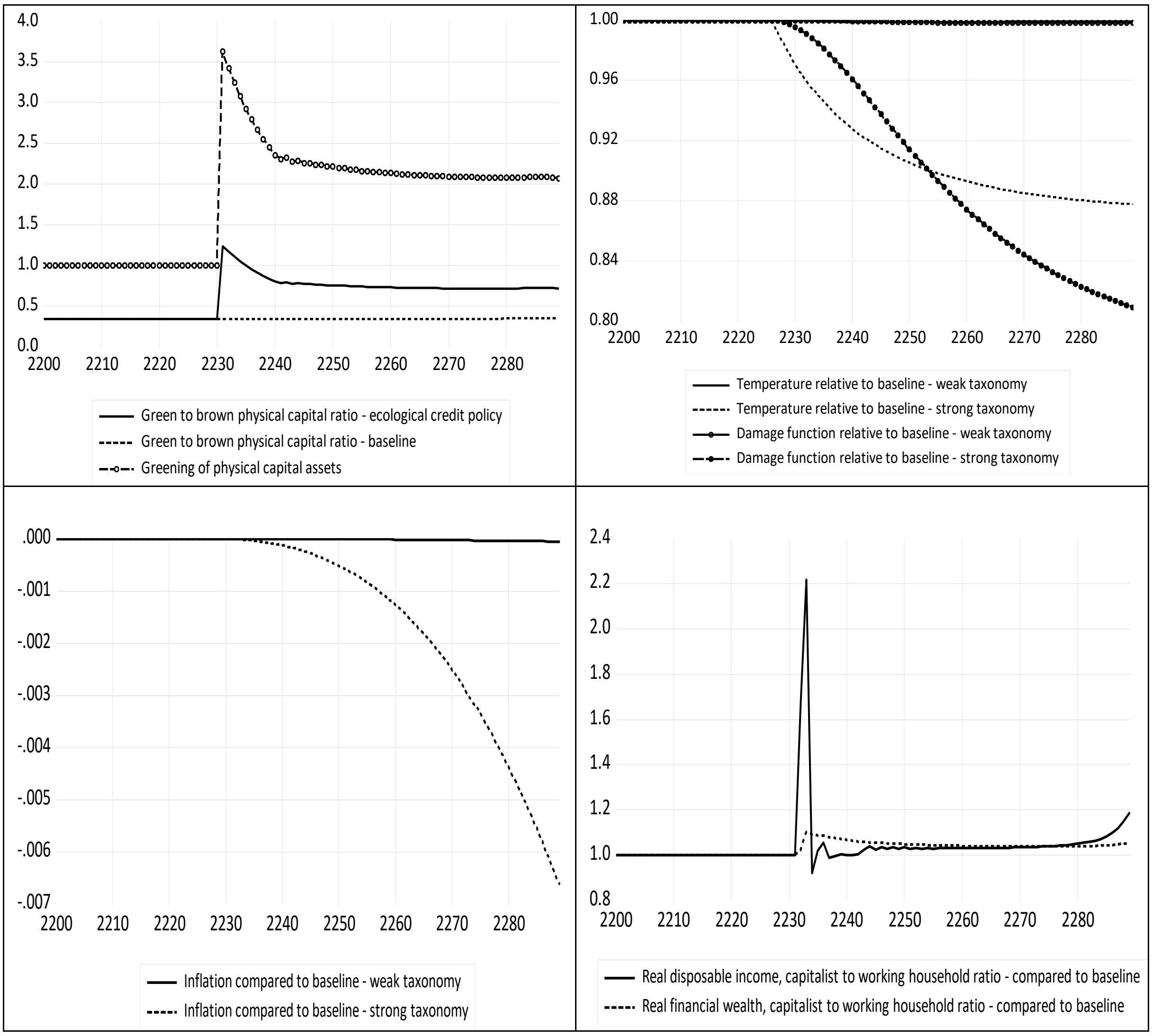
[10] "*The truth is that there is as yet no credible, socially just, ecologically-sustainable scenario of continually growing incomes for a world of nine billion people. In this context, simplistic assumptions that capitalism's propensity for efficiency will allow us to stabilise the climate or protect against resource scarcity are nothing short of delusional. Those who promote decoupling as an escape route from the dilemma of growth need to take a closer look at the historical evidence – and at the basic arithmetic of growth*" (Jackson, 2009, p. 57).

[11] See https://www.iter.org/proj/inafewlines

banks, investment fund and capital owner households. As such, it generates undesirable effects on SDG 10.

As shown in Figure 8, bank profits increasing as a result of the significant increase in ‘green’ loans and the decrease in default risk. Part of these profits are paid out as dividends to investment funds, which redistribute them to their members, which are capital owner households. Such dynamic therefore mechanically leads to an increase in income and wealth inequalities and has undesirable effects for SDG 10.

Figure 10 Effects on the productive structure and the ecosystem



6. Conclusion

The objective of this paper was to help frame the discussion on the financing of Agenda 2030 in a rigorous framework by introducing *Philia 1.0,* a new ecologically consistent stock-flow macroeconomic model. Philia 1.0 allows for the analysis of the relationships between the financial system, macroeconomic dynamics, and climate in a rigorous framework. It takes into account the entanglement of accounting and financial balance sheets, realistic monetary and financial mechanisms, the financialization regime of accumulation, stabilizing Central Bank

interventions, corporate diversity, household heterogeneity, energy and climate induced inflation, and some feedback effects of the natural system on the economy.
The comprehensive interpretation of the processes driven by different financial, economic and climate shocks has allowed us to compare and contrast the effects of the so-called 'reformist' green finance scenario, with those of a 'neoliberal green finance' scenario. Our simulations suggest that the 'reformist green finance' approach (such as the introduction of new green prudential ratios, articulated with the evolution of the role of the State as the issuer of green bonds of last resort) is superior to the 'neoliberal green finance' approach when it comes to greening financial and real sector balance sheets at the required pace, and maintaining financial stability.
Nevertheless, our results also indicate that the effect of such policies on climate ultimately depends on the robustness of the green taxonomy, and on the (uncertain) capacity of technical breakthrough to decouple economic growth from planetary material and energy limits. In addition, the reformist green finance strategy relies on significant issues of financial instruments. Access to capital income being segmented in the population, this is likely to induce an additional increase in income and wealth inequalities to the detriment of SDG 10.
More theoretical and applied research is needed, both to refine our understanding of the causal mechanisms presented here, and to shed light on the possible effects of alternative proposals, such as those put forth by the 'transformative green finance' strand of research. Developing a more complex version of the model - including agent-based microeconomic foundations - could also help gain richer insight on the potential effects of the various policies under scrutiny. The model could also be extended to focus on the effects of economic and financial integration, geopolitical shocks, and endogenized financial shocks. Finally, such modeling efforts will have to be undertaken in concertation with a wide variety of stakeholders in order to facilitate exchange of knowledge and ideas, and to contribute to the strengthening of economic policy in the face of current challenges.

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TECHNICAL APPENDIX (for online publication only)

1. The matrix structure

We use the following writing conventions. In the real sector, a transaction flow variable is denoted by a capital letter. In the financial sector, a lower-case letter denotes a flow variable, and an upper-case letter denotes a stock variable. For each variable included in the financial balance sheet and transaction matrices, the first subscript takes the values *s* or *d* and indicates whether the variable is a supply or demand variable. Except for real stocks of assets, all flow and stock variables have this index. The second subscript makes it possible, when necessary, to identify the sector to which the variable belongs: the household sector (h), worker households (w), capital-owning households (r), social and cooperative enterprises (c), capitalist enterprises (k), the banking sector (b), investment funds (i), the central bank (cb), or the public sector (g). The third subscript appears if a green (g) or brown (b) taxonomy applies to the variable. A subscript (-1) indicates that it is a lagged variable.

The macroeconomic balance sheet matrix consists of 72 variables, 47 of which are reported in Table A1, and 24 of which are aggregate variables that allow for more detailed monitoring of the financial structure of different institutional sectors. In order not to make Table 3 too long, the construction of the aggregate variables is described in the section presenting the accounting and behavioral equations of the model.

Table A1 represents the accounting framework of the model. For each asset appearing on the balance sheet of an institutional sector, there is a corresponding liability on the balance sheet of another sector. The fact that the debt incurred by firms has an ‘s’ (for ‘supply’) subscript may seem counterintuitive, but it can be explained as follows. Bank financing of the economy is modeled according to endogenous money theory. Firms determine a demand for financing (which carries an index ‘d’). The banking sector then evaluates this demand on the basis of various criteria specific to the macroeconomic situation, the borrower's profile, and the green taxonomy, and determines its financing offer. This financing offer (bearing the ‘s’ index) includes loans, bonds and commercial paper. The ‘s’ index appearing on the borrowers' balance sheet reflects that this ‘internal money’ created by the banking sector is always present on the liability side of the borrower’s balance sheet. These debt securities circulate on the secondary market, and are recorded as financial assets by the banks and the Central Bank, which adjust their holding targets according to portfolio selection criteria. This is why these stocks of assets on the banks' balance sheets are marked with a ‘d’ (demand) index. The volumes held by the Central Bank under quantitative easing do not carry a ‘d’ index so as not to burden the rating. These volumes nevertheless respond to a demand for Central Bank securities, since the transactions undertaken under *quantitative easing* are always at the initiative of the Central Bank. These different mechanisms are described by the model's equations.

The models developed by Godley and Lavoie (2012) are based on ‘fair value’ accounting. This approach means that the recorded value of financial liabilities is aligned with the fluctuations of the secondary market. While this makes it possible to maintain accounting consistency, it

does not correspond to the usual principles of accounting for loans (as acknowledged by Godley and Lavoie (2012)[12]) .
One contribution of Philia 1.0 to the SFC literature is to represent asset and liability volumes using 'historical cost' accounting principles. This approach is also more compatible with the consideration of natural capital in ecological accountingg (Richard and Rambaud, 2021). Of the financial liabilities reported in Table A1, only equity $p_e E_d = p_e E_s$ are therefore measured at market value. The dynamics of the stock market affect the balance sheets of the firms and investment funds that hold the shares (as well as the returns).
The effects of the revaluation of debt securities in secondary markets are incorporated into the behavioral matrix of transaction flows (table A2). For example, if a corporate bond with a face value of 100 euros and a coupon rate of 10% is valued at 110 euros, the debt on the borrower's balance sheet (100 euros) remains unchanged, but the bondholder makes a capital gain (10 euros). This is why the sum of the rows in Table A2 does not always equal zero. The difference between the interest or coupon payments by the debtor and the total return earned by the creditor is the capital gain, which is recorded in the last column.
This principle applies to all debt instruments in the model (securitized loan portfolios, corporate bonds, and term bonds). In addition to its impact on transactions, revaluation also affects various income streams, bank balance sheets, prudential ratios, and central bank monetary policy decisions.

