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Climate change mitigation and green energy investment: A stock-flow consistent model

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ABSTRACT

This paper develops a stock-flow consistent business cycle model integrating aggregate demand dynamics, income distribution, and ecological constraints to analyze climate mitigation strategies. We propose a two-sector framework distinguishing between energy and non-energy production. The model comprises wage and rent-earning households, firms in energy and non-energy sectors, a central bank, and commercial banks. Throughout the business cycle, energy sector firms gradually increase their share of green energy investment in the face of the low-carbon transition, replacing brown technologies with green alternatives. Through numerical simulations, we show that the pace of the energy transition influences both economic outcomes and emission trajectories. A negative shock to the green energy investment share – caused e.g. by policy inaction – not only slows the low-carbon transition but also depresses aggregate demand, wages, and employment. The paper examines possibilities for reducing the carbon intensity of production and provides insights into the interactions between ecological, macroeconomic, and distributive factors during the transition to a green economy.

1. Introduction

Climate economics has traditionally relied on supply-side models to analyze the impacts of climate change and environmental policies, viewing "the economics of climate change from the perspective of neoclassical economic growth theory" (Nordhaus, 2013, p. 1080). However, there is growing recognition that focusing on demand-driven solutions and on the social aspects of climate mitigation can provide valuable insights often overlooked by conventional neoclassical frameworks (IPCC, 2022, Ch. 5). This paper contributes to this emerging literature by developing a demand-led model that incorporates ecological constraints and distributional impacts.

Recent developments in climate macroeconomics have emphasized the importance of demand-side effects and distributional considerations. The ecological stock-flow consistent (SFC) literature has gained significant traction, with the development of large-scale models providing new insights into climate-economy interactions. Among other contributions surveyed in the next section, Distefano and D'Alessandro (2023) present recent developments in the EUROGREEN model, a simulation framework designed to conduct scenario analysis for the low-carbon transition with social equity. Amending the same model, Cano Ortiz et al. (2024, p. 14) discuss a trade-off between environmental and social goals, showing that "emission reductions coincide with an increase in inequality, while growing emissions are associated with falling inequality". Our paper contributes to resolving this tension by showing how progressive taxation directed towards green investment can simultaneously achieve emission reductions and maintain employment levels.

The timing and effectiveness of climate policies have also emerged as critical factors in recent research. Focusing on adaptation policies, Distefano et al. (2025) show that timely interventions play a crucial role in preventing unchecked debt accumulation driven by climate-related damages, while gradual interventions have minimal impact despite equivalent total investment. While we focus on climate mitigation policies, this finding aligns with our results showing that the effectiveness of government mitigation spending is crucial for accelerating the low-carbon transition. Furthermore, recent empirical evidence shows that climate-related risk drivers negatively affect financial asset prices, the cost of capital, and risk assessment (Campiglio et al., 2023), indicating that climate risks heighten firms' financial fragility — as also emphasized by NGFS (2024). This channel is also incorporated into our model by assuming that the accumulation of greenhouse gas (GHG) emissions in the atmosphere negatively impacts non-energy investment.

We adopt a demand-led approach, as it is "better suited for the study of the social transformation necessary to achieve sustainability in its

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many facets" (Rezai et al., 2013, p. 70), particularly in analyzing the interactions between economic activity, energy use, and greenhouse gas emissions. Environmental policies can significantly influence aggregate demand components — such as consumption, investment, and government spending. These demand-side effects, especially in the short run, shape both economic and environmental outcomes in ways often overlooked by supply-focused models. For instance, policies aimed at reducing energy intensity or promoting sustainable consumption patterns may have counter-intuitive consequences when accounting for demand-side responses. Lower energy use could potentially reduce aggregate demand and employment in the short run. Conversely, green investment programs might stimulate demand and lead to higher growth and emissions through rebound effects (Taylor et al., 2016). Capturing these demand-side dynamics is of key importance for designing effective environmental policies.

Our model is designed as a short-run model that focuses on the interaction between demand-driven dynamics and the energy transition over business cycle frequencies. While we abstract from long-run growth determinants, the model incorporates a steady state where emissions converge to zero through a logistic green transition process. This approach is aimed at analyzing how climate policies perform under different short-run economic conditions and how transition dynamics affect the feasibility and effectiveness of mitigation strategies.

Moreover, a key feature of our approach is the integration of Goodwin-type dynamics governing investment and income distribution. While output is determined by aggregate demand in the short run, profitability plays a crucial role in shaping investment decisions and the conflicting claims of workers and capitalists over the longer term. Additionally, investment is assumed to be influenced by environmental conditions. In this regard, a relevant reference is Oliveira and Lima (2020), which – despite adopting a different modeling framework – demonstrates that environmental quality affects profitability and capital accumulation, posing particular challenges for the economic growth of developing countries with high pollution levels. Oliveira and Lima (2020) argue that the solution to this 'ecological development trap' lies in an *Environmental Big Push*, involving the exogenous transfer of green technology from advanced to developing countries. By contrast, our study focuses on single-country modeling, advocating for government-led mitigation policies. Along these lines, we model the profit share as responsive to labor market tightness and incorporate a profit-squeeze mechanism. This approach captures feedback effects between distribution, demand, and accumulation that are absent from standard models. Furthermore, investment is assumed to depend on environmental conditions, particularly the flow of GHG emissions.

Numerical simulation exercises play a critical role in exploring the implications of demand-driven models incorporating environmental factors. As noted by Rezai et al. (2013), the interactions between economic and ecological variables in such models are characterized by inherent instability and complexity. Analytical solutions are often intractable, necessitating the use of simulation techniques to trace out the system's behavior under different scenarios and policy interventions. Our model employs simulation methods to examine how various environmental policies impact output, distribution, energy use, and emissions over time.

We present a medium-scale stock-flow consistent (SFC) model, with the aim of developing a fairly tractable model while providing a framework suited for drawing concrete policy implications. As noted by Carnevali et al. (2019), ecological SFC models represent one of the two most promising internal developments within the literature, alongside two-country models. The ecological SFC literature usually focuses on large-scale models, fully integrating real, financial, and ecological flows and stock. Some examples include the models developed by Dafermos et al. (2017, 2018) and Dafermos and Nikolaidi (2021, 2022), as well as the EUROGREEN model (D'Alessandro et al., 2020; Cieplinski et al., 2021; Distefano and D'Alessandro, 2023) and the LowGrow SFC (Jackson and Victor, 2020). Against this background, we build a smaller-scale SFC model that more easily allows to understand how the system's key levers influence our endogenous variables.

The article is structured as follows. After this Introduction, Section 2 provides a concise literature review of demand-led macrodynamic approaches to climate change mitigation policies, highlighting the research gap our study addresses. Section 3 presents a two-sector SFC model, outlining its key components, including the distinction between energy and non-energy production, different types of household consumption, and the role of the government in the low-carbon transition. Section 4 discusses parameter calibration, showing through numerical simulation the key dynamics of the models and, in particular, the effect of a delayed transition of macroeconomic and environmental dynamics. Section 5 presents our main findings and their policy implications, with a comparative discussion against related contributions in the literature. Last, Section 6 concludes, summarizing our findings.

2. Background literature

The present paper examines energy transition and climate change mitigation policies within a demand-led macrodynamic framework. Building on seminal contributions in the post-Keynesian literature,[1] our model integrates a Kalecki–Steindl–Minsky approach to macrodynamics. In particular, we incorporate Kalecki's insights on investment decisions – most notably the principle of increasing risk and the acceleration principle (Kalecki, 1971; Steindl, 1979) – while also following Minsky (1982) in emphasizing the roles of loans and internal funds in financing new investments.

The literature on ecological SFC models has expanded significantly in recent years, with several large-scale frameworks now providing comprehensive analyses of climate-economy interactions. Among the most prominent contributions is the EUROGREEN model (D'Alessandro et al., 2020; Cieplinski et al., 2021; Distefano and D'Alessandro, 2023; Cano Ortiz et al., 2024), a system dynamics ecological macroeconomics model that has been applied to France and Italy to simulate policies and scenarios for low-carbon transition with social equity. The model incorporates heterogeneous households classified by economic status, innovation processes driven by input-cost ratios for energy and labor, and a comprehensive tax-benefit system that allows to model the budgetary consequences of alternative policy instruments over time. Similarly, the LowGrow SFC model developed by Jackson and Victor (2020) provides a stock-flow consistent ecological macroeconomic simulation model for Canada, tracking carbon emissions and income distribution under various policy assumptions, while incorporating an environmental burden index (EBI) and a composite sustainable prosperity index (SPI) based on seven economic, social, and environmental performance indicators. More recently, Nalin et al. (2023) developed an ecological SFC model tailored to Latin American stylized facts, extending the approaches of Carnevali et al. (2019) and Dafermos et al. (2018). Their model examines how climate-related shocks – including stricter international commodity trade regulations and increased frequency of adverse climate events – can exacerbate the external financial constraints that determine growth paths in Latin American economies.

As detailed in the next section, we build on the line of SFC models developed by Serra and Gallo (2023) and Gallo and Serra (2024), drawing on Schoder (2017) to explain short-run economic fluctuations in demand-led dynamics. While Gallo and Serra (2024) examine the role of inventories in business cycles, Serra and Gallo (2023) propose a two-sector approach – closer to our present approach – although focusing on food inventories and the role of fiscal authorities in managing price and inventories to control inflationary pressures. In contrast, our study extends this framework by incorporating an environmental dimension

[1] See, Gallo and Serra (2024) for a comprehensive discussion of the theoretical foundations of the framework adopted here.

into the economic dynamics, further relying on the structural model of Gallo (2025) to analyze the low-carbon transition.

Accordingly, this paper addresses a research gap concerning the interactions between demand-side dynamics and environmental factors. In particular, we examine the feedback effects between income distribution, aggregate demand, and capital accumulation – with their implications for GHG emissions – and the ways in which environmental conditions feed back into the economy. Additionally, in the existing literature there is still a limited integration of environmental conditions in investment decisions. In that sense, our study investigates how demand-side dynamics shape both economic and environmental outcomes during the green energy transition, and how the speed of that transition influences both economic and environmental variables. By considering climate change mitigation policies, we explore whether low-carbon transition can be achieved without triggering degrowth and without exacerbating income inequality. Our central hypothesis is that a combination of targeted public policies and progressive taxation can address the concerns raised in the literature regarding these outcomes.