[12] *"For instance, a $100 bond issued by a corporation of a government may see its price rise temporarily to $120. With balance sheets evaluated at market prices, the bond will be entered as a $120 claim in the balance sheets of both the holder and the issuer of the bond, although the corporation or the government still look upon the bond as a $100 liability" (Godley and Lavoie 2012, pp.28-29)*

Table A1. Financial Balance Sheet Matrix

	Working households	*Capitalist households*	*Social enterprises*	*Capitalist enterprises*	*Banking sector*	*Investment funds*	*Central Bank*	*State*	$\sum$
Deposits	$+M_{d,w}$	$+M_{d,r}$			$-M_{s,h}$				*0*
Brown" loans			$-L_{s,c,b}$	$-L_{s,k,b}$	$L_{d,c,b} + L_{d,k,b}$		$QE_{l,c,b} + QE_{l,c,g}$		*0*
Green loans			$-L_{s,c,g}$	$-L_{s,k,g}$	$L_{d,c,g} + L_{d,k,g}$		$QE_{l,k,b} + QE_{l,k,g}$		
Brown" Bonds				$-B_{s,b}$	$+B_{d,b}$		$QE_{b,b}$		*0*
Green Bonds				$-B_{s,g}$	$+B_{d,g}$		$QE_{b,g}$		
Brown" commercial paper				$-CP_{s,b}$	$+CP_{d,b}$		$QE_{cp,b}$		*0*
Brown" commercial paper				$-CP_{s,g}$	$+CP_{d,g}$		$QE_{cp,g}$		
Corporate Actions				$-p_e E_s$		$+p_e E_d$			*0*
Government Bonds					$+GB_{d,b}$	$+GB_{d,s}$	QE_{gb}	$-GB_s$	
Investment fund units		$+S_{d,r}$				$-S_i$			*0*
Bank's equity					$-BE$	$+BE$			*0*
Refinancing					$-A_{d,b}$		$A_{s,b}$		
Monetary basis	$+H_{d,w}$	$+H_{d,r}$			$H_{d,b} + H_{ex}$		$-H_s$		*0*
Balance	$-V_w$	$-V_r$		*0*	*0*	*0*	$-K_{cb}$	$-V_g$	
$\sum$	*0*	*0*		*0*	*0*	*0*	*0*	*0*	*0*

Table A2 Transaction Behavioral Matrix

		Households	Productive enterprises		Banks		Investment funds		Central Bank		State	∑
			Current account	Account of capital	Current account	Capital Account	Current account	Capital Account	Current account	Capital Account		
Consumption		$-(C_w + C_r)$	$(C_s + C_k + C_g)$									0
Public expenditure			+G								-G	0
Fixed investment			$(I_s + I_k + I_g)$	$-(I_s + I_k + I_g)$								0
Taxes		$-(T_w + T_r)$									+T	0
Salaries		$WB_s + WB_g + WB_k$	$-(WB_s + WB_k + WB_g)$									0
Bank profits					$-P_b$		$+P_b$					0
Profits and surplus		$P_i + (1 - ret)P_c$	$-(P_c + P_k + P_g)$	$PU_k + ret\, P_c$			$+r_e\, E_s$	$-P_i$			P_g	$\Delta p_e E_{s,-1}$
Interest on	Refinancing				$-i_e A_{d,b,-1}$				$+i_e A_{s,b-1}$			0
	Deposits	$+i_d (M_{d,h,-1})$			$-i_d M_{s,h,-1}$							0
	Brown loans		$-(i_{l,c,b} L_{s,c,b,-1} + i_{l,k,b} L_{s,k,b,-1})$		$-(i_{l,c,b} L_{d,c,b,-1} + i_{l,k,g} L_{d,k,g,-1})$				$-(i_{l,c,b} QE_{s,c,b,-1} + i_{l,k,b} QE_{s,k,b,-1})$			0
	Green loans		$-(i_{l,c,g} L_{s,c,g,-1} + i_{l,k,g} L_{s,k,g,-1})$		$-(+i_{l,c,g} L_{d,c,g,-1} + i_{l,k,g} L_{d,k,g,-1})$				$-(i_{l,c,g} QE_{s,c,g,-1} + i_{l,k,g} QE_{s,k,g,-1})$			0
	Brown Bonds		$+i_{b,b} B_{s,b,-1}$		$+r_{b,b} B_{d,b,-1}$				$+r_{b,b} QE_{b,b,-1}$			$\Delta p_{b,b} B_{s,b,-1}$
	Green Bonds		$+i_{b,g} B_{s,g,-1}$		$+r_{b,g} B_{d,g,-1}$				$+r_{b,g} QE_{b,g,-1}$			$\Delta p_{b,g} B_{s,g,-1}$
	Brown commercial paper		$+i_{cp,b} CP_{s,b,-1}$		$+i_{cp,b} CP_{d,b,-1}$				$+i_{cp,b} QE_{cp,b,-1}$			0
	Green commercial paper		$+i_{cp,g} CP_{s,g,-1}$		$+i_{cp,g} CP_{d,g,-1}$				$+i_{cp,g} QE_{cp,g,-1}$			0
	Government Bonds				$+r_{gb} GB_{d,b,-1}$		$r_{gb} GB_{d,s,-1}$		$+r_{gb} QE_{gb,-1}$		$-i_g GB_{s,-1}$	$\Delta p_{gb} GB_{s,-1}$
Financing flows	Deposits	$-\Delta M_{d,h}$				$+\Delta M_{s,h}$						0
	Loans			$(l_{s,c,b} + l_{s,c,g} + l_{s,k,b} + l_{s,k,g})$		$-(l_{s,c,b} + l_{s,c,g} + l_{s,k,b} + l_{s,k,g})$						0
	Commercial paper			$(cp_{s,b} + cp_{s,g})$		$-(cp_{d,b} + cp_{d,g})$				$-(qe_{cp,b} + qe_{cp,g})$		0
	Bonds			$(b_{s,b} + b_{s,g}$		$-(b_{s,b} + b_{s,g})$				$-(qe_{b,b} + qe_{b,g})$		0
	Internal currency creation (memo)					$\boldsymbol{m_b}$						
	Issuance of corporate shares			$+e_s$				$-e_d$				0
	Issuance of investment fund units	$-s_{d,r}$						s_i				0
	Government Bonds					$-gb_{d,b}$		$-gb_{d,s}$		$-qe_{d,gb}$	$+gb_s$	0
	Reserve currency					$+\Delta H_d$				$-\Delta H_s$		
∑	0	0	0	0	0	0	0	0	0	0	0	0

Note: A (+) sign indicates a source of funds, a (-) sign indicates a use of funds. A capital letter indicates a stock of financial assets or a transaction in the real sector. A lower case letter indicates a flow of funds.

The inclusion of a matrix of fund flows reflecting the laws of thermodynamics, the carbon cycle, and the depletion of material and energy resources permits to embed the economy in the natural system. Table A3 describes the physical flow matrix of the model. This is based on a simplified version of the one developed model of Dafermos et.al (2018). The first column presents the material balance of the economy in gigatons (Gt). This column indicates that the total material inputs to the socioeconomic system in a year (material extracted Mmass of carbon from non-renewable energy CEN and oxygen 02 included in emissions are equal to the total material outputs in the same year (which include industrial CO2 emissions $EMIS$ and waste W), plus the change in the socio-economic stock ΔSES. The second column presents the energy balance of the economy in Exajoules (EJ). The total annual energy inputs into the socio-economic system include renewable RE and non-renewable NRE. They are necessarily equal to the total energy output (DE) in the same year.

Table A3 Material and energy balance

	Material reserves (Gt)	Energy reserves (Ej)
Inputs		
Material extraction	$+M$	
Renewable energy		$+RE$
Non-renewable energy	$+CEN$	$+NRE$
Oxygen used in combustion	$+02$	
Outputs		
Industrial CO2 emissions	$-EMIS$	
Waste	$-W$	
Dissipated energy (entropy)		$-ED$
Variation of the socio-economic stock	$-\Delta$SES	
Total	0	0

Note: Additions are indicated by a (+) sign. Reductions are indicated by a (-) sign.

Table A4 contains the physical stocks and flows matrix of the economy. This matrix describes the evolution of the stock of physical reserves REV_M, non-renewable energy reserves REV_E, atmospheric CO2 concentration, and the socio-economic stock SES. It introduces a distinction between material and energy resources and reserves, which are the stock of material and energy that can be consumed immediately in economic production. The first line of the matrix presents the stocks of the previous year. The last row shows the stocks observed at the end of the year following the additions and deletions caused by production. This material and energy balance constraint allows to align the model with the laws of thermodynamics. It ensures that energy and matter cannot be created or destroyed when they are transformed during economic processes (first law). In this matrix, the use of energy also leads to a dissipation of energy in the form of heat (law of entropy).

Table A4 Stocks and physical flows matrix

	Material reserves	Non-renewable energy reserves	Atmospheric concentration of C02	Socio-economic stock
Initial stock	REV_{M-1}	REV_{E-1}	$C02at_{-1}$	SES_{-1}
Conversion of resources to reserves	$+CON_M$	$+CON_E$		
CO2 emissions			$+EMIS$	
Production of material goods				$+YM$
Extraction/use of material and energy	$-M$	$-NRE$		
Net transfer to the oceans and biosphere			$+(\phi_{11} - 1)C02at_{-1} + \phi_{21}CO2up_{-1}$	
Destruction of the socio-economic stock				$-DIS$
Final stock	REV_M	REV_E	$C02at$	SES

Note: Additions are indicated by a (+) sign. Reductions are indicated by a (-) sign.

2. The equations of the model

We use the following writing conventions. In the real sector, a transaction flow variable is denoted by a capital letter. In the financial sector, a lower-case letter denotes a flow variable, and an upper-case letter denotes a stock variable. In addition, some variables have subscripts. The first subscript takes the values *s* or *d* and indicates whether the variable is a supply or demand variable. Except for real asset stocks, all flow and stock variables have this subscript. The second index allows us, when necessary, to identify the sector to which the variable belongs: the household sector (h), worker households (w), capital-owner households (r), social and cooperative enterprises (c), capitalist enterprises (k), the banking sector (b), investment funds (i), the central bank (cb), or the public sector (g). The third index appears if a green (g) or brown (b) taxonomy applies to the variable. A subscript (-1) indicates that it is a lagged variable. A variable is preceded by the sign Δ is taken as first difference. Finally, Greek letters are used to represent the parameters of the model. The list of parameter value is taken from literature and can be found in the model code.

2.1. Macroeconomic income

Nominal GDP (Y) is the sum of expenditures on goods and services, including consumption C, investment I and government spending G (equation 1). In addition, we follow Carnevali et.al (2021) and include two categories of households: capital-owner households and worker households. Investments come from all three sectors (the public sector, the capitalist enterprise sector and the social enterprise sector). Macroeconomic consumption is the sum of the consumption of each category of households:

$$Y = C + I + G \quad (1.1)$$
$$I = I_k + I_c + I_p \quad (1.2)$$
$$C = C_w + C_r \quad (1.3)$$

Annual inflation is driven by inflation expectations indexed to the last observed rate, and by natural causes related to natural disasters and the scarcity of material and energy resources (equation 1.4). The inflation rate gives the general price level (equation 1.5) and real GDP (equation 1.6)

$$\pi = o_1\pi_{-1} + o_2(dep_{l-1} + dep_{m-1} + d_{t-1}) \tag{1.4}$$
$$p = p_{-1}(1+\pi) \tag{1.5}$$
$$\hat{Y} = \widehat{Y_{-1}} + \frac{(Y - Y_{-1})}{(1+\pi)} \tag{1.6}$$

The model includes two categories of households: capital-owners and workers, who are differentiated by the nature of the income they receive, and by the financial investments they make.
The nominal disposable income of working households YD_w is equal to the sum of wages paid by firms $YD_w$the redistributed surplus of third sector firms P_s (net of the share devoted to self-financingret_s) and the interest on their bank deposits $i_d M_{w-1}$. The income of capital-owner households YD_r is equal to the sum of the profits of investment funds P_i, capital gains on their investment fund shares ΔS, interest on their bank deposits $i_r M_{r-1}$. The model has two income tax brackets θ_w and θ_r (for capital and labor income).

$$YD_w = \left[WB_s + WB_g + WB_k + (1 - ret_c)P_c + i_d M_{d,w-1}\right](1 - \theta_w) \tag{2.1}$$
$$YD_r = \left(P_i + i_d M_{d,r-1}\right)(1 - \theta_r) \tag{2.2}$$

Real disposable income for both categories of households takes into account the effects of inflation on income and financial wealth (Godley & Lavoie, 2012) :

$$\widehat{YD}_w = \frac{YD_w}{p} - \pi V_{w-1} \tag{2.3}$$
$$\widehat{YD}_r = \frac{YD_r}{p} - \pi V_{r-1} \tag{2.4}$$

In each production firm sector $i = (s, g, k)$ salaries paid are a fixed proportion ι of turnover so that $WB_i = \iota C_i$. Finally, tax revenues are given by the following equation:

$$T_w = \theta_w\left[WB_s + WB_g + WB_k + (1 - ret_c)P_c + i_d M_{d,w-1}\right] \tag{3.1}$$
$$T_r = \theta_r\left[\left(P_i + i_d M_{d,r-1}\right)\right] \tag{3.2}$$
$$T = T_w + T_r \tag{3.3}$$

2.2. Households

Household consumption

For each household category, real consumption is determined by an incompressible threshold (α_0), disposable income (by a factor α_1) and total financial wealth (by a factor α_2). Climate damage decreases the propensity to consume of households, that build up precautionary savings (Godley and Lavoie, 2012; Dafermos et.al, 2018; Carnevali et.al, 2021). Nominal consumption is equal to real consumption, multiplied by the price index.

$$\widehat{C_w} = \alpha_0 + \alpha_{1w}\left(\widehat{YD_w}\right) + \alpha_{2w}(\widehat{V_{w-1}}\,) \tag{4.1}$$
$$\widehat{C_r} = \alpha_0 + \alpha_{1r}\left(\widehat{YD_r}\right) + \alpha_{2r}(\widehat{V_{r-1}}\,) \tag{4.2}$$
$$\alpha_{2w,r} = \frac{\alpha_{2w,r}}{(1 - \vartheta d_{t-1})} \tag{4.3}$$
$$C_w = p\widehat{C_w} \tag{4.4}$$
$$C_r = p\widehat{C_r} \tag{4.5}$$

Equations (5.1) to (5.4) describe the stock of physical capital and annual depreciation allowances. Equations (5.5) to (5.7) describe the distribution of household consumption in the capitalist sector, the public sector and the social economy sector. The share of household consumption allocated to each sector is fixed: the economy is thus characterized by an oligopolistic market structure (De Loecker et al., 2020).

$$K = K_k + K_c + K_p \tag{5.1}$$
$$DA = DA_k + DA_c + DA_p \tag{5.2}$$
$$K_b = K_{k,b} + K_{c,b} + K_{p,b} \tag{5.3}$$
$$K_g = K - K_b \tag{5.4}$$
$$C_c = \alpha_{1,c} C \tag{5.5}$$
$$C_k = \alpha_{2,k} C \tag{5.6}$$
$$C_p = C - C_c - C_k \tag{5.7}$$

Each year, the share of unspent household disposable income is added to the nominal financial savings of each household category. Real financial savings are obtained by dividing nominal savings by the macroeconomic price index.

$$V = V_w + V_r \tag{6.1}$$
$$\hat{V} = \frac{V}{p} \tag{6.2}$$
$$V_w = V_{w-1} + (YD_w - C_w\,) \tag{6.3}$$
$$\widehat{V_w} = \frac{V_w}{p} \tag{6.4}$$
$$V_r = V_{r-1} + (YD_r - C_r\,) \tag{6.5}$$
$$\widehat{V_r} = \frac{V_r}{p} \tag{6.6}$$

Households' portfolio choice

The demand for and supply of financial assets are modeled using the principles proposed by Godley and Lavoie (2012) and the literature on consistent stock-flow models (Le Héron and Mouakil, 2008). The allocation of financial wealth between financial assets and a current account (or cash) depends on the liquidity preference of households. This initial allocation is then modulated by expected returns on different financial asset classes, according to parameters that respect the usual constraints of symmetry, horizontality and verticality (Godley and Lavoie, 2012).

Nevertheless, working and capital-owner households have different investment opportunities. Working households hold their wealth in the form of term and current accounts. Given the level of liquidity preference, working households will want to hold a given proportion of their income in deposits κ_{w1} and another $(1-\kappa_{w1})$ in the form of cash. As equation (9) shows, this proportion is modulated by two elements: the interest paid by banks on deposits i_{d-1} and the demand for money for transaction purposes, which increases with disposable income $(\frac{YD_h}{V_w})$. The demand for demand deposits (cash) is obtained by accounting equality (equation 7.2).

$$\frac{M_{d,w}}{V_{w-1}} = \kappa_{10} + \kappa_{11} i_{d-1} + \kappa_{12} \frac{YD_w}{V_{w-1}} \tag{7.1}$$

$$H_{d,w} = V_w - M_{d,w} \tag{7.2}$$

In equation (7.1) $\kappa_{12} = -(\kappa_{11})$.

Capital-owner households hold bank deposits, cash, and mandate investment funds to make investments in financial markets. This is a notable difference from existing models (Dafermos et.al; 2018, Carnevali et.al, 2020) where households make their investment decisions directly.
The proportion of capitalist households' financial wealth held in each asset is modulated by changes in deposit interest rates i_d, their expectations of returns r_S^e for their investments in funds, and the level of disposable income relative to wealth $\frac{YD_r}{V_r}$. The liquidity preference of capitalist households increases with climate damage; which leads them to want to hold more bank deposits and less risky securities regardless of the returns observed in the markets as in Dafermos et.al (2018). This is illustrated by a portfolio choice matrix equation (8.1):

$$\begin{pmatrix} M_{d,r} \\ S_{d,r} \\ H_{d,r} \end{pmatrix} = \begin{pmatrix} \gamma_{10} \\ \gamma_{20} \\ \gamma_{30} \end{pmatrix} V_{r-1} + \begin{pmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & -\gamma_{24} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} \end{pmatrix} \begin{pmatrix} i_d \\ r_i^e \\ 0 \\ d_{t-1} \end{pmatrix} V_{r-1} + \begin{pmatrix} \gamma_{15} \\ \gamma_{25} \\ \gamma_{35} \end{pmatrix} YD_r \tag{8.1}$$

The first three columns of the parameter matrix respect the two *vertical* constraints ($\sum_{i=1}^{I} \gamma_{i0} = 1$; $\sum_{i=1}^{I} \gamma_{ij} = 0$); as well as the usual *symmetry* constraints (Godley and Lavoie, 2012) : $\gamma_{ij} = \gamma_{ji}$; $\forall i \neq j$. We add two additional constraints to reflect the impact of climate damage on asset allocation. In the presence of climate damage will be reluctant to shift their wealth to riskier assets following the release of financial information. This is reflected by the constraint $\gamma_{24} = -(\gamma_{14} + \gamma_{34})$. On the other hand, climate damage increases the initial level of liquidity preference in proportion to a parameter Ω : $\gamma_{10} = \gamma_{10,-1}\big(1 + \Omega(d_{t-1)}\big)$. The last equation is replaced by an accounting identity to avoid over-identification:

$$H_{d,r} = V_r - M_{d,r} - S_{d,r} \tag{8.2}$$

At the aggregate level, household financial assets held in sigh and current accounts are obtained via the usual accounting identities:

$$M_{d,h} = M_{d,w} + M_{d,r} \tag{9.1}$$
$$H_{d,h} = V - M_{d,h} - S_{d,r} \tag{9.2}$$

2.3. Firm investment

2.3.1. Social enterprises

In the real economy, many social enterprises are cooperatives that do not make a profit. Their operating surpluses are instead considered financial surpluses that are fully redistributed to the employed members, in proportion to their contribution to the enterprise's activities. Cooperatives do not raise capital on the financial markets, do not pay dividends, and their equity is not tradeable. They finance their investment projects through self-financing and bank loans. Finally, investment decisions are based on the objective of contributing to ecological and social values (rather than maximizing profit or market power) (Aubert and Hollandts, 2022).
Their surpluses are therefore equal to their turnover (final consumption, investment expenditure, government orders and investment expenditure of public enterprises), net of wages, depreciation costs and interest paid on past bank loans:

$$P_c = C_c + I_{s,c} + \varsigma_1\left(G + I_{s,g}\right) - WB_c - DA_c - \left(i_{l,c,b}L_{s,c,b-1} + i_{l,c,g}L_{s,c,g-1}\right) \tag{10}$$

In each period, social enterprises inherit a global stock of productive capital K_{s-1} which is the sum of a stock of brown capital $K_{c,b}$ and green capital $K_{c,g}$. The new capital stock K_c is obtained by subtracting depreciation allowances DA_c and adding the productive investment I_c to the stock inherited from the previous period:

$$K_c = K_{c,-1} - DA_c + I_{s,c} \tag{11}$$

Depreciation and amortization (DA_c) are linked to the rate of capital obsolescence. This rate is homogeneous and is expressed as a fixed proportion 0$< \lambda_0 < 1$ of the brown capital stock $K_{s,b-1}$ and green $K_{s,g-1}$ held at the beginning of the fiscal year.
Social enterprises adopt a virtuous investment behavior and use part of the depreciation allowances of brown capital to build up a stock of ‘green’ capital. This principle is aligned with principles of ecological accounting (Rambaud and Richard, 2021). The accelerated depreciation of brown capital in proportion to the adaptation ad to observed climate destruction d_{t-1} (equation 12.2) allows social enterprises to increase the proportion of green capital in their assets, independently of their stock of capital target.

$$DA_c = DA_{c,b} + DA_{c,g} \tag{12.1}$$
$$DA_{c,b} = \lambda_0(1 - ad * d_{t-1})K_{c,b-1} \tag{12.2}$$
$$DA_{c,g} = \lambda_0(1 + ad * d_{t-1})K_{c,b-1} \tag{12.3}$$

The investment demand of social enterprises follows the canonical partial accelerator model frequently used in macroeconomic modeling (Godley and Lavoie, 2012; Mazier, 2020; Clévenot et.al, 2010, 2012). The target value of the productive capital stock $K^T$is determined according to a Kaleckian logic. It is a positive function of ι_1 of the rate of surplus achieved in the previous period, this effect being modulated by the debt ratio (which here has a negative effect ι_2) (Mazier & Reyes-Ortiz, 2020)

$$K_c^T = K_{c,-1}\left(1 + \iota_1\left(\frac{P_{c,-1}}{K_{c,-1}} - \iota_2\frac{D_{s,c,-1}}{K_{c,-1}}\right)\right) \tag{13}$$

As equation (14.1) shows, the gross demand for productive investment of social enterprises ($I_{c,d}$) has two components: the first is a partial adjustment objective ($\nu < 1$) between the target value of the stock of fixed capital K_c^T and the stock of machines $K_{c,-1}$ inherited from the previous period. The second component consists of the depreciation allowances needed to replace worn-out machines (DA_c). The total investment demand of social enterprises is decomposed into a demand for brown investments $I_{d,c,b}$ and green investments $I_{d,c,g}$ (equations 14.2 and 14.3). The relative importance of green investment demand depends on the dynamics driven by public investments (Mazzucato, 2018; Carnevali et.al, 2021) and the extent of observed climate damage.

$$I_{d,c} = v_{c1}\left(K_c^T - K_{c,-1}\right) + DA_c \tag{14.1}$$

$$I_{d,c,g} = \omega_c I_{d,c}\left(1 + ad \times d_{t-1} + \frac{\Delta I_{s,g}}{I_{s,g,-1}}\right) \tag{14.2}$$

$$I_{d,c,b} = I_{d,c} - I_{d,c,g} \tag{14.3}$$

The investment demand, net of depreciation and amortization, and the self-financing rate ret_c allows us to calculate the annual demand for credit from social enterprises $l_{s,d}$ (equation 15.1). This is broken down into a demand for 'green' credit and a demand for 'brown' credit (equations 15.2 and 15.3):

$$l_{d,c} = l_{d,c,g} + l_{d,c,b} \tag{15.1}$$

$$l_{d,c,g} = I_{d,c,g} - P_c\left(ret_c\,\frac{I_{d,c,g}}{I_{d,c}}\right) \tag{15.2}$$

$$l_{d,c,b} = I_{d,c,g} - P_c\left(ret_c\,\frac{I_{d,c,b}}{I_{d,c}}\right) \tag{15.3}$$

The effective brown, green and total investment of social enterprises is equal to the sum of the credits obtained from the banks $l_{s,c}$ (with $l_{s,c} \leq l_{d,c}$), depreciation allowances $DA_c$and self-financing $ret_c P_c$ (equations 16.1 to 16.3). The evolution of the stocks of 'brown' debt, 'green' debt and total debt accumulated in the balance sheet of social enterprises is given by equations (16.4) to (16.6). Equation (16.7) gives the annual credit flows to social enterprises:

$$I_{s,c} = I_{s,c,g} + I_{s,c,b} \tag{16.1}$$

$$I_{s,c,g} = I_{d,c,g} - \left(l_{d,c,g} - l_{s,c,g}\right) \tag{16.2}$$

$$I_{s,c,b} = I_{d,c,b} - \left(l_{d,c,b} - l_{s,c,b}\right) \tag{16.3}$$

$$l_{s,c} = l_{s,c,b} + l_{s,c,g} \tag{16.4}$$

$$L_{s,c,g} = L_{s,c,g,-1} + l_{s,c,g} \tag{16.5}$$

$$L_{s,c,b} = L_{s,c,b,-1} + l_{s,c,b} \tag{16.6}$$

$$L_{s,c} = L_{s,c,b} + L_{s,c,g} \tag{16.7}$$

Finally, the green and brown productive capital stocks are given by equations (17.1) and (17.2). The green capital stock is equal to the stock inherited from the previous period, plus new green investments, plus depreciation allowances to accelerate the replacement of brown capital by green capital (see equation 12.2). The stock of brown capital is obtained by accounting identity.

$$K_{c,g} = K_{c,g-1} + I_{s,c,g} - DA_{c,g} \quad (17.1)$$
$$K_{c,b} = K_c - K_{c,g} \quad (17.2)$$