Our main findings show that a negative shock to the green investment share both slows transition and dampens aggregate demand, while government effectiveness – and the speed of its response – is crucial for achieving net-zero emissions and avoiding degrowth scenarios. We further find that financing mitigation policies through progressive taxation – specifically, increasing taxes on rentier income – is consistent with reducing emissions.

3. Model

The present model adopts a strictly monetary, 'follow-the-money' perspective. This means that we track income and financial flows (e.g., investment, revenues, debt financing) and the resulting evolution of stocks (e.g., debt, deposits), rather than modeling physical units of energy or materials. This choice is motivated by our core research focus: understanding the financial feasibility and macroeconomic implications of the low-carbon transition. Therefore, in our model the transition is fundamentally constrained by the availability of green capital in the energy sector, the allocation of investment, and financing conditions. By focusing on monetary flows, the model can explicitly represent the short-run effects of transitioning to green energy sources, while assessing at the same time the distributional effects and feedbacks through the economy via costs, prices, and wages. While physical constraints (e.g., resource depletion, energy return on investment) are undoubtedly critical in the long term, their effects are ultimately mediated through the financial and macroeconomic system in the shorter term. This monetary approach is well-established in the economic literature for analyzing system-wide interactions (Caiani et al., 2016; Jackson and Victor, 2020) and provides a complement to biophysical-economic models.[2]

The economy is closed to international trade. There are two productive sectors: the non-energy sector – which produces a homogeneous good used for consumption and investment – and the energy sector, that supplies an input (energy) to the former, and undergoes a gradual shift from brown energy sources to green technologies (e.g., renewable energy) as part of the low-carbon transition. Moreover, the commercial banking sector supplies credit to firms, with loan costs based on the discount interest rate – set by the central bank – and a markup rule.

Households are divided into two groups: worker households, who supply labor and earn wages, and rentier households, who own the firms and commercial banks, receiving all profits. Finally, the government operates under a balanced budget, it taxes households and allocates tax revenues towards financing a technology that supports the energy transition. Tables 3 and 4 in Appendix A present the balance sheet and transaction flow matrices of this economy.

[2] See, for instance, King (2020).

Our model features a two-sector economy consisting of an energy sector and a non-energy sector. The energy sector plays a crucial role in the transition towards a low-carbon economy. Over the course of the business cycle, it is assumed that firms operating in the energy sector gradually increase their share of green energy investment in the face of the low-carbon transition. This transition is captured through the evolution of the green investment share in the energy sector in Section 3.9. The dynamics of this sectoral reallocation are governed by a logistic growth process, whose speed can be influenced by government policy intervention. As the energy sector expands its green capacity, this structural transformation leads to a corresponding reduction in greenhouse gas emissions, with emission flows maintaining a procyclical relationship with aggregate output (as found in the empirical literature, see Doda, 2014; Cohen et al., 2018, 2022) until the steady state is reached.

Production across all sectors is driven by demand. In the non-energy sector, firms adjust their production to meet aggregate demand, ensuring market clearing for the non-energy good. The production level in this sector also determines the output of the energy sector, as it serves as the sole consumer of energy. Moreover, an endogenous supply of credit money in the banking sector accommodates the firms' demand for loans, as their investment decisions are independent of prior savings.

To isolate business cycle dynamics, we follow Schoder (2017) in assuming an exogenously given deterministic growth trend. All model variables are expressed as deviations from this trend component.[3] The model's steady state represents a balanced growth path characterized by net-zero emissions, corresponding to a situation in which the green share of energy investment has reached its maximum level and all stock variables grow at the trend rate.

Our results indicate that fiscal policies for the energy transition can simultaneously stimulate economic activity and reduce GHG emissions, showing that climate mitigation does not necessarily require degrowth but rather effective policy intervention. Consistent with Taylor et al. (2016), the simulations highlight the role of government mitigation spending in achieving net-zero emissions. The analysis also explores different funding mechanisms for fiscal policy, concluding that taxing rentier income produces effects on the energy transition comparable to those of taxing wages. This result indicates that, within our demand-led framework, progressive taxation can support emission reduction.

The following subsections describe the behavior of each actor in this economy: worker households (Section 3.1), rentier households 3.2, firms in the energy sector 3.3, firms in the non-energy sector 3.4, central bank and commercial banks 3.5, and government 3.6. Moreover, Section 3.7 presents the goods market equilibrium in the non-energy sector, Section 3.8 outlines the determination of nominal wage inflation, and Section 3.9 discusses the environmental outcomes of the economic dynamics.

3.1. Worker households

Worker households derive their income solely from wages, earned through employment in the non-energy sector. Consequently, their total real income is given by $\omega_t L_t$, where L_t represents the employment level and ω_t denotes the real wage in period t. They consume their entire income net of taxes, where τ_w is the tax rate on wage income. The level of consumption by worker households is expressed as:

$$C_{w,t} = (1 - \tau_w)\omega_t L_t \tag{1}$$

[3] We deliberately abstract from the determinants of this long-run growth trend, which could be either demand-led (through autonomous demand components in post-Keynesian growth models) or supply-led (as in neoclassical growth theory).

As mentioned earlier, all nominal growing variables are expressed in real terms and detrended by dividing them by the product of a deterministic growth trend γ_t and the price level p_t. For instance, the nominal consumption level of worker households $\tilde{C}_{w,t}$ becomes the detrended real variable $C_{w,t} = \frac{\tilde{C}_{w,t}}{\gamma_t p_t}$ in Eq. (1). Notice that the normalization procedure results in all growing variables from period $t-1$ being divided by $(\Pi_{p,t}\Gamma)$, where $\Gamma = \frac{\gamma_t}{\gamma_{t-1}}$ and $\Pi_{p,t} = \frac{p_t}{p_{t-1}}$ represent the growth factors of the deterministic growth trend and the price level, respectively. This normalization procedure applies to all growing variables in the model, thus isolating business cycle dynamics.

3.2. Rentier households

Rentier households own the firms in both productive sectors and the commercial banks, earning profits from the energy sector ($Z_{e,t}$), non-energy sector ($Z_{n,t}$), and banks (B_t). Additionally, they receive interest income on their previous deposits ($M_{r,t}$). Each period t, they decide on their consumption level ($C_{r,t}$) and the amount to allocate to deposits ($M_{r,t}$) based on their disposable income after taxes. Their budget constraint, which is satisfied as an equality, is represented by Eq. (2):

$$C_{r,t} + \left[M_{r,t} - \frac{M_{r,t-1}}{\Pi_{p,t}\Gamma}\right] = (1-\tau_r)\left[B_t + Z_{n,t} + Z_{e,t} + r_{m,t-1}\frac{M_{r,t-1}}{\Pi_{p,t}\Gamma}\right] \tag{2}$$

where τ_r is the tax rate on rentiers' income and $r_{m,t}$ denotes the interest rate on deposits. Furthermore, rentiers consume a constant fraction $(1-s_r)$ of their disposable income after taxes and save the remaining portion as deposits:

$$C_{r,t} = (1-s_r)(1-\tau_r)\left[(B_t + Z_{n,t} + Z_{e,t}) + \frac{r_{m,t-1}}{\Pi_{p,t}}\frac{M_{r,t-1}}{\Gamma}\right] \tag{3}$$

3.3. Energy sector

The energy sector produces a single homogeneous input exclusively used in the production of the non-energy good. Consequently, the production level in the energy sector ($Y_{e,t}$) is demand-driven, determined by the energy requirements in the other sector. Moreover, given the stock of physical capital in the energy sector $K_{e,t-1}$ and a constant ratio of potential output to capital ($v_e > 0$), capacity utilization ($0 < u_{e,t} < 1$) adjusts to meet production needs:

$$Y_{e,t} = u_{e,t} v_e K_{e,t-1} \tag{4}$$

For simplicity, we assume that production in the energy sector does not require labor, as represented in Eq. (4). This assumption streamlines the analysis of labor market dynamics, as only the non-energy sector employs the labor force. Additionally, we focus on scenarios where energy demand remains insufficient to fully utilize productive capacity in that sector, ensuring that $u_{e,t}$ remains below unity throughout the model dynamics.

Investment decisions in both sectors are independent of prior savings and are driven by expected future demand conditions. Given that the non-energy sector is the sole consumer of energy, the investment behavior of energy firms is guided by the anticipated growth of this single source of demand – using the non-energy sector's accumulation rate as a proxy for expected demand growth. This assumption implies that both sectors operate with the same accommodation rate. Formally:

$$\frac{I_{e,t}}{K_e} = \frac{I_{n,t}}{K_n} \tag{5}$$

where $I_{e,t}$ and $I_{n,t}$ are the investment levels in the energy and non-energy sectors, respectively, and variables without the time subscript represent their corresponding steady-state values. Moreover, $I_{e,t}$ represents the total investment in the energy sector, which is allocated between green and brown energy sources, where the latter contributes to GHG emissions. Section 3.9 details the evolution of the investment shares in these two energy types.