2.3.2. Capitalist enterprises

Financialized governance

The gross profits of capitalist enterprises (P_k) is equal to the sum of turnover net of the wage share, depreciation costs and interest payments, which include payments on previous loans ($i_{l,k}L_{s,k,-1}$)bonds ($i_b B_{s,-1}$) and commercial paper ($i_{cp}CP_{s,-1}$). Each of these terms is broken down according to the green or brown taxonomy. An additional index on loans is needed since social enterprises also use this type of financing (with different a different interest rate) :

$$P_k = C_k + I_{s,k} + \varsigma_2\left(G + I_{s,g}\right) - WB_k - DA_k - \left(i_{l,k,b}L_{s,k,b,-1} + i_{l,k,g}L_{s,k,g,-1} + i_{b,b,-1}B_{s,b,-1} + i_{b,g,-1}B_{s,g,-1} + i_{cp,b}CP_{s,b-1} + i_{cp,g}CP_{s,g-1}\right) \quad (18)$$

A large theoretical and empirical literature indicates that the governance of capitalist firms has evolved towards a financialized model characterized by the hegemony of shareholders over stakeholders involved in production and management (Van der Zwan, 2014; Gimet et.al, 2019; Mazier and Reyes, 2020). In the model, the boards of directors of capitalist firms are therefore controlled by investment funds, which impose an annual target for ROE on managers. This target is calculated by adding a risk premium $\hat{\delta}$ in excess of the total rate of return on risk-free assets (i.e. the total return on Treasury bonds), modulated by the expected inflation rate $\hat{\pi}$ (equation 19).

$$r_{e,k} = (1 + \pi)(r_{gb} + \hat{\delta}) \quad (19)$$

This total rate of return $r_{e,k}$ includes both the capital gain and the dividends paid. Investment funds therefore determine their dividend payout request Div_d as the difference between this ROE target and the realized capital gains. The demand for dividends decreases when unrealized capital gains increase, and vice versa (equation 20.1). This mechanism is consistent with the life-cycle theory of corporate finance: firms that are growing more slowly tend to pay more dividends than those whose market valuation is rising rapidly (Mueller, 1972; Hasnawati, 2020). The dividends actually paid by capitalist firms to investment funds (Div_s) are equal to the required dividends, within the limit of realized profits (equation 20.2).

$$Div_d = \left(\overline{r_{e,k}}.P_{k,-1} - CG_{e,-1}\right)z_0; z_0 = 1 \; iff \, \overline{r_{e,k}}.P_{k,-1} > CG_{e,-1} \quad (20.1)$$
$$Div_s = Min\left(Div_d; P_{k,-1}\right) \quad (20.2)$$

Retained earnings PU_k is the difference between realized profits and dividend payments P_k and dividend payments (equation 21). These profits are allocated to the financing of productive investments. The funds potentially allocated to the financing of investments thus increase with the stock market valuation of capitalist firms, which makes it possible to reduce dividend payments to shareholders.

$$PU_k = P_{k,-1} - Div_s \quad (21)$$

Investment behavior

In each period, capitalist firms inherit a global stock of productive capital K_{k-1} which is the sum of a stock of brown capital $K_{k,b}$ and green capital $K_{k,g}$. The new capital stock K_k is obtained by subtracting depreciation allowances DA_k and adding productive investment $I_{s,k}$ to the stock inherited from the previous period:

$$K_k = K_{k-1} - DA_k + I_{s,k} \quad (22.1)$$
$$K_{k,b} = K_{k,b,-1} - DA_{k,b} + I_{s,k,b} \quad (22.2)$$
$$K_{k,g} = K_{k,g,-1} - DA_{k,g} + I_{s,k,g} \quad (22.3)$$

Depreciation and amortization (DA_k) are linked to the rate of capital obsolescence ($0< \lambda_0 < 1$). Unlike social enterprises, profit-oriented capitalist enterprises do not accelerate the depreciation of brown capital by green capital (equations 23.1-23.3).

$$DA_k = DA_{k,b} + DA_{k,g} \quad (23.1)$$
$$DA_{k,b} = \lambda_0 K_{k,b-1} \quad (23.2)$$
$$DA_{k,g} = \lambda_0 K_{k,g-1} \quad (23.3)$$

The principles governing the investment demand of capitalist enterprises are similar to those of social enterprises. The main difference lies in the addition of a new term linked to financial profitability and assigned a negative coefficient ι_3. The inclusion of this term reflects the cannibalization of productive investment by financial activities, such as the development of merger and acquisition activities, or the share buyback policies on secondary markets that have been documented recently (Von Treek, 2008; Clévenot et.al, 2010; Mazier and Reyes, 2020). If the profitability standard set by investment funds $r_{e,k}$increases, firms will turn to financial activities for profits rather than productive investments.

$$K_K^T = K_{k_{-1}}\left(1 + \iota_1 \frac{P_{k-1}}{K_{k_{-1}}} - \iota_2\left(\frac{F_{s,k,-1}}{K_{k_{-1}}} - r_{e,k}\right)\right) \quad (24)$$

As shown in equations (25.1) to (25.3), the investment demand of capitalist firms is modeled along similar lines as that of social enterprises. Interest rates and bank rationing have no impact on the volume of investment, given the possibilities of recourse to the equity market. Capitalist enterprises investment are therefore not rationed: all projects with positive NPV are financed (by debt or equity), in line with corporate finance theory (equations 25.4 to 25.6).

$$I_{d,k} = v_{k1}(K_k^T - K_{k-1}) + DA_k \quad (25.1)$$
$$I_{d,k,g} = \omega_k I_{d,k}\left(1 + ad \times d_{t-1} + \frac{\Delta I_{s,g}}{I_{s,g,-1}}\right) \quad (25.2)$$
$$I_{d,k,b} = I_{d,k} - I_{d,k,g} \quad (25.3)$$
$$I_{s,k} = I_{s,k,g} + I_{s,k,g} + e_d \quad (25.4)$$
$$I_{s,k,g} = I_{d,k,g} - (f_{d,k,g} - f_{s,k,g}) \quad (25.5)$$
$$I_{s,k,b} = I_{d,k,b} - (f_{d,k,b} - f_{s,k,b}) \quad (25.6)$$

Financing structure

Decisions about the financial structure of capitalist firms are modeled using the pecking order theory ((Mayers and Maljuf, 1984). This theory seems to have gained validity during the

COVID-19 pandemic in the Eurozone (Pettenuzzo et.al, 2021). Capitalist firms therefore prefer to draw on their retained earnings to finance their investments. They primarily issue debt (short- and long-term loans and bonds) to finance the demand for productive investment that exceeds their retained earnings net of dividend payments. Finally, they issue new shares only if this is necessary to fill the residual gap between their financing needs, self-financing and the supply of debt finance (equation 26.4).

The annual demand for external financing by capitalist firms ($f_{d,k}$) is given by equations (26.1) to (26.3). Equity issues are given by equation (26.4) and correspond to the difference between the demand for debt ($f_{d,k}$) and the total volume of debt obtained from the banking sector ($f_{s,k} \leq f_{d,k}$). Equations (26.5) to (26.10) break down this annual flow of debt into loans, bonds and commercial paper. This allocation is driven by the portfolio choices of investment banks. In the model, as in the euro area, there is no separation between depository banks and investment banks.

$$f_{d,k} = f_{d,k,g} + f_{d,k,b} \quad (26.1)$$

$$f_{d,k,g} = I_{d,k,g} - DA_{k,g} - PU_k \left(\frac{I_{d,k,g}}{I_{d,k}} \right) \quad (26.2)$$

$$f_{d,k,b} = I_{d,k,b} - DA_{k,b} - PU_k \left(\frac{I_{d,k,b}}{I_{d,k}} \right) \quad (26.3)$$

$$e_s = f_{d,k} - f_{s,k} \quad (26.4)$$

$$cp_{s,b} = cp_{d,b} \quad (26.5)$$

$$cp_{s,g} = cp_{d,g} \quad (26.6)$$

$$b_{s,b} = b_{d,b} \quad (26.7)$$

$$b_{s,g} = b_{d,g} \quad (26.8)$$

$$l_{s,k,b} = l_{d,k,b} \quad (26.9)$$

$$l_{s,k,g} = l_{d,k,g} \quad (26.10)$$

$$f_{s,k} = f_{s,k,b} + f_{s,k,g} \quad (26.11)$$

Liabilities

The volume of liabilities appearing in the balance sheet of the capitalist business sector are given in historical accounting values by equations (27.1) to (27.8). The total value of the debt carried on their balance sheets is given by equations (27.9) and (27.10). In accordance with the taxonomy adopted, this debt is decomposed into a 'green' and a 'brown' segment. The value of the total, brown and green capital stocks are given by equations (27.12) and (27.13).

$$E_s = E_{s,-1} + e_s \quad (27.1)$$

$$CP_{s,b} = CP_{s,b,-1} + cp_{s,b} \quad (27.2)$$

$$CP_{s,g} = CP_{s,g,-1} + cp_{s,g} \quad (27.3)$$

$$CP_s = CP_{s,b} + CP_{s,g} \quad (27.4)$$

$$B_{s,b} = B_{s,b,-1} + b_{s,b} \quad (27.5)$$

$$B_{s,g} = B_{s,g,-1} + b_{s,g} \quad (27.6)$$

$$B_{s,k} = B_{s,b} + B_{s,g} \quad (27.7)$$

$$L_{s,k,b} = L_{s,k,b,-1} + l_{s,k,b} \quad (27.8)$$

$$L_{s,k,g} = L_{s,k,g-1} + l_{s,k,g} \quad (27.9)$$

$$L_{s,k} = L_{s,k,b} + L_{s,k,g} \quad (27.8)$$

$$D_{s,k} = D_{s,k,b} + D_{s,k,g} \tag{27.9}$$
$$D_{s,k,b} = CP_{s,b} + B_{s,b} + L_{s,k,b} \tag{27.10}$$
$$D_{s,k,g} = CP_{s,g} + B_{s,g} + L_{s,k,g} \tag{27.11}$$
$$K_{k,g} = K_{k,g-1} + I_{s,k,g} - DA_{k,g} \tag{27.12}$$
$$K_{k,b} = K_k - K_{k,g} \tag{27.13}$$

2.4. The banking sector

Inside money creation

The modeling of the banking sector is consistent with endogenous money theory, where credits make deposits (Godley and Lavoie, 2012; Lagoarde-Segot, 2020; Ehnts, 2017). Equations (28) and (29) show that commercial banks provide liquidity ($H_{s,h}$) and bank deposits ($M_{s,h}$) to households on demand:

$$H_{s,h} = H_{d,h} \tag{28}$$
$$M_{s,h} = M_{d,h} \tag{29}$$

The creation of inside money by the banking sector is linked to the financing of the economy through credit. In each period, the banks examine the demand for loans from social enterprises $l_{d,s}$ and the demand for debt from capitalist enterprises $f_{d,k}$. They then determine the total flow of internal money m_b newly issued to social enterprises $l_{s,c}$ and capitalist enterprises $f_{s,k}$. The money issued for each category of enterprise has a 'green' and a 'brown' segment (equations 30.2 and 30.3). Similarly, the total flow of domestic money is also decomposed into a 'green' segment $m_{b,g}$ and a 'brown' segment $m_{b,b}$ (equations 30.4 and 30.5).

$$M_b = M_{b,-1} + m_b \tag{30.1}$$
$$m_b = l_{s,c} + f_{s,k} \tag{30.2}$$
$$l_{s,c} = l_{s,c,g} + l_{s,c,b} \tag{30.3}$$
$$f_{s,k} = f_{s,k,g} + f_{s,k,b} \tag{30.4}$$
$$m_{b,g} = l_{s,c,g} + f_{s,k,g} \tag{30.5}$$
$$m_{b,b} = l_{s,c,b} + f_{s,k,b} \tag{30.6}$$

The processes for evaluating applications for bank financing differ significantly by sector (social enterprises and capitalist enterprises) and by project type (brown or green investment). In the case of social enterprises, the loan offer is conditioned by the value of the collateral provided by the borrower (Mac an Bhaird, 2010). Once the debt accumulated in previous periods exceeds a fraction γ of the value of the total capital stock, the banking sector rejects the loan application. In this case, the annual investment capacity of the social enterprise sector will be equal to the value of its surplus allocated to self-financing (equations 31.1 and 32.2). This constraint, however, does not affect capitalist enterprises. Finally, banks consider credit risk when calculating the total supply of credit for each type of project ($LR_{c,g-1}$ for green investments and $LR_{c,b-1}$ for brown investments, respectively).

$$l_{s,c,g} = l_{d,c,g}\left(1 - LR_{c,g-1}\right) \, iff \; L_{s,c,-1} < \gamma^{-1}K_{c,-1} \tag{31.1}$$
$$l_{s,c,b} = l_{d,c,b}\left(1 - LR_{c,b-1}\right) iff \; L_{s,c,-1} < \gamma^{-1}K_{c,-1} \tag{31.2}$$
$$f_{s,k,g} = f_{d,k,g}\left(1 - LR_{k,g,-1}\right) \tag{31.3}$$

$$f_{s,k,b} = f_{d,k,b}\left(1 - LR_{k,b,-1}\right) \tag{31.4}$$

he assessment of credit risk depends on both macroeconomic conditions (observed economic growth rate and the cost of refinancing with the Central Bank) and the debt ratio observed in the relevant industry (Le Héron and Mouakil, 2008; Minsky; 1986; Lavoie, 2014). In addition, banks consider the contribution of their fossil fuel investments to the increase in systemic risk up to the parameter Ψ (Aglietta and Spain, 2016). The assessment of 'brown' credit risk thus increases with climate damage (equations 32.1 to 32.4).

$$LR_{c,g} = a_1\left(\frac{L_{s,c}}{K_c}\right) - b_1.\left(\frac{\Delta Y}{Y_{-1}}\right) + c_1.i_e \tag{32.1}$$

$$LR_{c,b} = LR_{c,g}\left(1 + \Psi d_{t-1} - \omega_p \frac{\Delta p_{l,c,b}}{p_{l,c,b,-1}}\right) \tag{32.2}$$

$$LR_{k,g} = a_1\left(\frac{F_{s,k,g}}{K_k}\right) - b_1.\left(\frac{\Delta Y}{Y_{-1}}\right) + c_1.i_e \tag{32.3}$$

$$LR_{k,b} = LR_{k,g}\left(1 + \Psi d_{t-1} - \omega_p \frac{\Delta p_{l,k,b}}{p_{l,k,b,-1}}\right) \tag{32.4}$$

Bank portfolio choice

Unlike social enterprises, the debt contracted by capitalist enterprises does not only take the form of bank loans but also of short and long-term bonds (equations (26.5) to (26.10)). The structuring of the debt of these firms is driven by the demand for securities from investment banks (which are integrated into the banking sector). After determining the overall volume of financing provided, banks determine the debt structure of capitalist firms via their portfolio choice. As equations (33.1) and (33.2) show, this structure is determined by the banks' portfolio choices. These choices depend on the relative monetary returns observed in the 'green' and 'brown' segments of the debt market.

$$\begin{pmatrix} b_{d,b} \\ l_{d,k,b} \\ cp_{d,b} \end{pmatrix} = \begin{pmatrix} \chi_{10} \\ \chi_{20} \\ \chi_{30} \end{pmatrix}.f_{s,k,b} + \begin{pmatrix} \chi_{11} & -\chi_{12} & -\chi_{13} \\ -\chi_{21} & \chi_{22} & -\chi_{23} \\ -\chi_{31} & -\chi_{32} & \chi_{33} \end{pmatrix}.\begin{pmatrix} r_{b,b} \\ i_{l,k,b} \\ i_{cp,b} \end{pmatrix} f_{s,k,b} \tag{33.1}$$

$$\begin{pmatrix} b_{d,g} \\ l_{d,k,g} \\ cp_{d,g} \end{pmatrix} = \begin{pmatrix} \chi_{10} \\ \chi_{20} \\ \chi_{30} \end{pmatrix}.f_{s,k,g} + \begin{pmatrix} \chi_{11} & -\chi_{12} & -\chi_{13} \\ -\chi_{21} & \chi_{22} & -\chi_{23} \\ -\chi_{31} & -\chi_{32} & \chi_{33} \end{pmatrix}.\begin{pmatrix} r_{b,g} \\ i_{l,k,g} \\ i_{cp,g} \end{pmatrix} f_{s,k,g} \tag{33.2}$$

The parameters of the matrix respect the *vertical* constraints (Tobin, 1969) $\sum_{i=1}^{I}\chi_{i0} = 1$; $\sum_{i=1}^{I}\chi_{ij} = 0$; as well as the usual *symmetry* constraints (Godley and Lavoie, 2012) : $\chi_{ij} = \chi_{ji}$; $\forall i \neq j$. To avoid overidentifying problems, we compute the bank demand for corporate paper ($CP_{d,b}$) using the balance sheet constraint instead (equations 34.1 and 34.2).

$$cp_{d,b} = f_{s,k,b} - b_{d,b} - l_{d,k,b} \tag{34.1}$$

$$cp_{d,g} = f_{s,k,g} - b_{d,g} - l_{d,k,g} \tag{34.2}$$

$$cp_d = cp_{d,g} + cp_{d,b} \tag{34.3}$$

$$b_d = b_{d,g} + b_{d,b} \tag{34.4}$$

Stocks of risky assets

The volumes of stocks of risky assets on banks' balance sheets are given by equations (35.1) to (35.11). Note that each of these stocks is impacted by the Central Bank's asset purchases. They are thus equal to the difference between the stocks of debt appearing on the borrowers' balance sheets and the stock of risky assets appearing on the Central Bank's balance sheet. Since the Central Bank's interventions are aligned with the 'market neutrality' principle, the volumes of repurchases of each asset class are weighted by their importance in the banking portfolios[13] .

$$CP_d = CP_{d,b} + CP_{d,g} \tag{35.1}$$
$$B_d = B_{d,b} + B_{d,g} \tag{35.2}$$
$$L_d = L_{d,b} + L_{d,g} \tag{35.3}$$
$$CP_{d,b} = CP_{s,b} - \frac{CP_{s,b,-1}}{CP_{s,-1}} qe_{cp,-1} \tag{35.4}$$
$$CP_{d,g} = CP_{s,g} - \frac{CP_{s,g,-1}}{CP_{s,-1}} qe_{cp,-1} \tag{35.6}$$
$$B_{d,b} = B_{s,b} - \frac{B_{s,b,-1}}{B_{s,-1}} qe_{b,-1} \tag{35.7}$$
$$B_{d,g} = B_{s,g} - \frac{B_{s,g,-1}}{B_{s,-1}} qe_{b,-1} \tag{35.8}$$
$$L_{d,b} = L_{d,k,b} + L_{d,c,b} \tag{35.9}$$
$$L_{d,g} = L_{d,k,g} + L_{d,c,g} \tag{35.10}$$
$$L_{d,k,b} = L_{s,k,b} - \frac{L_{s,k,b,-1}}{L_{s,-1}} qe_{l,-1} \tag{35.11}$$
$$L_{d,k,g} = L_{s,k,g} - \frac{L_{s,k,g,-1}}{L_{s,-1}} qe_{l,-1} \tag{35.12}$$
$$L_{d,c,b} = L_{s,c,b} - \frac{L_{s,c,b,-1}}{L_{s,-1}} qe_{l,-1} \tag{35.13}$$
$$L_{d,c,g} = L_{s,c,g} - \frac{L_{s,c,g,-1}}{L_{s,-1}} qe_{l,-1} \tag{35.14}$$
$$D_d = CP_d + B_d + L_s \tag{35.15}$$
$$F_s = D_d - L_{s,c} \tag{35.16}$$

Refinancing operations

The banking sector provides deposits to households on demand (36.1). As shown in equation (36.2), prudential regulations force the banking sector to accumulate reserve requirements ($H_{d,m}$) at the Central Bank; as a fixed proportion ρ_1 of total bank deposits (M_s).
In line with endogenous money theory, the amount of funding provided by the banking sector is not constrained by the reserves initially on its balance sheet since the monetary system guarantees continuous ex-post access to reserves (Ehnts, 2017). Commercial banks have

[13] Note here that L_d corresponds to the demand for bank loan portfolios by banks. These portfolios are equal to the supply of loans initially created by the banks $L_{s,k} + L_{s,c}$ in response to the demand of the firms, net of the repurchases of loans by the Central Bank.

borrowing access to the Central Bank, which acts as lender of last resort (via the *main refinancing operations*[14]).
The reserve assets created by the Central Bank ($H_{d,l}$) takes the form of advance A_b (equations 36.4 and 36.5)[15] . Each year, a given proportion of the reserve requirement is also provided by the central bank's asset purchase program (H_{qe}). The demand for Central Bank loans is therefore equal to the difference between reserve requirements and the issuance of reserve money through quantitative easing (equation 36.3). The demand for reserve money issued through quantitative easing is equal to the supply by the central bank (equation 36.6):

$$M_{s,h} = M_{d,h} \tag{36.1}$$
$$H_{d,m} = \rho_1.(M_{s,h,-1}) \tag{36.2}$$
$$H_{d,l} = H_{d,m} - H_{d,qe} \tag{36.3}$$
$$A_{d,b} = H_{d,l}\, iff H_{d,l} > 0 \tag{36.4}$$
$$A_{s,b} = A_{d,b} \tag{36.5}$$
$$H_{d,qe} = H_{s,qe} \tag{36.6}$$

The difference between total reserves H_d (which correspond to the monetary base M0) and required reserves is equal to excess reserves H_{ex} (equation 36.7). Each individual bank can of course exchange these excess reserves for interest-bearing financial instruments. But in this case, the excess reserves are transferred from one bank's balance sheet to another, leaving the consolidated balance sheet of the banking sector unchanged, as well as the amount on the central bank's balance sheet. Banks deposit these excess reserves in the Central Bank's deposit facility.

$$H_{ex} = H_d - H_{d,m} \tag{36.7}$$

Banks' income statement

Equation (37.1) describes the simplified income statement of the banking sector P_b. The income of the banking sector is equal to the sum of the yield on their Treasury bond holdings, the interest earned on brown and green loans to social enterprises and capitalist enterprises, the total yield on brown and green bonds issued by capitalist enterprises, and the coupons earned for holding brown and green commercial paper issued by capitalist enterprises. In accordance with the Eurozone framework, required reserves are remunerated at the main refinancing operations rate, and excess reserves are remunerated at the deposit facility rate.
Banks' expenses include interest paid to depositors and interest payments to the $i_d(M_{h,d-1})$ and interest payments to the Central Bank for advances from the marginal lending facility $i_e(A_{d,b-1})$. Bank profits are distributed to shareholders (investment funds) in the form of dividends (equation 37.2).

[14] Individual banks also lend or borrow reserves from each other in the interbank market. At the macro level, however, these transactions cancel each other out, leaving the total amount of reserves on the consolidated balance sheet of the banking sector unchanged.
[15] These borrowings frequently take the form of a repurchase agreement with a typical maturity of one week to three months. Given the annual frequency of the model, these transactions have no impact on the structure of bank assets and liabilities. Only the financial cost of the loan, i.e. the interest paid to the central bank, is therefore taken into account.

$$P_b = i_{gb}\left(GB_{d,b,-1}\right) + i_{l,k,b}\left(L_{d,k,b,-1}\right) + i_{l,k,g}\left(L_{d,k,g,-1}\right) + i_{l,c,b}\left(L_{d,c,b,-1}\right) + i_{l,c,g}\left(L_{d,c,g,-1}\right) + i_{cp,b}\left(CP_{d,b,-1}\right) + i_{cp,g}\left(CP_{d,g,-1}\right) + i_{b,g}\left(B_{d,g,-1}\right) + i_{b,b}\left(B_{d,b,-1}\right) + i_e H_{d,b,-1} + i_{df} H_{ex,-1} - \left[i_{d-1}\left(M_{d,h,-1}\right) + i_e\left(A_{d,b-1}\right)\right] \quad (37.1)$$

$$Div_b = P_b z_1; z_1 = 1\ iff P_b > 0 \quad (37.2)$$

Prudential regulations

The capital adequacy ratio

The volume of bank equity is derived from the balance sheet of the banking sector banks (as shown in equation 38.1). It corresponds to the difference between bank assets (reserve money, stock of sovereign securities portfolio, stock of credit money) and bank liabilities (demand deposits and advances obtained from the Central Bank).

In Philia 1.0, it is the Central Bank rather than the government, that intervenes to stabilize the banking sector. This feature of the model reflects the fact that financial stability objectives have been taken into account in the formulation of monetary policies since the 2008 financial crisis and even more so since the COVID-19 pandemic (Restoy, 2020)[16]. Unlike governments after the 2008 crisis, the central bank does not recapitalize the banking sector, but changes the risk structure of its assets through asset repurchase programs, financed by reserve money issuance. The ex-ante value of weighted risky assets WR^a is given by equation (38.3), where η_1, η_2, η_3 are the risk weights assigned to the stocks of loans, bonds and commercial paper, respectively. These stocks are marked to market to reflect vulnerability of balance sheets to secondary market fluctuations.