Eq. (6) represents the dynamics of the capital stock of the energy sector over time:

$$K_{e,t} = I_{e,t} + (1-\delta)\frac{1}{\Gamma}K_{e,t-1} \tag{6}$$

where $\delta > 0$ represents a constant depreciation rate. Since investment decisions follow an independent function, firms in both sectors rely on new borrowing from commercial banks to finance a fraction ξ of their investment, while the remaining fraction $(1-\xi)$ is covered using current profits. For simplicity, the fractions ξ and $(1-\xi)$ are assumed to be identical across both sectors, and firms do not retain profits. Eq. (7) describes the change in the debt balance for firms in the energy sector, which is entirely determined by the debt-financed portion of their investment. Additionally, there is no debt amortization, and the interest payment on debt (i.e., their financial cost) is subtracted from the profits distributed to rentier households, along with the remaining fraction of the investment, as Eq. (8) shows:

$$D_{e,t} - \frac{D_{e,t-1}}{\Pi_{p,t}\Gamma} = \xi I_{e,t} \tag{7}$$

$$Z_{e,t} = Y_{e,t} - (1-\xi)I_{e,t} - \frac{r_{D,t-1}}{\Pi_{p,t}\Gamma}D_{e,t-1} \tag{8}$$

3.4. Non-energy sector

The non-energy sector produces a single homogeneous good, used for consumption and investment. In the production process, firms combine three inputs - physical capital ($K_{n,t-1}$), labor ($L_{n,t}$), and energy - through a fixed-coefficient technology:

$$Y_{n,t} = \min\{v_K u_{n,t} K_{n,t-1}; v_L L_t; v_{n,e} Y_{e,t}\} \tag{9}$$

where v_K denotes the potential output-to-capital ratio, $u_{n,t}$ is the capacity utilization rate of the physical capital stock in the non-energy sector, v_L represents the output-to-labor ratio, and $v_{n,e}$ is the ratio of non-energy output to energy input. Notice that we assume constant output-energy ratio (or energy productivity) and energy-labor ratio (or energy intensity), represented as $\frac{Y_{n,t}}{Y_{e,t}} = v_{n,e}$ and $\frac{Y_{e,t}}{L_t} = \frac{v_L}{v_{n,e}}$, respectively. Additionally, we do not account for labor productivity growth, which could contribute to mitigation by enhancing energy efficiency (Taylor et al., 2016).[4] Nonetheless, the model still captures the energy transition, as the energy sector shifts from brown to green energy sources (Section 3.9).

Since production is demand driven (as we discuss in Section 3.7), the goods market equilibrium determines the production level ($Y_{n,t}$). In turn, Eq. (9) specifies the capacity utilization rate $u_{n,t}$, the energy input utilized ($Y_{e,t}$, as detailed in the previous subsection), and the employment level:

$$L_t = \frac{Y_{n,t}}{v_L} \tag{10}$$

For a constant output-to-labor ratio, the average real labor cost of production is represented by ϕ_t:

$$\phi_t = \frac{\omega_t L_t}{Y_{n,t}} = \frac{\omega_t}{v_L} \tag{11}$$

As ϕ_t is a function of the real wage, the real labor cost of production is affected by changes in the nominal wage, which we detail in Section 3.8, and price inflation ($\Pi_{p,t}$). Regarding the pricing decision,

[4] For an analysis of the relationship between pollution and labor productivity in a demand-led model, see, for example, Oliveira and Lima (2022).

firms set a mark-up on the average labor cost, in line with Kalecki (1971), Schoder (2017), and Serra and Gallo (2023):

$$1 = (1+\varepsilon)\left(\frac{\Pi_{w,t}}{\Pi_w}\right)^{-\varphi_{\phi\pi}}\phi_t \tag{12}$$

where $\varepsilon > 0$ denotes the mark-up factor, $\Pi_{w,t}$ represents wage inflation, and $\varphi_{\phi\pi} > 0$ is a parameter.[5] The investment decision follows Eq. (13). Firms base their investment plans on expected sales – proxied by sales in the previous period ($Y_{n,t-1}$) – as well as on their outstanding debt (D_{t-1}), the financial cost of that debt – captured by the interest rate ($r_{D,t}$) – and the labor cost of production (ϕ_t). All variables are expressed as ratios to their respective steady-state values. From this perspective, it is the deviation of each variable from its long-term growth trend that drives changes in investment behavior.[6] Additionally, we assume that the flow of GHG emissions, given by $\Delta\Omega_t$, affects the investment decision. The dynamics of $\Delta\Omega_t$ is detailed in Section 3.9.

$$\frac{I_{n,t}}{K_n} = \left[1-(1-\delta)\frac{1}{\Gamma}\right]\left(\frac{Y_{n,t-1}}{Y_n}\right)^{\varphi_{i,y}}\left(\frac{D_{n,t-1}}{D_n}\right)^{-\varphi_{i,d}}\left(\frac{r_{D,t}}{r_D}\right)^{-\varphi_{i,r_d}}\left(\frac{\phi_t}{\phi}\right)^{-\varphi_{i,\phi}}\left(\frac{1+\Delta\Omega_t}{1+\Delta\Omega}\right)^{-\varphi_{i,\Omega}} \tag{13}$$

where $\varphi_{i,y}$, $\varphi_{i,d}$, φ_{i,r_d}, $\varphi_{i,\phi}$, and $\varphi_{i,\Omega}$ are positive parameters that measure the responsiveness of investment to deviations of the corresponding variables from their steady-state levels — as represented by the variables without the time subscript. The evolution of $K_{n,t}$ is given by:

$$K_{n,t} = I_{n,t} + (1-\delta)\frac{1}{\Gamma}K_{n,t-1} \tag{14}$$

Similar to the energy sector, as discussed in Section 3.3, firms in the non-energy sector also rely on new borrowing to finance a fraction ξ of their investment, with the remaining portion covered by cash flows, as shown in Eqs. (15) and (16). Additionally, firms in the non-energy sector also distribute all profits to rentiers after remunerating the inputs used in production (labor and energy), paying for the fraction $(1-\xi)$ of their investment, and servicing the interest on debt, as detailed in Eq. (16).

$$D_{n,t} - \frac{D_{n,t-1}}{\Pi_{p,t}\Gamma} = \xi I_{n,t} \tag{15}$$

$$Z_{n,t} = Y_{n,t} - \omega_t L_{n,t} - Y_{e,t} - (1-\xi)I_{n,t} - \frac{r_{D,t-1}}{\Pi_{p,t}\Gamma}D_{n,t-1} \tag{16}$$

3.5. Central bank and commercial banks

The central bank acts through setting the discount rate (r_M) aiming at controlling price inflation. The monetary policy decision is influenced by deviations of price inflation and economic activity in the non-energy good sector from their steady-state levels.

$$\frac{r_{M,t}}{r_M} = \left(\frac{\Pi_{p,t}}{\Pi_p}\right)^{\varphi_{r,\pi}}\left(\frac{Y_{n,t}}{Y_n}\right)^{\varphi_{r,y}} \tag{17}$$

Moreover, commercial banks lend to firms, accommodating with an endogenous supply of money credit their demand for credit to fund their investments. The borrowing cost is given by a mark-up rule on the discount interest rate:

$$r_{D,t} = (1+\theta)r_{M,t} \tag{18}$$

where $r_{D,t}$ is the interest rate charged by commercial banks on new loans and θ is a mark-up factor. Furthermore, as anticipated in Section 3.2, commercial banks distribute to rentiers their profits, given by the difference between the debt servicing of firms and the remuneration on deposits that banks pay:

$$B_t = \frac{r_{D,t-1}}{\Pi_{p,t}}\frac{D_{n,t-1}}{\Gamma} + \frac{r_{D,t-1}}{\Pi_{p,t}}\frac{D_{e,t-1}}{\Gamma} - \frac{r_{M,t-1}}{\Pi_{p,t}}\frac{M_{r,t-1}}{\Gamma} \tag{19}$$

3.6. Government

The government maintains a balanced budget, taxing households at rates τ_w on labor income and τ_r on other types of income. All tax revenues are allocated to a demand-enhancing expenditure, which supports technologies aimed at advancing the energy transition. A similar public effort to mitigate climate change is noted in Rezai et al. (2018). In this context, we draw on Tavani and Zamparelli (2017) by assuming that technical progress is costly, although in our model, this cost is specifically associated with the energy transition. Eq. (20) outlines the budget constraint of the government:

$$G_t = \tau_w\omega_t L_t + \tau_r\left(B_t + Z_{n,t} + Z_{e,t} + \frac{r_{M,t-1}}{\Pi_{p,t}}\frac{M_{r,t-1}}{\Gamma}\right) \tag{20}$$

Notice that, as the government taxes rentier households – who save a fraction of their income – and spend all tax revenues, our model features a similar effect to the one analyzed by Rezai et al. (2013), according to which "mitigation expenditure increases the investment multiplier and thus output" (p. 73).

3.7. Equilibrium

The equilibrium of the model is achieved when markets clear in both sectors. As discussed earlier, production in both sectors is determined by demand conditions, with capacity utilization in both physical capital stocks adjusting to maintain equilibrium. In the energy sector, production matches the demand for energy required in the production of the non-energy good. In the non-energy sector, the supply–demand equilibrium is governed by aggregate demand conditions:

$$Y_{n,t} = C_{w,t} + C_{r,t} + I_{e,t} + I_{n,t} + G_t \tag{21}$$

3.8. A conflicting-claims bargaining process

Eqs. (11)–(12) and (22)–(24) represent a dynamics that determines the average real labor cost of production (ϕ_t), price inflation ($\Pi_{p,t}$), wage inflation ($\Pi_{w,t}$), the bargaining power of workers (v_t) in the conflicting-claims process, and the real wage (ω_t). Wage inflation is a function of the gap between workers' desired level of real wage (ω_w^d), which is exogenously given, and the real wage from the preceding period:

$$\Pi_{w,t} - 1 = v_t\left(\omega_w^d - \omega_{t-1}\right) \tag{22}$$

where v_t measures the bargaining power of workers over the negotiation of nominal wage inflation, which varies according to employment conditions relative to a steady-state level:

$$\frac{v_t}{v} = \left(\frac{L_t}{L}\right)^{\varphi_{vl}} \tag{23}$$

where φ_{vl} is a positive parameter. Last, the growth rate of real wages is given by the difference between nominal wage inflation and price inflation:

$$\frac{\omega_t}{\omega_{t-1}} - 1 = \Pi_{w,t} - \Pi_{p,t} \tag{24}$$

[5] The mark-up formulation in Eq. (12) follows the approach introduced by Schoder (2017). Although the price level does not appear explicitly on the left-hand side of the equation, it is important to note that it is embedded in the denominator of ϕ_t, as defined in Eq. (11).

[6] For instance, $Y_{n,t-1}/Y_n$ can be interpreted as an indicator of the output gap.