The target value for the portfolio of risky assets WR^T is given by equation (38.4) (given the value of the capital adequacy ratio $CAR^T$and the value of equity BE). The annual asset repurchases qe thus bring the ex-post value of the weighted risky assets WR towards the target WR^T (38.5 and 38.6).

$$BE = H_d + p_{gb} GB_{d,b} + + p_{l,k,b} L_{d,k,b} + + p_{l,k,g} L_{d,k,g} + p_{l,c,b} L_{d,c,b} + p_{l,c,g} L_{d,c,g} + p_{b,b} B_{d,b} + p_{b,g} B_{d,g} + p_{cp,b} CP_{d,b} + p_{cp,g} CP_{d,g} + \left(A_{s,b} - M_{s,h}\right) \quad (37.1)$$

$$CAR^T = \overline{CAR^T} \quad (37.2)$$

$$WR^a = \left(\eta_1\left(+ p_{l,k,b} L_{d,k,b} + p_{l,k,g} L_{d,k,g} + p_{l,c,b} L_{d,c,b} + p_{l,c,g} L_{d,c,g}\right) + \eta_2\left(p_{b,b} B_{d,b} + p_{b,g} B_{d,g}\right) + \eta_3\left(p_{cp,b} CP_{d,b} + p_{cp,g} CP_{d,g}\right)\right) \quad (37.3)$$

$$WR^T = \frac{BE}{CAR^T} \quad (37.4)$$

$$WR = WR^a - qe \quad (37.5)$$

$$qe^T = (WR^a - WR^T)z_2 ;\ z_2 = 1\ iff\ WR^a > WR^T \quad (37.6)$$

The liquidity ratio

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[16] This seems particularly true in the euro area: "*monetary policy cannot turn a blind eye to rising financial stability risks. This was one of the main conclusions of our monetary policy strategy review, which we completed in July of this* year" (Isabel Schnabel, executive board of the ECB, December 2021). See https://www.ecb.europa.eu/press/key/date/2021/html/ecb.sp211208_2~97c82f5cfb.en.html

The liquidity ratio is the ratio of class 1 assets to total deposits (equation 38.2). Class 1 assets include reserve money (including reserve requirements) and Treasury bonds. The banking sector adjusts its purchases of government bonds each year to bring the liquidity ratio LCR with its regulatory target (LCR^T) set at 100% (BIS, 2019).
As equation (38.1) shows, banks target a stock of government bonds $GB_{d,b}^T$ to close the gap between the ex ante liquidity coverage ratio and the LCR^a with the regulatory target LCR^T. The banking sector thus increases its stock of sovereign securities following an increase in bank deposits M_s or an increase in the liquidity preference of households ζ (equation 38.4).

$$LCR^T = \overline{LCR^T} \tag{38.1}$$

$$LCR^a = \frac{GB_{d,b-1} + H_d}{\zeta M_s} \tag{38.2}$$

$$GB_{d,b}^T = \zeta M_s LCR^T - H_d \tag{38.3}$$

$$\zeta = \left(\frac{GB_s + H_d}{M_{s,h}}\right)(1 + \gamma_{10}) \tag{38.4}$$

$$gb_{d,b} = GB_{d,b}^T - GB_{d,b,-1} \tag{38.5}$$

$$GB_{d,b} = GB_{d,b,-1} + gb_{d,b} \tag{38.6}$$

Investment funds

The investment fund industry is conceived as the command center of the financialized economy. It brings together unlisted intermediaries, such as institutional investors, asset management companies, and insurance companies. Investment funds hold the entire equity of the banking sector. The profits of banks from their lending and investment activities are then transferred to capital-owner households via investment funds.
The funds mobilize the savings of capital-owner households by issuing shares. Capital-owner households thus delegate to investment funds the management of part of their savings. Capital-owner households thus hold, through the funds, all the equity of capitalist enterprises and the banking sector. The investment funds then compose portfolios of risk-free assets (sovereign securities) and equities issued by capitalist companies. They also receive the part of payments associated to debt payments that is incorporated in the dividends paid out by banks. The volume of investment fund shares issued in response to demand from capitalist households is given by equations 39.1:

$$S_i = S_{d,r} \tag{39.1}$$

Investment funds hold the shares issued by capitalist companies (39.2) :

$$E_d = E_s \tag{39.2}$$

Unlike banks which are subject to prudential regulation, investment funds have a preference for risky assets and therefore get rid of sovereign securities if they detect profit opportunities in the equity market. The demand of investment funds for Treasury bonds thus serves as a buffer to absorb fluctuations in their balance sheets, which are affected by fluctuations in the secondary market (equation 39.3). Investment funds buy government bonds if the savings they obtain from rentier households exceed the investment opportunities in the issued equity market and vice versa (equations 39.3 and 39.4).

$$GB_{d,s} = S_i - p_e E_d - BE \quad (39.3)$$
$$gb_{d,s} = \Delta GB_{d,s} \quad (39.4)$$

The profits of investment funds P_i include the dividends paid by banks, and the total return on their portfolio of assets, which includes the shares of capitalist firms and sovereign securities (equation 39.5). These profits are returned in full to capital-owner households.

$$P_i = Div_b + r_e E_{d,-1} + r_{gb} GB_{d,s,-1} \quad (39.5)$$

2.5. The Central Bank

Since 2008, and more markedly with the COVID-19 crisis, the mandate of Central Banks in developed countries includes the objective of maintaining financial stability. This is materialized by a change in the modalities of monetary policy, with on the one hand the transition to a floor system for the determination of interest rates, and on the other hand the multiplication of asset repurchase programs (which are the corollary of the floor system).
The modeling of the Central Bank's behavior reflects this evolution. In the euro area, the Central Bank's asset purchase policies still aim at market neutrality (ECB, 2020; Finance Watch, 2021). The quantitative easing policies described in section 4.4.1. therefore do not differentiate between green and brown financial assets, and do not affect the 'green' structure of bank balance sheets. This mechanism is described by equations (40.1) to (40.12). Note also that the Central Bank acts as a buyer of last resort for government debt securities (40.13).

$$qe_{l,b} = qe_{l,k,b} + qe_{l,c,b} \quad (40.1)$$
$$qe_{l,g} = qe_{l,k,g} + qe_{l,c,g} \quad (40.2)$$
$$qe_l = qe_{l,g} + qe_{l,b} \quad (40.3)$$
$$qe_{cp} = qe_{cp,g} + qe_{cp,b} \quad (40.4)$$
$$qe_{l,k,b} = qe^T \frac{L_{s,k,b,-1}}{D_{d,-1}} \quad (40.5)$$
$$qe_{l,k,g} = qe^T \frac{L_{s,k,g,-1}}{D_{d,-1}} \quad (40.6)$$
$$qe_{l,c,b} = qe^T \frac{L_{s,c,b,-1}}{D_{d,-1}} \quad (40.7)$$
$$qe_{l,c,g} = qe^T \frac{L_{s,c,g,-1}}{D_{d,-1}} \quad (40.8)$$
$$qe_{cp,b} = qe^T \frac{CP_{s,b,-1}}{D_{d,-1}} \quad (40.9)$$
$$qe_{cp,g} = qe^T \frac{CP_{s,g,-1}}{D_{d,-1}} \quad (40.10)$$
$$qe_{b,b} = qe^T \frac{B_{d,b,-1}}{D_{d,-1}} \quad (40.11)$$
$$qe_{gb} = \Delta GB_{d,cb} \quad (40.12)$$
$$GB_{d,cb} = GB_s - GB_{d,s} - GB_{d,b} \quad (40.13)$$

The volumes of risky and risk-free assets held by the Central Bank are given by equations (41.1) to (41.11):

$$QE_{l,b} = QE_{l,k,b} + QE_{l,c,b} \quad (41.1)$$

$$QE_{l,g} = QE_{l,k,g} + QE_{l,c,g} \tag{41.2}$$
$$QE_{l,k,b} = QE_{l,k,b,-1} + qe_{l,k,b} \tag{41.3}$$
$$QE_{l,k,g} = QE_{l,k,g,-1} + qe_{l,k,g} \tag{41.4}$$
$$QE_{l,c,b} = QE_{l,c,b,-1} + qe_{l,c,b} \tag{41.5}$$
$$QE_{l,c,g} = QE_{l,c,g,-1} + qe_{l,c,g} \tag{41.6}$$
$$QE_{cp,b} = QE_{cp,b,-1} + qe_{cp,b} \tag{41.7}$$
$$QE_{cp,g} = QE_{cp,g,-1} + qe_{cp,g} \tag{41.8}$$
$$QE_{b,b} = QE_{b,b,-1} + qe_{b,b} \tag{41.9}$$
$$QE_{b,g} = QE_{b,g,-1} + qe_{b,g} \tag{41.10}$$
$$QE_{gb} = GB_{d,cb} \tag{41.11}$$

These asset purchase policies have the effect of inflating the Central Bank's balance sheet and increasing the volume of reserve money held by the banking sector beyond the reserve requirements H_{br}. These excess reserves of the sector are deposited in the Central Bank's deposit facility (see equation 36.6). The evolution of the monetary base H_s (M0) is given by equation (41.13).

$$H_{s,qe} = H_{s,qe,-1} + qe_{-1}^{T} \tag{41.12}$$
$$H_{s,b} = H_{d,m}$$
$$H_s = H_{s,b} + H_{s,qe} \tag{41.13}$$

These operations are financed by annual reserve currency issues, which are added to the stock inherited from the previous period $H_{s,qe}$. The annual profit of the Central Bank is determined by its profit and loss account. It is the sum of the returns on its securities portfolio, minus the remuneration of required reserves at the refinancing rate ($i_e H_{bd-1}$) and the remuneration of excess reserves at the deposit facility rate ($i_{df} H_{ex-1}$).

$$F_{cb} = r_{l,k,b}QE_{l,k,b,-1} + r_{l,k,g}QE_{l,k,g,-1} + r_{l,c,b}QE_{l,c,b,-1} + r_{l,c,g}QE_{l,c,g,-1} + r_{b,b}QE_{b,b,-1} + r_{b,g}QE_{b,g,-1} + i_{cp,b}QE_{cp,b,-1} + i_{cp,g}QE_{cp,g,-1} + r_{gb}QE_{gb,-1} + +i_e A_{s,b,-1} - i_e H_{d,b,-1} - i_{df} H_{ex-1}. \tag{42}$$

A minor difference with the models developed by Godley and Lavoie (2012) is that central bank profits are not distributed to the government, but are added, as in the euro area, to the central bank's equity. Annual profits or losses are added to the value of the central bank's equity K_{cb} (which is taken from its balance sheet). Fluctuations in the value of assets in secondary markets affect the Central Bank's balance sheet. It is important to note however that the equity value is only an accounting residual: the Central Bank is not a market participant, and can operate normally with negative equity[17] (Archer and Moser-Boehm, 2013)

$$K_{cb} = or + p_{l,k,b}QE_{l,k,b,-1} + p_{l,k,g}QE_{l,k,g,-1} + p_{l,c,b}QE_{l,c,b,-1} + p_{l,c,g}QE_{l,c,g,-1} + p_{b,b}QE_{b,b,-1} + p_{b,g}QE_{b,g,-1} + QE_{cp,b,-1} + QE_{cp,g,-1} + p_{gb}QE_{gb,-1} + F_{cb} - H_s \tag{43}$$

$$or = \overline{or} \tag{44}$$

[17] *"Central banks are not commercial banks. They do not seek profit and are not subject to the same financial constraints as private institutions. In practice, this means that most central banks could lose money to the point of negative equity and still operate perfectly normally"* (Archer and Moser-Boehm, 2013, p.1)

2.6. Interest rates

Banking rates and money market rates

Monetary policy is based on the floor system, in which the two main policy tools are the deposit facility rate and asset purchase programs. This strategy (in effect in the euro area since 2015), aligns the prime rate target (ESTER) with the deposit facility rate. It relies on the issuance of excess reserves through *quantitative easing*. Since these excess reserves are mandatorily deposited in the ECB's deposit facility, the Central Bank only needs to adjust this deposit rate in one direction or the other to see the interbank market rate converge immediately (Lavoie, 2014). The interbank market rate i_e is therefore equal to the deposit facility rate i_{df}. This rate is off-market and does not depend on the size of the monetary base (Moore, 1988):

$$i_e = i_{df} \quad (45.1)$$
$$i_{df} = \widehat{i_{df}} \quad (45.2)$$

Bank behavior follows the principles outlined in Le Heron and Mouakil (2008) and Lavoie (2014). Banks' preference for liquidity $(\sigma_1 + \sigma_2)$ as well as the credit risk LR associated with each market segment ('brown' or 'green') and each category of borrower (social enterprises and capitalist enterprises) jointly determine the risk structure of interest rates[18] . The liquidity premium applies uniformly to the 'brown' and 'green' sectors (equations 46.1 and 46.2). Asset repurchases decrease this liquidity premium and the entire term structure (equations 46.5 to 46.7).

$$i_{l,k,g} = i_{cp,g} + \sigma_2 \quad (46.1)$$
$$i_{l,k,b} = i_{cp,b} + \sigma_2 \quad (46.2)$$
$$i_{l,c,g} = i_{l,k,g} + \left(LR_{c,g} - LR_{k,g}\right) \quad (46.3)$$
$$i_{l,c,b} = i_{l,k,b} + \left(LR_{c,b} - LR_{k,b}\right) \quad (46.4)$$
$$i_{cp,g} = i_e + LR_{k,g} + \sigma_1 \quad (46.5)$$
$$i_{cp,b} = i_e + LR_{k,b} + \sigma_1 \quad (46.6)$$
$$\sigma_1 = \sigma_{1,-1} - \varphi qe \quad (46.7)$$

Banks determine the deposit rate i_d by applying a mark-up to the σ_3 to the refinancing rate (i_e). This implies that the model can account for negative customer rates as observed in the euro area over the last decades.

$$i_d = i_{d,-1} + \Delta i_e \quad (47)$$

The interest rate on government bonds is equal to the interbank rate, to which is added a liquidity risk premium that is lower than that applied to private issuers, because the risk of insolvency and illiquidity of the government is zero (as long as it borrows in its own currency, which is the case in this model).

$$i_g = i_e + \sigma_1 \quad (48)$$

[18] A reduction in the prime rate of the system i_e may therefore fail to reduce long-term rates if credit risk and/or liquidity preference increases sufficiently (Lavoie, 2014).