3.9. Energy transition and GHG emissions dynamics

Throughout the business cycle, it is assumed that firms in the energy sector gradually increase their share of investment in green, low-carbon technologies to meet decarbonization requirements.[7] This process is captured by Eq. (25), where $\alpha_{e,t}$ represents the share of energy sector investment allocated to green technologies:

$$\alpha_{e,t} = \alpha_{e,t-1}[1 + r(G)(\alpha_e^{max} - \alpha_{e,t-1})] \tag{25}$$

where $\alpha_{e,t}$ is the green energy investment share. The variable gradually converges to its steady state α_e^{max}, following a logistic growth process. The intrinsic growth rate of this process is, however, not likely to be parametric, being affected by uncertainty, and economic as well as environmental policies. In particular, through fiscal policy, the government can accelerate the speed of the low-carbon transition – as captured by $r = r(G)$.[8] For the sake of simplicity, we assume a linear effect of government spending on the transition path of $\alpha_{e,t}$, such that $r = \varphi_{\alpha,G}G$.[9] Accordingly, Eq. (25) becomes:

$$\alpha_{e,t} = \alpha_{e,t-1}[1 + \varphi_{\alpha,G}G(\alpha_e^{max} - \alpha_{e,t-1})] \tag{26}$$

The diffusion process described in Eqs. (25) and (26) shares the same conceptual foundation with the formulation proposed by Gallo (2025), in that both frameworks model the gradual reallocation of investment shares towards green technologies, with green technology adoption starting slowly, accelerating during the diffusion phase, and decelerating as full adoption is approached. However, our approach introduces two key differences. First, in Gallo (2025) the adjustment leads to a fully green investment allocation ($\alpha_e^{\max} = 1$). Second, in the latter the speed of the low-carbon transition is assumed to be time-invariant, an assumption that is relaxed in our paper. However, both contributions reflect an empirically grounded rationale for the transition mechanism, consistent with stylized facts on technological diffusion. As argued in Gallo (2025), the dynamics of green technology adoption are shaped by both learning processes and policy interventions. The first channel is supported by recent evidence from IRENA (2024, p. 51), which documents high learning rates in renewable technologies. Second, by allowing the speed of adjustment to depend on government intervention, the present model captures both the self-reinforcing dynamics of technological learning and the enabling role of public intervention (Castrejon-Campos et al., 2022; Herzer, 2025).

The resulting sectoral shift affects emissions dynamics: as the energy sector's share of total investment rises to support the low-carbon transition, the net accumulation of greenhouse gas (GHG) emissions is expected to slow. Denoting cumulative emissions by Ω, their flow is represented as $\Delta\Omega$. Furthermore, as documented by the empirical literature Doda (2014) and Cohen et al. (2018, 2022), emission flows tend to be positively correlated with output over the business cycle. This is captured by the second term of Eq. (27):[10]

$$\Delta\Omega = (\alpha_{e^{max}} - \alpha)\left(\frac{1 + \nu_{n,e}}{\nu_{n,e}} \cdot Y_n\right)^{\psi_\Omega} \tag{27}$$

where ψ_Ω captures the sensitivity of GHG emissions to total output.

[7] It is important to acknowledge that our model abstracts from relative price considerations and cost differentials between green and non-green energy sources. This simplification allows us to focus on the quantity dynamics of the transition over the business cycle, while the analysis of price effects and technology choice considerations remains beyond the scope of this study.

[8] For a policy-oriented discussion, see Semmler et al. (2021).

[9] To ensure that our results are not driven by the particular assumption on this functional form, we test an alternative nonlinear specification of $r(G)$ in the Online Appendix D.

[10] It is important to note that the term in round brackets is equal to total output, i.e. $\frac{1+\nu_{n,e}}{\nu_{n,e}} Y_{n,t} = \frac{Y_{e,t}+Y_{n,t}}{Y_{n,t}} Y_{n,t} = Y_{e,t} + Y_{n,t}$.

The structure of the model is summarized, in its key elements in Fig. 1.

4. Parameter calibration and simulation results

The model is simulated in line with the empirical literature and evidence for the US economy. Specifically, we fine-tune the model to ensure that certain key variables, such as the shares in national product of investment, consumption by workers and capitalists, etc., match the real-world data observed in the United States from the first quarter of 1992 up to the last quarter of 2019, prior to the pandemic-induced crisis. In doing so, the model's parameters are not estimated; rather, the calibration is intended to roughly match empirical moments and to serve an illustrative purpose. The analysis therefore relies on simulations to highlight the model's internal mechanisms and to examine the effects of varying selected parameters. Given the similar scope, many parameters that are in common with Gallo and Serra (2024) are taken from their contribution. Parameter values and exogenous variables are reported in Tables 1 and 2.

The model is simulated in Dynare (Adjemian et al., 2022). We generate impulse response functions (IRFs) using the stoch_simul command in Dynare, running the simulation for 50 periods, assuming that the economy starts from its steady-state values (Appendix B). Simulations are expressed as log-deviations from the steady state. All measurement equations are reported in the Online Appendix C. We emphasize that these simulations assume the model's steady-state equilibrium and analyze deviations from that state following non-cumulative shocks of one standard deviation in selected variables of interest. Furthermore, this numerical simulation should be interpreted as an exercise aimed at indicating the direction of the impacts rather than estimating their precise magnitude or the time required for convergence.

Since the simulations analyze deviations from an equilibrium state, it is important to highlight that GHG emissions dynamics also converge to a steady state in the exercise — in correspondence of net-zero emissions. Given that the steady state features decoupling of the model's economic and environmental dimensions, any exogenous disturbance temporarily reintroduces an interaction between the two spheres, generating positive net emissions. In particular, a negative one-standard-deviation shock to the share of green energy investment captures a situation in which the diffusion of green technologies slows down or faces policy and/or technological setbacks.[11] This mechanism reflects an adverse shift in the pace of the energy transition, illustrating the economys dynamic adjustment process toward the steady state. Therefore, the analysis explores how a slowdown in the low-carbon transition affects macroeconomic dynamics under different parameter configurations. By comparing the macroeconomic and emission responses to a negative shock in the speed of the low-carbon transition, we illustrate how the economy-environment interaction influences the transitional path towards net-zero emissions. The results of this analysis are presented in Figs. 2–5.

The baseline results are compared against three alternative scenarios. First, we show the effect of a reduction or increase in the tax rates on rentier income (τ_r) and labor income (τ_w). Next, we discuss how a change in the sensitivity of the energy sector investment share to government spending can affect the environmental and economic dimension of the model. Parameter values for these alternative scenarios are reported in brackets in Table 1.

As previously explained, the analysis captures the transition dynamics from an initial steady state characterized by a relatively low share of

[11] As can be verified in the replication codes available online, the shock is applied to Equation Eq. (26). Similar shocks are applied to other variables, as reported in Online Appendix D, which shows the economic dimension of the model and its consistency with standard post-Keynesian results through impulse response functions that exclude environmental dynamics.

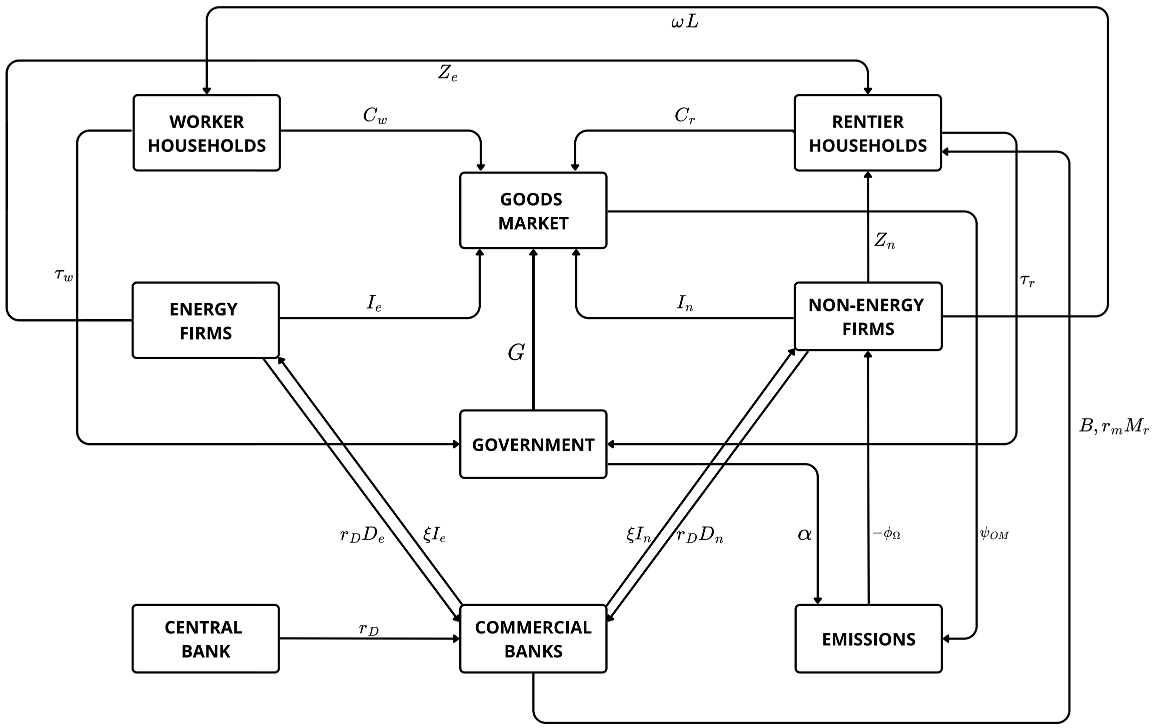

Fig. 1. Model representation.

Table 1
Parameter values.