Throughout all simulations, the interest rate structure is the following: $i_l > i_{cp} > i_g > i_e > i_d$.

Bond rates

The coupon rate for brown and green corporate bonds is equal to the interest rate on the loans, minus the expected capital gain. This equation ensures that corporate bond coupons take into account interest rate risk: if investors anticipate a price decline they will demand a higher coupon rate and vice versa. In addition, several recent financial studies have detected the presence of a 'greenium' in the bond markets: that is, a positive difference between the actuarial rate of a brown and a green bond (Agliardi & Agliardi, 2021). This 'greenium' is driven by the appetite of 'responsible' investors for debt products that meet the Green Bond Principles; and by the increasing use of green bonds as a vehicle for portfolio liquidity (Zerbib, 2020). The greenium is the key vehicle for sustainable finance in the so-called 'neoliberal green finance' agenda (Jäger and Schmidt, 2021). The model therefore includes a greenium that is a function of the climate damage observed in the previous period. The coupon rate of brown and green corporate bonds is thus given by equations (49.1) and (49.2). In the model, the bonds are sold at par, so this coupon rate is equal to the actuarial rate[19] .

$$i_{b,b} = i_{l,k,b} - \sigma_5 \left(\frac{CG^e_{b,b}}{B_{s,b,-1}} \right) \tag{49.1}$$

$$i_{b,g} = i_{l,k,g} - \sigma_5 (1 - \gamma d_{t-1}) \left(\frac{CG^e_{b,g}}{B_{s,g,-1}} \right) \tag{49.2}$$

2.7. The formation of expectations in financial markets

Returns on financial assets

The total annual return on corporate bonds, Treasury bonds and securitized loan portfolios is the sum of the coupon rate and the realized capital gain :

$$r_{b,b} = i_{b,b,-1} + \frac{CG_b}{p_{b,b,-1}} \tag{50.1}$$

$$r_{b,g} = i_{b,g,-1} + \frac{CG_b}{p_{b,g,-1}} \tag{50.2}$$

$$r_{gb} = i_{gb,-1} + \frac{CG_{gb}}{p_{gb,-1}} \tag{50.3}$$

$$r_{l,k,b} = i_{l,k,b,-1} + \frac{CG_{l,k,b}}{p_{l,k,b}} \tag{50.4}$$

$$r_{l,k,g} = i_{l,k,g,-1} + \frac{CG_{l,k,g}}{p_{l,k,g}} \tag{50.5}$$

$$r_{l,c,b} = i_{l,c,b,-1} + \frac{CG_{l,c,b}}{p_{l,c,b}} \tag{50.6}$$

$$r_{l,c,g} = i_{l,c,g,-1} + \frac{CG_{l,c,g}}{p_{l,c,g}} \tag{50.7}$$

[19] In this case the apparent interest rate is equal to the coupon rate.

Formation of prices

In the stationary state model, the prices of securities are given as stationary unit processes. The expected capital gains on the bond and loan portfolios depend on an adaptive expectations model: their values in the previous period, plus an error correction mechanism where ψ represents the speed of adjustment of expectations:

$$CG^e_{b,b} = CG_{b,b,-1} + \psi\left(CG_{b,b,-1} - CG^e_{b,b,-1}\right) \quad (51.1)$$
$$CG^e_{b,g} = CG_{b,g,-1} + \psi\left(CG_{b,g,-1} - CG^e_{b,g-1}\right) \quad (51.2)$$
$$CG^e_{l,k,b} = CG_{l,k,b,-1} + \psi\left(CG_{l,k,b,-1} - CG^e_{l,k,b,-1}\right) \quad (51.3)$$
$$CG^e_{l,k,g} = CG_{l,k,g,-1} + \psi\left(CG_{l,k,g,-1} - CG^e_{l,k,g,-1}\right) \quad (51.4)$$
$$CG^e_{l,c,b} = CG_{l,s,b,-1} + \psi\left(CG_{l,s,b,-1} - CG^e_{l,s,b,-1}\right) \quad (51.5)$$
$$CG^e_{l,c,g} = CG_{l,s,g,-1} + \psi\left(CG_{l,s,g,-1} - CG^e_{l,s,g,-1}\right) \quad (51.6)$$
$$CG^e_{gb} = CG_{gb,-1} + \psi\left(CG_{gb,-1} - CG^e_{gb,-1}\right) \quad (51.7)$$
$$CG^e_{e} = CG_{e,-1} + \psi\left(CG_{e,-1} - CG^e_{e,-1}\right) \quad (51.8)$$

Capital gains and total return

The realized capital gains are given by the following equations:

$$CG_{gb} = \Delta p_{gb}(GB_{s-1}) \quad (52.1)$$
$$CG_{b,b} = \Delta p_{b,b}.(B_{s,b,-1}) \quad (52.2)$$
$$CG_{b,g} = \Delta p_{b,g}.(B_{s,g,-1}) \quad (52.3)$$
$$CG_{l,k,b} = \Delta p_{l,k,b}.(L_{s,k,b,-1}) \quad (52.4)$$
$$CG_{l,k,g} = \Delta p_{l,k,g}.(L_{s,k,g,-1}) \quad (52.5)$$
$$CG_{l,c,b} = \Delta p_{l,c,b}.(L_{s,c,b,-1}) \quad (52.6)$$
$$CG_{l,c,g} = \Delta p_{l,c,g}.(L_{s,c,g,-1}) \quad (52.7)$$
$$CG_{e} = \Delta p_{e}.(E_{s,-1}) \quad (52.8)$$

2.8. The public sector

Equation (53) defines the government's budget constraint. Every net government expenditure has a counterpart in government bond issuance. Net government bond issuance (by volume) is the difference between government spending (including direct spending in the private sector and payments to owners of government bonds) and the sum of tax revenues and profits of government enterprises[20] .

$$gb_s = \ Max\ ((G + I_{s,g} + i_g GB_{s,-1}) - (T + P_g); 0) \quad (53.1)$$
$$GB_s = GB_{s,-1} + gb_s \quad (53.2)$$

Public enterprises operate in a similar way to the other two sectors, with two differences. First, their capital account is consolidated with the government budget constraint: the losses, profits and financing needs of public enterprises are integrated with the government budget constraint (equation 53.1). The income statement is thus equal to the difference between revenues, wages

[20] Conversely, annual losses of public companies are financed by Treasury bond issues.

paid and depreciation (equation 54.1). Second, the productive capital target K_g^T for public enterprises does not depend on past revenues but on policy decisions. These decisions establish a target growth rate for the total productive capital stock g_{k1} as well as for the green capital stock g_{k1} (equations (54.4) to (54.6)).

$$P_g = C_g - WB_g \tag{54.1}$$
$$WB_g = WB - WB_c - WB_k \tag{54.2}$$
$$DA_g = \lambda K_{g,-1} \tag{54.2}$$
$$K_g^T = (1 + g_{k1})K_{g,-1} \tag{54.3}$$
$$K_g = K_{g,-1} + I_{s,g} - DA_g \tag{54.4}$$
$$I_{d,g} = K_g^T - K_g + DA_g \tag{54.4}$$
$$I_{d,g,g} = g_{k2} I_{d,g} \tag{54.5}$$
$$I_{d,g,b} = I_{d,g} - I_{d,g,g} \tag{54.5}$$
$$I_{s,g} = I_{d,g} \tag{54.6}$$

2.9 Closure of the macroeconomic block

The equality between the supply of reserve money (equation 41.4) and the demand for reserve money by banks (equation 36.4) is ensured by the complete accounting structure of the model. The hidden equation is therefore the following:

$$H_s = H_d \tag{55}$$

2.10 The ecosystem block

The ecosystem modeling follows the principles and parameterization initially proposed by Dafermos et.al (2018) and then simplified by Carnevali et.al (2021). The ecosystem block tracks changes in material reserve stocks, reserves, recycling, waste emissions, total energy consumption, fossil and renewable, CO2 emissions, climate change, and induced economic damages.

It ensures that the model respects the first law of thermodynamics (energy and matter cannot be created or destroyed when transformed) as well as the second (economic processes transform low-entropy energy (e.g. fossil fuels) into high-entropy dissipated energy. Energy is measured in exajoules and matter in gigatons. Here we describe the equations that are nested within these accounting matrices.

The production of material goods YM is a proportion of μ_e of annual real GDP. This proportion is modulated by the share of 'brown' and 'green' capital in the productive structure of the economy (equation 57.1 and 57.2).

$$YM = \mu_e Y \tag{57.1}$$
$$\mu_e = \mu_g \frac{K_g}{K} + \mu_s \frac{K_b}{K} \tag{57.2}$$

The annual extraction of matter from the Earth system M is the difference between material production and the value of the recycled socio-economic stock REC. This stock is expressed as a proportion of the discarded socio-economic stock DISThis stock is expressed as a proportion of the discarded socio-economic stock, which is itself related to the obsolescence of capital (equations 57.4 and 57.5).

$$M = YM - REC \quad (57.3)$$

$$REC = \rho_e * DIS \quad (57.4)$$

$$DIS = \mu_e[DA + \zeta SES_{-1}] \quad (57.5)$$

The production of material goods YM increases the stock of durable goods $D_c$which is added to the socio-economic stock SES (net of the annually discarded stock DIS) (equations (57.6 and 57.7). The annual material waste emissions WA is the difference between the discarded socioeconomic stock and the recycled socioeconomic stock REC (equation 57.8). The conversion of natural resources into material stocks CON and the production of material goods decreases the stock of material reserves available for production RES_M (equations 57.9 to 57.11). The carbon mass CEN and the oxygen stock are given by equations (57.12) and (57.13).

$$D_c = D_{c,-1} + YM - \zeta D_{c,-1} \quad (57.6)$$

$$SES = SES_{-1} + YM - DIS \quad (57.7)$$

$$WA = DIS - REC \quad (57.8)$$

$$REV_M = REV_{M,-1} - CON_M - M \quad (57.9)$$

$$CON_M = \sigma_M RES_{M,-1} \quad (57.10)$$

$$RES_M = RES_{M,-1} - CON_M \quad (57.11)$$

$$CEN = \frac{EMIS}{car} \quad (57.12)$$

$$02 = EMIS - CEN \quad (57.13)$$

The energy expenditure required for the production E is broken down into renewable energy RE and renewable energy NRE in proportion to the parameter η_e (equation 58.1 to 58.3). The energy used in each period is dissipated (DE) according to the second law of thermodynamics (equation 58.4). The change in the energy reserve stock is equal to the conversion of energy resources into reserves CON_e net of the energy dissipated annually (equation 58.5). The stock of available energy resources RES_e decreases in proportion to its conversion into energy reserves, which is done according to a parameter σ_e (equation 58.5 to 58.7).