Parameter	Description	Value
Γ	Deterministic growth factor of output	1.006
ε	Price mark-up	0.554
δ	Capital depreciation rate	0.014
θ	Mark-up on discount rate	1.140
$\varphi_{\phi\pi}$	Wage inflation elasticity of the markup	0.100
$\varphi_{i,d}$	Investment sensitivity to debt	0.010
$\varphi_{i,r}$	Investment sensitivity to interest rate	0.200
$\varphi_{i,\phi}$	Investment sensitivity to labor cost	0.200
$\varphi_{i,y}$	Investment sensitivity to output	0.200
$\varphi_{r,\pi}$	Taylor rule sensitivity to inflation	1.500
$\varphi_{r,y}$	Taylor rule sensitivity to output	0.125
φ_{vL}	Bargaining power sensitivity to employment	0.500
ω_w^d	Workers' desired real wage	1.890
ξ	Fraction of investment financed by debt	0.130
s_r	Rentiers' saving rate	0.291
τ_w	Tax rate on wages	0.2 (0.14; 0.26)
τ_r	Tax rate on rentier income	0.2 (0; 0.4)
u_e	Capacity utilization (energy)	0.800
v_e	Potential output-to-capital ratio (energy)	0.076
v_K	Potential output-to-capital ratio (non-energy)	0.126
v_L	Output-to-labor ratio	2.921
Ψ_Ω	Emissions sensitivity parameter	0.500
$\varphi_{i,\Omega}$	Investment sensitivity to emissions	−0.500 (−0.35; −0.65)
$\varphi_{\alpha,G}$	Effectiveness of government mitigation spending	0.5 (0.35; 0.65)
$\alpha_{n,\max}$	Maximum green share of energy investment	0.900
ρ_{in}	Persistence of investment shock	0.500
ρ_r	Persistence of interest rate shock	0.500
ρ_{tw}	Persistence of wage tax shock	0.500
ρ_{tr}	Persistence of rentier tax shock	0.500
ρ_v	Persistence of bargaining power shock	0.500
ρ_Ω	Persistence of emissions shock	0.500
$v_{n,e}$	Non-energy to energy output ratio	6.667

green investment – where GHG emissions remain positive ($dev\Omega > 0$) – to a steady-state equilibrium in which green investment reaches a level sufficient to achieve a net-zero GHG emissions scenario ($dev\Omega = 0$). In all cases, a negative shock to the green investment share initially raises GHG emissions ($dev\Omega > 0$), which, in turn, adversely affects macroeconomic dynamics through the investment channel.

As shown in Fig. 2, the magnitude of the peaks and troughs in the IRFs is larger (in absolute values) when the rentier income tax rate is

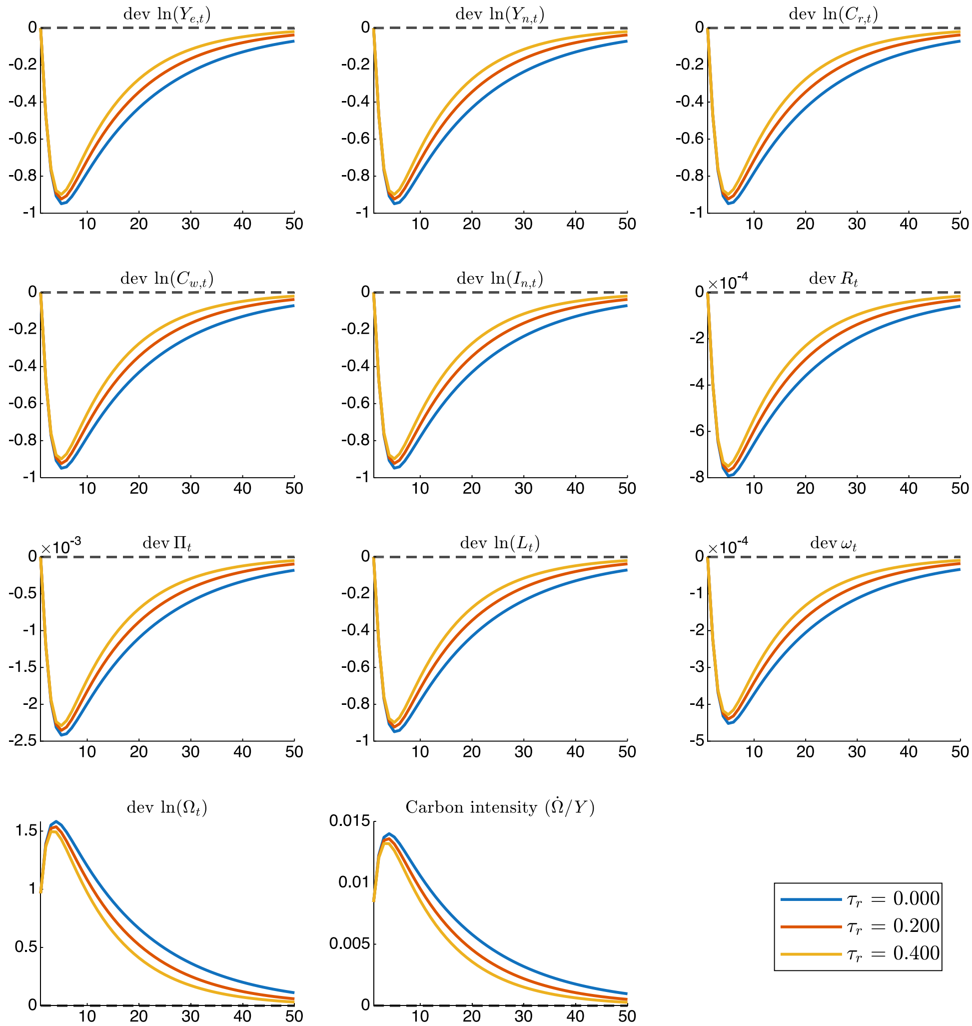

Fig. 2. Impulse responses to a random negative disturbance to the share of green energy investment (e.g., triggered by an energy shock) under different tax rates on rentier income.
Note: The graphs show, from top left to right, log deviations in energy output, non-energy output, rentier consumption, worker consumption, non-energy investment, interest rate, inflation, employment, real wage, GHG emissions, and carbon intensity.

lower. Conversely, a higher rentier tax rate ($\tau_r = 0.4$) compared to the baseline scenario mitigates the negative effects of the shock. It reduces both the positive impact on GHG emissions and the adverse effects on macroeconomic variables, while accelerating the convergence to the steady state. Thus, Fig. 2 features both the demand-boosting effect of mitigation expenditure and its indirect influence on investment through emission reduction. A similar pattern emerges in Fig. 3, where a higher tax rate on wages leads to lower worker consumption but is offset by increased mitigation spending, which, in turn, stimulates investment by curbing emissions.

The effectiveness of mitigation policies chiefly depends on the parameter $\varphi_{\alpha,G}$ (Fig. 4), which captures the sensitivity of the green share of energy-sector investment to government spending. When the sensitivity decreases ($\varphi_{\alpha,G} = 0.35$), the emission peak becomes more pronounced, and the transitional dynamics towards the steady state – and hence net-zero emissions – become considerably slower. These effects propagate to macroeconomic dynamics through the impact of emissions on non-energy sector investment, leading to lower output, consumption, and real wages. Conversely, if the sensitivity increases ($\varphi_{\alpha,G} = 0.65$) – for instance, due to the government directing a higher share of public spending into renewable energy projects – the negative shock to α generates more contained adverse effects, and the economy reaches the steady state faster.

The investment sensitivity to GHG emissions ($\varphi_{i,\Omega}$) proves to be a key determinant of how the economy responds to green energy investment shocks through the investment channel, while leaving emissions dynamics unchanged (Fig. 5). In other terms, this sensitivity parameter affects the transmission mechanism from emissions to investment, rather than the environmental outcome itself. The parameter significantly influences macroeconomic dynamics; when investment sensitivity to emissions is weaker ($\varphi_{i,\Omega} = -0.350$), the negative shock to the green energy investment share generates more contained effects on output, consumption, and employment, with smaller peaks and troughs in the adjustment process. Conversely, when investment becomes more sensitive to environmental conditions ($\varphi_{i,\Omega} = -0.650$), the same emission trajectory produces amplified macroeconomic responses. The contractionary effects on non-energy investment, output, and employment are more pronounced, as are the subsequent recovery dynamics. This parameter thus captures how strongly the real economy responds to environmental conditions via the investment channel, playing a significant role in determining the magnitude of business cycle fluctuations.

Fig. 6 displays the results of a Sobol-based global sensitivity analysis for a subset of our parameter space, focusing on those with direct policy-relevance (e.g. tax rates, mitigation spending sensitivity) and/or

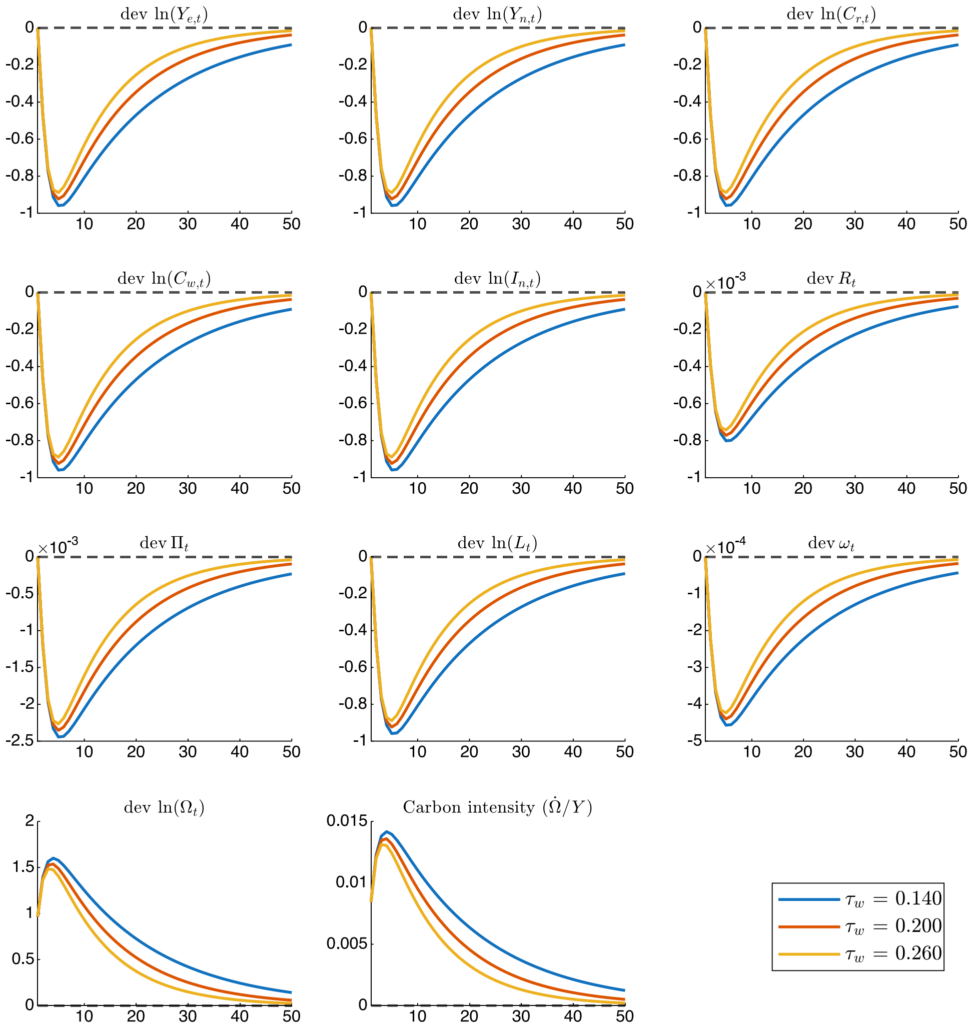

Fig. 3. Impulse responses to a random negative disturbance to the share of green energy investment (e.g., triggered by an energy shock) under different tax rates on wages.
Note: The graphs show, from top left to right, log deviations in energy output, non-energy output, rentier consumption, worker consumption, non-energy investment, interest rate, inflation, employment, real wage, GHG emissions, and carbon intensity.

those that are not well identified in the existing literature (e.g. investment sensitivities). The sensitivity analysis is implemented through Latin Hypercube Sampling with 1000 parameter combinations, examining the sensitivity of maximum absolute energy-sector output deviations (`max|devlnYecom|`) to a random negative shock applied to the green investment share (α). The methodology employs correlation-based sensitivity indices as proxies for first-order Sobol indices, systematically varying all model parameters within their calibrated ranges and computing the absolute correlation between parameter values and the resulting impulse response magnitudes. The analysis reveals an extreme concentration of model sensitivity in the parameter capturing the investment elasticity to emissions ($\varphi_{i,\Omega}$), which achieves a sensitivity index of approximately 0.95, indicating that variations in this single parameter account for nearly all variance in the energy sector's response to green investment shocks. The remaining parameters, including all other investment sensitivities, exhibit markedly lower sensitivity indices (all below 0.2), showing that the model's green transition dynamics are fundamentally governed by the behavioral parameter linking investment decisions to GHG emissions rather than by conventional macroeconomic or fiscal policy parameters.

5. Discussion and policy implications

Our results highlight relevant implications of integrating an environmental dimension to a demand-led macrodynamic framework. For instance, while reallocating resources from household consumption to public spending has no direct economic effect – since both agents spend their entire income – the rebalancing of aggregate demand components influences economic dynamics once carbon emissions and climate change mitigation policies are taken into account. This occurs because emissions affect investment, and consequently, the growth of aggregate demand. Furthermore, delaying the green transition – for example, by reducing the scope and ambitions of government mitigation policies – has adverse effects for investment and economic growth, leading to fossil fuel lock-in effects. As Distefano et al. (2025) also emphasize, the pace of government action to limiting both economic and environmental damage is ok key importance.

Furthermore, we address trade-offs identified in recent studies Cano Ortiz et al. (2024) by examining how climate change mitigation can be reconciled with improvements in income distribution. We argue that a balanced progressive tax system, combined with public spending on energy transition, can contribute to reducing emissions, while sustaining wage and employment levels. Both exercises demonstrate that emissions can be reduced without triggering a degrowth scenario

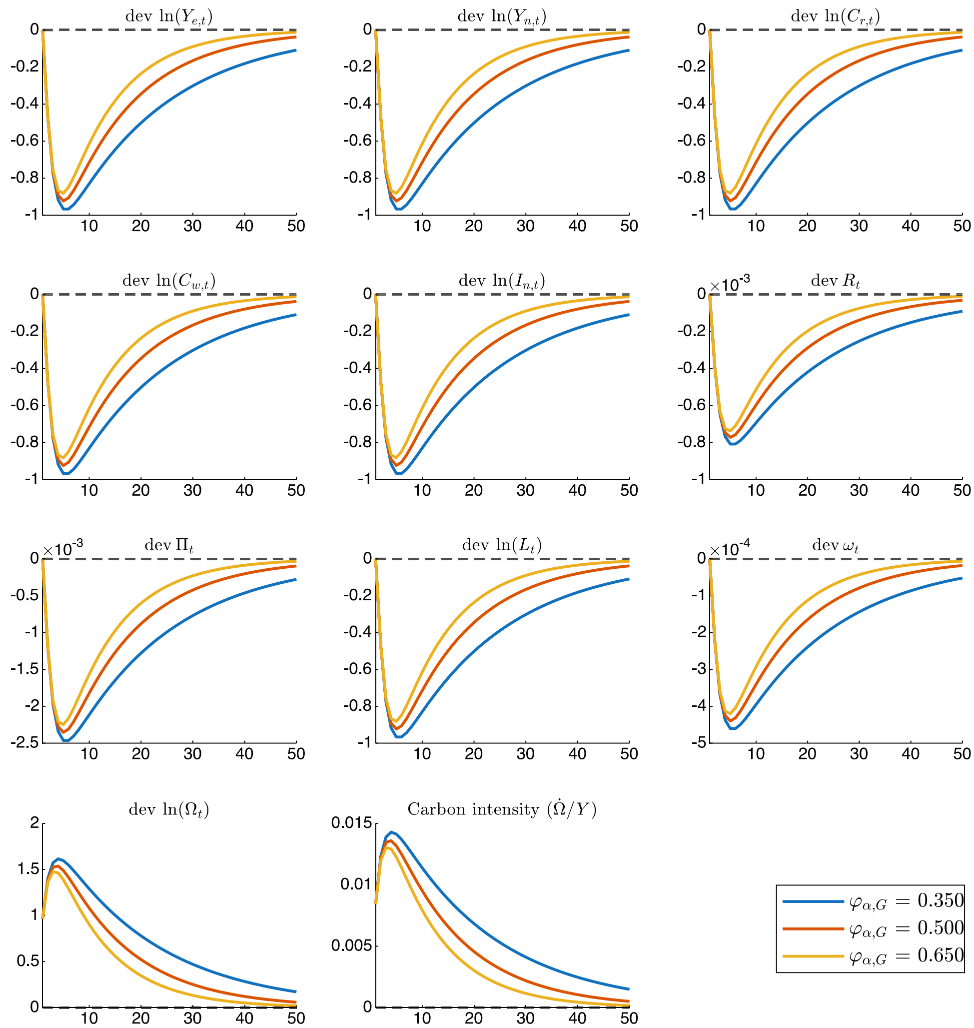

Fig. 4. Impulse responses to a random negative disturbance to the share of green energy investment (e.g., triggered by an energy shock) under different energy sector sensitivity to government spending.
Note: The graphs show, from top left to right, log deviations in energy output, non-energy output, rentier consumption, worker consumption, non-energy investment, interest rate, inflation, employment, real wage, GHG emissions, and carbon intensity.

or lowering employment, as shown by the yellow curve in both figures – addressing concerns raised by Rezai et al. (2013). While some macroeconomic rebound effects are observed, with higher mitigation expenditure stimulating economic activity – as also emphasized by Taylor et al. (2016) – we identify feedback effects from economic growth on the government's balanced budget. This, in turn, sustains higher mitigation spending, enabling a more intensive shift towards cleaner energy sources along the growth trajectory.

Hence, our results suggest that even in a demand-led model – where demand-boosting policies accelerate economic activity and, consequently, GHG emissions – the cost of the energy transition does not have to fall solely on workers. In fact, financing mitigation policies through rentier taxation can also contribute to reducing emissions. This finding is particularly relevant given Taylor's (2016) concerns about climate policies exacerbating income inequality and intensifying distributional conflicts.

We also emphasize that the effectiveness of these policies depends on the underlying economic structure.[12] For instance, our sensitivity analysis shows that the transition towards a low-carbon scenario hinges on the government's capacity to stimulate green energy investment. As expected, higher energy intensity of production (captured by $1/\nu_{n,e} = Y_e/Y_n$) raises net emissions and dampen economic activity. However, when comparing the IRFs for Y_e with the parameters of the investment function, we verify that economic dynamics are relatively less sensitive to changes in the former, highlighting the importance of demand-side factors – namely, the ones concerning investment decision – in emissions dynamics. Likewise, our results remain largely unchanged when altering parameters related to firms' borrowing decisions (ξ) and interest rates.

Nonetheless, the IRF analysis shows that economic dynamics are highly responsive to the degree of investment sensitivity to changes in the environmental side of the model: a stronger responsiveness of investment to GHG emissions (captured by the parameter $\varphi_{i,\Omega}$) amplifies economic volatility along the trajectory towards equilibrium. The IRFs indicate that all economic variables considered in the analysis are significantly affected by this parameter – spanning both the nominal and real sides of the model. Furthermore, the model's outcomes prove highly sensitive to variations in the investment sensitivity to emissions. This highlights the importance of incorporating the environmental dimension into macroeconomic analysis, as climate change is likely to influence investment decisions.

[12] Our code, data, IRFs, and sensitivity analysis results are available at: https://github.com/ettore-gallo/Pereira_Serra-Gallo/tree/main.