$$E = \varepsilon_y Y \quad (58.1)$$

$$RE = \eta_e E \quad (58.2)$$

$$NRE = E - RE \quad (58.3)$$

$$DE = RE + NRE \quad (58.4)$$

$$REV_e = REV_{e,-1} + CON_e - NRE \quad (58.5)$$

$$CON_e = \sigma_e RES_e \tag{58.6}$$

$$RES_e = RES_{e,-1} - CON_e \tag{58.7}$$

Annual CO2 ($EMIS$) emissions are the sum of land emissions ($EMIS_l$) emissions (which decline at an exogenous rate lr) and industrial emissions ($EMIS_{in}$) which depend on the consumption of non-renewable energy (equations 59.1 to 59.3). Equations (59.4) to 59.6) describe the carbon cycle: the net transfers of carbon from the atmosphere to the biosphere and ocean reservoirs $CO2_{up}$ and $CO2_{lo}$ increasing the atmospheric concentration of CO2 ($CO2_{at}$) concentration (equation 59.4). The accumulation of CO2 in the atmosphere increases radiative forcing F and the atmospheric and oceanic temperature T_{at} and oceanic temperature T_{lo} (equations 59.7 to 59.10).

$$EMIS_{in} = \beta_0 + \beta_e NRE \tag{59.1}$$

$$EMIS_l = EMIS_{l-1}(1 - lr) \tag{59.2}$$
$$EMIS = EMIS_{in} + EMIS_l \tag{59.3}$$

$$CO2_{at} = EMIS + \varphi_{11} CO2_{at,-1} + \varphi_{21} CO2_{up,-1} \tag{59.4}$$

$$CO2_{up} = \varphi_{12} CO2_{at,-1} + \varphi_{22} CO2_{up,-1} + \varphi_{32} CO2_{lo,-1} \tag{59.5}$$

$$CO2_{lo} = \varphi_{23} CO2_{up,-1} + \varphi_{33} CO2_{lo,-1} \tag{59.6}$$

$$F = F_2 log_2 \frac{C02_{at}}{CO2_{pre}} + F_{ex} \tag{59.7}$$

$$F_{ex} = F_{ex,-1} + fex \tag{59.8}$$

$$T_{at} = T_{at-1} + t_1 \left[F - \left(\frac{F_2}{sens}\right) T_{at,-1} - t_2(T_{at-1} - T_{lo-1})\right] \tag{59.9}$$

$$T_{lo} = T_{lo-1} + t_3\left(T_{at,-1} - T_{lo-1}\right) \tag{59.10}$$

Energy intensity ε_y carbon intensity β_e of non-renewable energy, and the share of renewable energy in the energy mix η_e are averages of the energy (and carbon) intensity of brown capital and green capital, weighted by their respective weights in the total productive capital stock (equations 60.1 to 60.3). The depletion ratios of material and energy reserves dep_m and energy reserves dep_e are obtained by dividing the ratio of material and energy extraction by the respective delayed reserves (equations 60.4 and 60.5). The climatic damage is a function of the atmospheric temperature variations (equation 60.6). This coefficient is used to calculate capital obsolescence for all firms. This variable also affects inflation, consumption demand, household portfolio choices, bank financing decisions, and the term structure of interest rates.

$$\varepsilon_y = \varepsilon_g \frac{K_g}{K} + \varepsilon_b \frac{K_b}{K} \tag{60.1}$$

$$\beta_e = \beta_g \frac{K_g}{K} + \beta_b \frac{K_b}{K} \tag{60.2}$$

$$\eta_y = \eta_g \frac{K_g}{K} + \eta_b \frac{K_b}{K} \tag{60.3}$$

$$dep_m = \frac{M}{REV_{M-1}} \tag{60.4}$$

$$dep_e = \frac{NRE}{REV_{E-1}} \tag{60.5}$$

$$d_t = 1 - \frac{1}{\left[1 + \varrho_1 TEMP_{at} + \varrho_2 {TEMP_{at}}^2 + \varrho_3 {TEMP_{at}}^{\varrho_4}\right]} \tag{60.6}$$

4. Validation of the model

4.1. Steady state and accounting consistency of the model

We first loosely calibrate initial stock values using Eurozone level data and set all the models parameter values with reference to the literature[21]. We then use numerical simulations to bring the macroeconomic system to a steady state and then explore the model's response to several macroeconomic and financial shocks[22] (Reyes-Ortiz, 2020; Carnevali et.al, 2021). Then, we introduce the climate block to inspect the effect of climate shocks on the economy. Finally, we use this scenario as a baseline and change some relationships and parameters, in order to analyze the potential impact of economic policy proposals.
We use Broyden's algorithm to bring the macroeconomic system to a stationary state (without taking into account climate shocks). This state is reached after 214 iterations and remains stable over 686 periods. Table 2 shows the value of the observed growth rate for the main variables of the model, as well as the absolute values reached in the first period of the stationary state.

[21] Starting values and parameters are not shown for space-saving purposes but can be found in the model code.
[22] This state is defined as a state where the stock and flow variables remain in a constant relationship to each other.

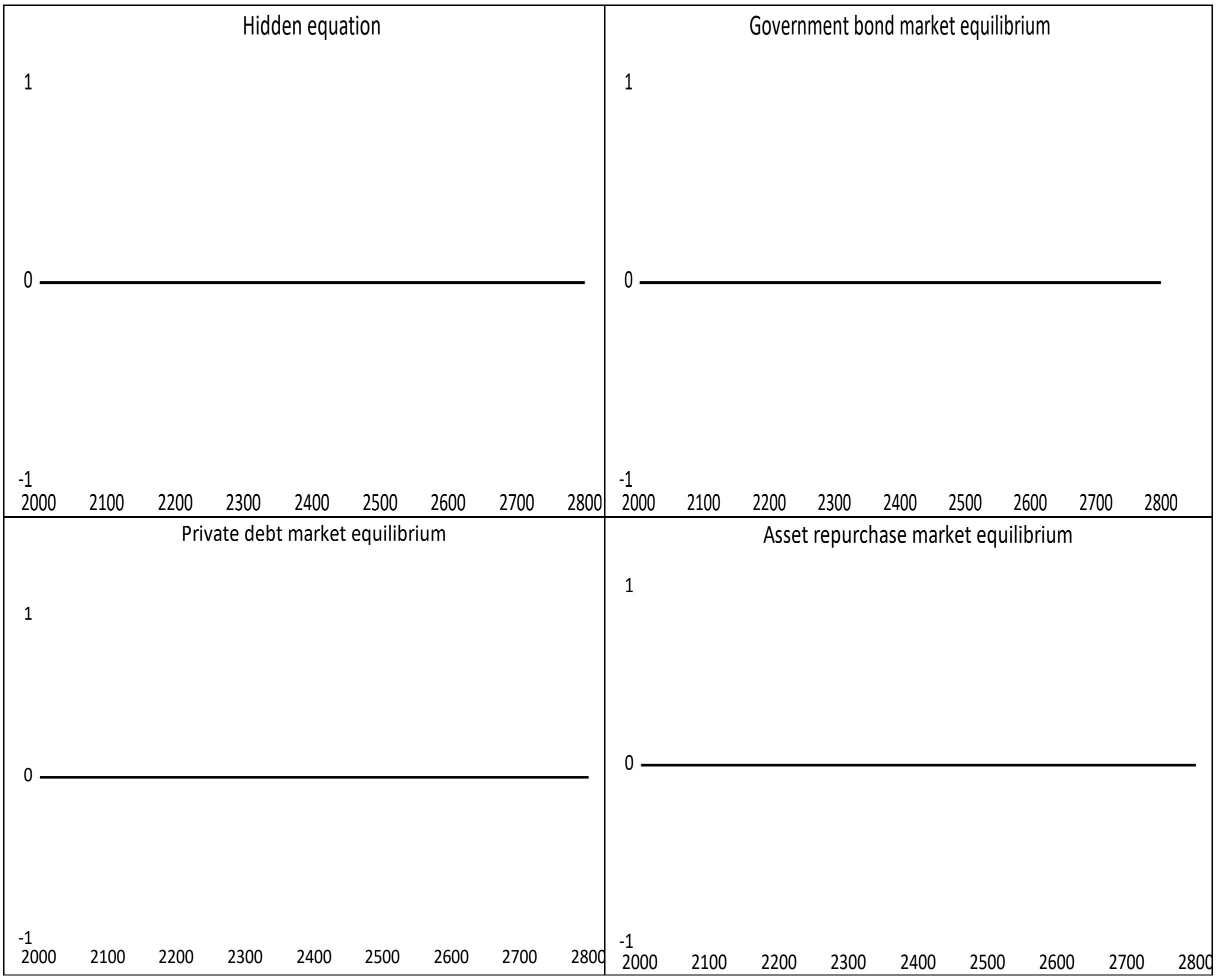
The model is calibrated to approximate the values observed in the European Union. Thus, all the nominal variables grow at an annual rate strictly equal to 4.27% (which is close to the economic growth rate observed in the EU in 2022 before the war in Ukraine).
Nominal GDP is 15 trillion and the total stock of claims held by banks is 50 trillion - in line with values observed in the same year. The structure of interbank rates and the interest rate applied to term bonds (with a maturity of one year) are aligned with the rates observed in the euro area in 2022. Interest rates are calibrated to the values observed before the 2008 financial crisis and the exceptional monetary policies of asset purchases. The range of rates respects the risk structure of interest rates and the term structure of interest rates. Prudential ratios (capital adequacy and liquidity ratio) are equal to those observed in the euro zone in 2022.
The graphs presented in Figure 1 allow us to verify the accounting consistency of the model. In all the simulations and all the states of the model, the equality between money supply and demand (the hidden equation of the model $H_s = H_d$) is respected. The equilibrium condition on the financial markets (treasury bills, a risky asset market, and the money market) is also respected.

Table 2 Steady state of the model

Macroeconomic variables	**Annual growth**	**Initial value steady state (millions of**
Nominal GDP	4.27%	15,299,420
Inflation	0%	
Disposable income (working households)	4.27%	4,049,664
Disposable income (capitalist households)	4.27%	1,022,581
Investment (social enterprises)	4.27%	97,557
Investment (capitalist companies)	4.27%	10,812,260
Consumption (capitalist households)	4.27%	913,641
Consumption (working households)	4.27%	3,470,888
Brown capital stock	4.27%	167,887,400
Green capital stock	4.27%	570,124,30
Financing structure		
Social enterprise brown loans	4.27%	48,644
Green borrowing by social enterprises	4.27%	24,120
Brown loans of capitalist companies	4.27%	722,524
Green borrowing by capitalist companies	4.27%	242,288
Issuance of green bonds by capitalist companies	4.27%	216,726
Issuance of brown bonds by capitalist companies	4.27%	646,294
Issuance of green treasury bills by capitalist	4.27%	107,695
Issuance of brown commercial paper by capitalist	4.27%	312,155
Issuance of shares of capitalist companies	4.27%	20,133
Dividends paid to shareholders	4.27%	1,253,128
Banking sector		
Total stock of receivables held on capitalist	4.27%	54,729,060
Liquidity ratio	0%	100%
Capital adequacy ratio	0%	30%
Borrower risk, social enterprises, green loans	0%	0.012
Borrower risk, social enterprises, brown loans	0%	0.013
Borrower risk, capitalist companies, green	0%	0.009
Borrower risk, social enterprises, brown financing	0%	0.088
Stock of reserve money issued under QE	0%	0
Dividends paid to shareholders	4.27%	48520
Profits		

Social enterprise profit	4.27%	495,877
Profit of capitalist enterprises	4.27%	8,710,702
Profit from investment funds	4.27%	1,332,681
Bank profits	4.27%	3,334,376
Real interest rates		
Deposit facility rate Central Bank	0%	-0.500%
Refinancing rate	0%	0%
Rate of return on deposits	0%	0.010%
Rate of return on term bonds	0%	1.130%
Interest rates on social enterprise green loans	0%	7.42%
Interest rates on social enterprise brown loans	0%	7.43%
Interest rates on green loans from capitalist	0%	7.02%
Interest rates on brown loans from capitalist	0%	7.01%
Interest rates on brown bonds	0%	7.01%
Interest rates on green bonds	0%	7.01%
Interest rate on brown bills	0%	2.01%
Interest rate on green commercial paper	0%	2.01%
Secondary market price	0%	1

Figure 1 Accounting consistency of the model



Note: the top left graph shows the difference between the supply and demand of central bank money. This equality is induced by the accounting consistency of the model. The top right graph shows the difference between the supply and demand of Treasury bills. The bottom left graph shows the difference between the stocks of risky assets held by the banking sector and the Central Bank and the liabilities on the balance sheet of private firms. The bottom right chart shows the difference between the Central Bank money issued under quantitative easing and the excessive stocks of reserve money accumulated by banks at the deposit facility.

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