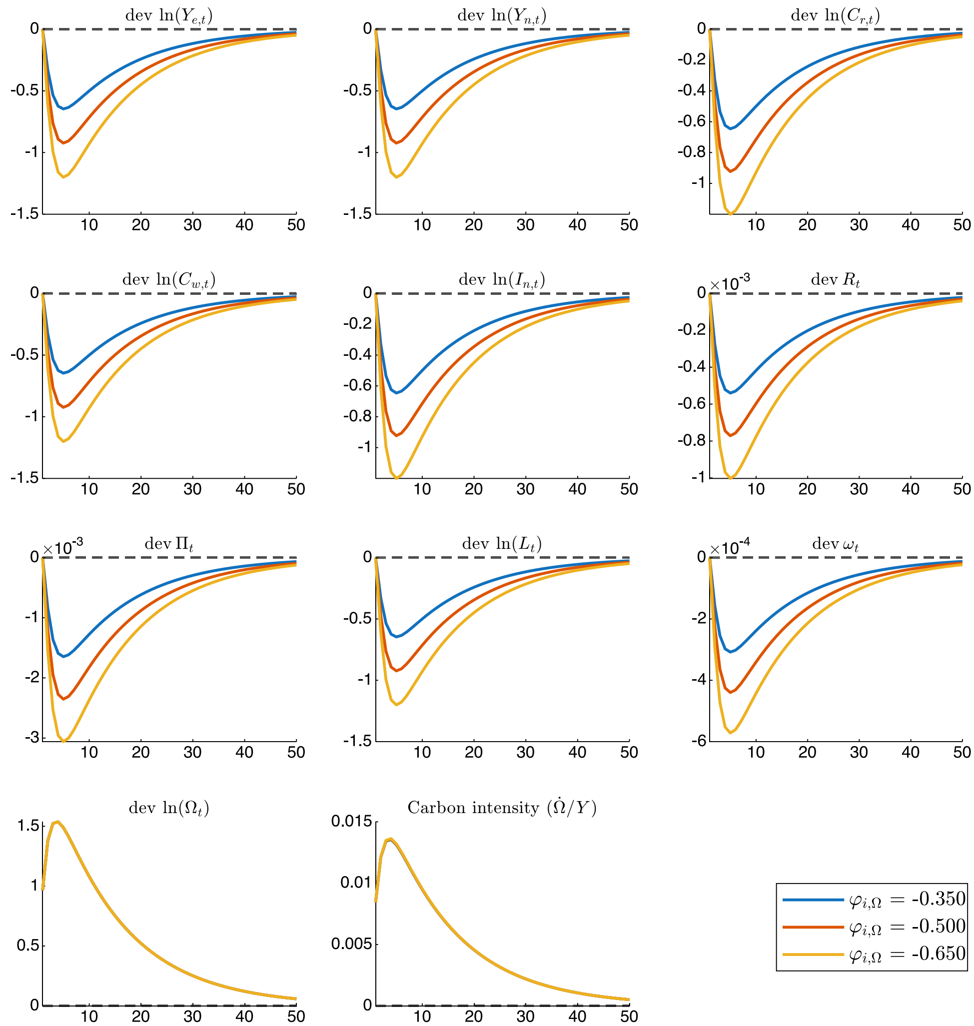

Fig. 5. Impulse responses to a random negative disturbance to the share of green energy investment (e.g., triggered by an energy shock) under different investment sensitivity to GHC emissions.
Note: The graphs show, from top left to right, log deviations in energy output, non-energy output, rentier consumption, worker consumption, non-energy investment, interest rate, inflation, employment, real wage, GHG emissions, and carbon intensity.

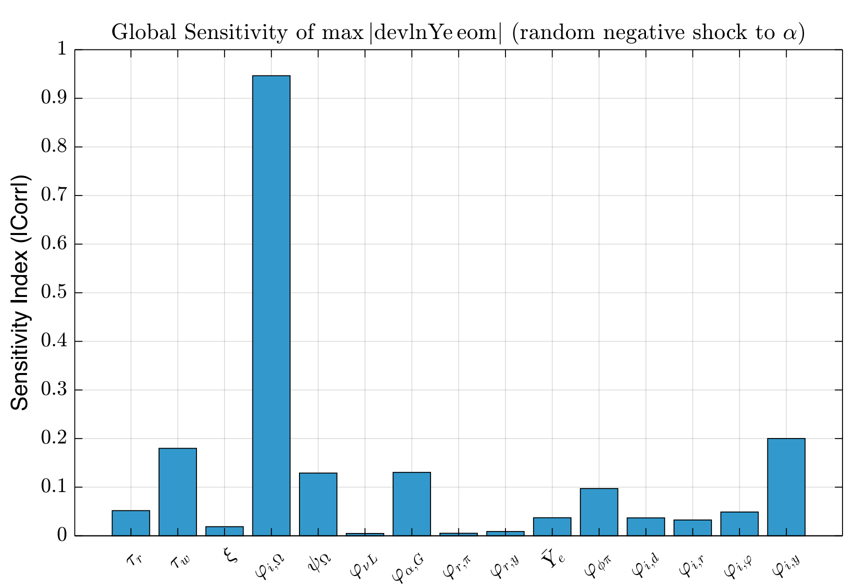

Fig. 6. Global sensitivity analysis.

Table 2
Steady-state values (calibrated).

Parameter	Description	Value
Π_p	Price inflation	1.006
K_n	Capital stock (non-energy)	9.896
Y_n	Output (non-energy)	1.000
Y_e	Output (energy)	0.150
Y	Total output	1.150
L	Employment	0.342
C_r	Rentier consumption	0.079
C_w	Worker consumption	0.515
r_m	Deposit interest rate	0.006
Π_w	Wage inflation	1.006
v	Bargaining power	0.527
ϕ	Real labor cost	0.644
r_d	Loan interest rate	0.014
wp	Nominal wage	1.879
D	Total debt	2.737
Ω_{diff}	Change in emissions	0.000
I_e	Investment (energy)	0.050
I_n	Investment (non-energy)	0.200
D_e	Debt (energy)	0.547
D_n	Debt (non-energy)	2.190
K_e	Capital stock (energy)	2.474
M_r	Rentier deposits	2.737
G	Government expenditure	0.156
Z_e	Profits (energy)	0.099
Z_n	Profits (non-energy)	0.002
B	Bank profits	0.020
u_n	Capacity utilization (non-energy)	0.800

6. Conclusion

This paper developed a stock-flow consistent model that integrates macroeconomic and ecological dynamics to explore the implications of the energy transition. Our analysis demonstrates that demand-driven stock-flow consistent models can provide useful insights into climate-environment-distribution feedbacks and, hence, the design of mitigation policies. The proposed framework models the interactions between investment decisions, income distribution, and emission dynamics during the transition to green low-carbon emitting energy sources. The model is populated by workers, rentiers, firms operating in the energy and non-energy sectors, the central bank, and commercial banks.

Simulation results indicate that fiscal policies accelerating the transition towards cleaner energy sources can simultaneously mitigate climate risks and stimulate economic activity through demand-side channels. Additionally, we explore the distributional impacts of the low-carbon transition. While the question of *who bears the cost of the low-carbon transition* ultimately hinges on political economy considerations, it is important to note that the model shows that a reduction in the tax rate on rentier income produces rebound effects by stimulating rentier's consumption and aggregate demand, thereby raising the carbon intensity of production. Conversely, a lower tax rate on wage income stimulates private consumption while reducing mitigation expenditures, thus negatively affecting GHG emissions. Therefore, a balanced progressive taxation strategy – taxing rentiers more heavily than wage earners – would enable the government to allocate more resources to mitigation strategies, thereby accelerating the transition to net-zero emissions. Crucially, our simulations demonstrate that financing mitigation policies through rentier taxation –rather than wage taxes – avoids degrowth scenarios and maintains employment levels, addressing concerns about distributional trade-offs raised by Rezai et al. (2013). Higher rentier tax rates accelerate convergence to net-zero emissions by funding public spending in mitigation, while progressive redistribution sustains aggregate demand without necessarily leading to an increase in GHG emissions.

The model's structuralist foundations emphasize how sectoral reallocation of investment within the energy sector (e.g., scaling up renewable investment) generates positive feedback loops: expanded green capacity reduces emissions while creating new demand through employment and consumption linkages. Conversely, slowing the pace of the transition amplifies macroeconomic instability, as shown by our impulse-response analysis. A negative shock to the green investment share triggers persistent emission overshooting, which propagates adverse macroeconomic effects through the investment channel, depressing output and real wages.

Finally, a delayed transition – stemming from reduced effectiveness of government mitigation spending – creates path-dependent effects and fossil lock-in, slowing down emission reduction and delaying the achievement of decarbonization goals. By contrast, enhanced effectiveness of mitigation spending and more decisive actions from public authorities significantly accelerate the transition to cleaner energy sources, facilitating emission abatement.

One limitation of our model is that it incorporates only a single type of energy transition policy, which is a government expenditure on a technology that accelerates the low-carbon transition, financed under a balanced-budget framework. However, alternative policy instruments – such as emission limits and carbon taxes – have played a significant role in shaping the broader policy debate. While these alternatives are indeed compelling, exploring their implications lies beyond the scope of this paper and represents a promising avenue for future research. Furthermore, our focus on business cycle dynamics means we do not explore all aspects of long-run structural change; hence, future research could extend our framework by endogenizing the long-run growth trend and incorporate alternative transition as well as innovation dynamics.

CRediT authorship contribution statement

Gustavo Pereira Serra: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Ettore Gallo:** Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization.

Table 3
Balance sheet matrix.

	WH	RH	E firms	N firms	Gov.	Banks	Σ
Loans			$-D_{e,t}$	$-D_{n,t}$		$+D_t$	0
Deposits		$+M_{r,t}$				$-M_{r,t}$	0
Fixed Capital			$+K_{e,t}$	$+K_{n,t}$			$+K_{e,t}+K_{n,t}$
Net Worth		$-NW_{r,t}$	$-NW_{e,t}$	$-NW_{n,t}$		$-NW_{B,t}$	$-(K_{e,t}+K_{n,t})$
Σ	0	0	0	0	0	0	0

Notes: WH: worker households; RH: rentier households; E Firms: firms in the energy sector; N Firms: firms in the non-energy sector; Gov.: government; Banks: commercial banks.

Declaration of competing interest

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

Appendix A. Transaction flow and balance sheet matrices

See Table 3 and Table 4.

Appendix B. Steady state of the model

This appendix presents the steady state of the model. Using Eq. (1), worker households' consumption level in the steady state is:

$$C_w = (1-\tau_w)\omega L \tag{28}$$

The consumption level of rentier households in the steady state is given by Eq. (3). Alternatively, using Eqs. (3), (8), (16), and (19), it can be expressed as:

$$C_r = (1-s_r)(1-\tau_r)\Big[Y_n - \omega L - (1-\xi)(I_n + I_e)\Big] \tag{29}$$

The level of deposits can be calculated as a residual of rentiers' consumption function, using Eqs. (3) and (29). Alternatively, because of the stock-flow consistency of the model, the same result is obtained from:

$$M_r = D_e + D_n \tag{30}$$

Eqs. (31)–(34) and (35)–(39) represent the steady state of the energy and non-energy sectors, in this order:

$$Y_e = u_e v_e K_e \tag{31}$$

$$I_e = K_e\Big[1-(1-\delta)\frac{1}{\Gamma}\Big] = \frac{Y_e}{v_e u_e}\Big[1-(1-\delta)\frac{1}{\Gamma}\Big] \tag{32}$$

$$D_e = \frac{\xi I_e}{1-\frac{1}{\Pi_p \Gamma}} \tag{33}$$

$$Z_e = Y_e - (1-\xi)I_e - \frac{r_D}{\Pi_p \Gamma} D_e \tag{34}$$

$$Y_n = v_K u_n K_n = v_L L = v_{n,e} Y_e \tag{35}$$

$$I_n = K_n\Big[1-(1-\delta)\frac{1}{\Gamma}\Big] = \frac{Y_n}{v_K u_n}\Big[1-(1-\delta)\frac{1}{\Gamma}\Big] \tag{36}$$

$$\phi = \frac{1}{(1+\varepsilon)} = \frac{\omega}{v_L} \tag{37}$$

$$D_n = \frac{\xi I_n}{1-\frac{1}{\Pi_p \Gamma}} \tag{38}$$

$$Z_n = Y_n - \omega L - Y_e - (1-\xi)I_n - \frac{r_D}{\Pi_p \Gamma} D_n \tag{39}$$

With respect to the banking sector, the interest rate on new loans and commercial bank profits are, respectively:

$$r_D = (1+\theta)r_M \tag{40}$$

$$B = \frac{r_D}{\Pi_p}\frac{D_n}{\Gamma} + \frac{r_D}{\Pi_p}\frac{D_e}{\Gamma} - \frac{r_M}{\Pi_p}\frac{M_r}{\Gamma} \tag{41}$$

Using Eqs. (20), (28), and (29), we may express government spending as:

$$G = \tau_w \omega L + \tau_r\Big[Y_n - \omega L - (1-\xi)(I_n + I_e)\Big] \tag{42}$$

Furthermore, the goods market equilibrium and wage-price inflation are, in this order:

$$Y_n = C_w + C_r + I_e + I_n + G \tag{43}$$

$$\Pi_p = \Pi_w = 1 + v\Big(\omega_w^d - \omega\Big) \tag{44}$$

Proceeding to the calibration of the model, we attribute values to the steady state of the following variables: I_e, I_n, r_M, u_e, u_n, $Y_n = 1$, Y_e, Γ, δ, θ, v, ξ, Π_p, τ_r, τ_w, ω_w^d, and (ωL). Table 2 in the manuscript presents the calibrated values for these variables. To make the calibration procedure clearer, three explanations are in order. First, given the normalization $Y_n = 1$, the parameter s_r is calibrated to ensure the goods-market equilibrium at that value. We follow Schoder (2017) in assuming that the consumption level of rentiers represents the adjustment variable. It is important to note, however, that calibrating s_r in this manner is not a requirement for maintaining the model's stock-flow consistency – as detailed in Tables 3 and 4. Rather, this calibration is solely intended to satisfy the normalization condition $Y_n = 1$. It is also worth emphasizing that s_r remains constant throughout the simulations – i.e. it is not recalibrated dynamically to enforce equilibrium conditions.

Using Eqs. (29) and (43), the rentier households' marginal propensity to consume is calibrated as follows:

$$s_r = \frac{\xi(I_n + I_e)}{(1-\tau_r)[Y_n - \omega L - (1-\xi)(I_n + I_e)]} \tag{45}$$

Second, with Π_p, v, and ω_w^d, Eq. (44) gives Π_w and ω. Then, the employment level (L) results from the calibration of the wage share (ωL). Furthermore, Eqs. (35) and (37) determine v_L and ϕ, which we use to calibrate the mark-up factor ε.

Finally, Eqs. (32), (36), and (35) determine v_e, v_K, and $v_{n,e}$, in this order. Then, Eqs. (31) and (35) determine K_e and K_n, respectively. The calculation of the values for all the other variables in the steady state is straightforward from the equations presented in this appendix.

Appendix C. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.ecolecon.2025.108863.

Data availability

No data was used for the research described in the article.

Table 4
Transactions flow matrix.

	WH	RH	E firms		N firms		Gov.	Banks		Σ
			Current	Capital	Current	Capital		Current	Capital	
Consumption	$-C_{w,t}$	$-C_{r,t}$			$+(C_{w,t}+C_{r,t})$					0
Investment				$-I_{e,t}$	$+(I_{e,t}+I_{n,t})$	$-I_{n,t}$				0
Gov. expenditure					$+G_t$		$-G_t$			0
Wages	$+\omega_t L_t$				$-\omega_t L_t$					0
Energy consumption			$+Y_{e,t}$		$-Y_{e,t}$					0
Firms' Profits		$+(Z_{e,t}+Z_{n,t})$	$-Z_{e,t}-(1-\xi)I_{e,t}$	$+(1-\xi)I_{e,t}$	$-Z_{n,t}-(1-\xi)I_{n,t}$	$+(1-\xi)I_{n,t}$				0
Banks' Profits		$+B_t$						$-B_t$		0
Depos. Interests		$+r_{m,t-1}M_{r,t-1}$						$-r_{m,t-1}M_{r,t-1}$		0
Taxes	$-\tau_w\omega_t L_t$	$-\tau_r(Z_{e,t}+Z_{n,t}+B_t+r_{m,t-1}M_{r,t-1})$					$+\tau_w\omega_t L_t+\tau_r(Z_{e,t}+Z_{n,t}+B_t+r_{m,t-1}M_{r,t-1})$			0
Loan Interests			$-r_{D,t-1}D_{e,t-1}$		$-r_{D,t-1}D_{n,t-1}$			$+r_{D,t-1}D_{t-1}$		0
Δ Deposits		$-\Delta M_{r,t}$							$+\Delta M_{r,t}$	0
Δ Loans				$+\Delta D_{e,t}$		$+\Delta D_{n,t}$			$-\Delta D_t$	0
Σ	0	0	0	0	0	0	0	0	0	0

Notes: Non-normalized variables. WH: worker households; RH: rentier households; E Firms: firms in the energy sector; N Firms: firms in the non-energy sector; Gov.: government; Banks: commercial banks.

References

Adjemian, S., Bastani, H., Juillard, M., Karamé, F., Mihoubi, F., Mutschler, W., Pfeifer, J., Ratto, M., Rion, N., Villemot, S., 2022. Dynare: Reference manual version 5. Dynare Working Papers 72, CEPREMAP.

Caiani, A., Godin, A., Caverzasi, E., Gallegati, M., Kinsella, S., Stiglitz, J.E., 2016. Agent based-stock flow consistent macroeconomics: Towards a benchmark model. J. Econom. Dynam. Control 69, 375–408.

Campiglio, E., Daumas, L., Monnin, P., von Jagow, A., 2023. Climate-related risks in financial assets. J. Econ. Surv. 37 (3), 950–992.

Cano Ortiz, D., Spinato Morlin, G., D'Alessandro, S., Heydenreich, T., 2024. The impact of green policies on carbon inequalities in Italy: A macrosimulation approach. In: Proceedings of the 30th International Input-Output Association Conference. Santiago, Chile, July 1–5, 2024, URL: https://www.iioa.org/conferences/30th/papers/files/5133_paper_IIOA.pdf.

Carnevali, E., Deleidi, M., Pariboni, R., Passarella, M.V., 2019. Stock-flow consistent dynamic models: Features, limitations and developments. In: Frontiers of Heterodox Macroeconomics. Springer, pp. 223–276.

Castrejon-Campos, O., Aye, L., Hui, F.K.P., Vaz-Serra, P., 2022. Economic and environmental impacts of public investment in clean energy RD&D. Energy Econ. 168, 113134.

Cieplinski, A., D'Alessandro, S., Guarnieri, P., 2021. Environmental impacts of productivity-led working time reduction. Ecol. Econom. 179, 106822.

Cohen, G., Jalles, J.T., Loungani, P., Marto, R., 2018. The long-run decoupling of emissions and output: evidence from the largest emitters. Energy Policy 118, 58–68.

Cohen, G., Jalles, J.T., Loungani, P., Pizzuto, P., 2022. Trends and cycles in CO_2 emissions and incomes: Cross-country evidence on decoupling. J. Macroecon. 1–16.

Dafermos, Y., Nikolaidi, M., 2021. How can green differentiated capital requirements affect climate risks? A dynamic macrofinancial analysis. J. Financ. Stab. 54, 100871.

Dafermos, Y., Nikolaidi, M., 2022. Assessing climate policies: an ecological stock–flow consistent perspective. Eur. J. Econ. Econ. Policies 19 (3), 338–356.

Dafermos, Y., Nikolaidi, M., Galanis, G., 2017. A stock-flow-fund ecological macroeconomic model. Ecol. Econom. 131, 191–207.

Dafermos, Y., Nikolaidi, M., Galanis, G., 2018. Climate change, financial stability and monetary policy. Ecol. Econom. 152, 219–234.

D'Alessandro, S., Cieplinski, A., Distefano, T., Dittmer, K., 2020. Feasible alternatives to green growth. Nat. Sustain. 3 (4), 329–335.

Distefano, T., D'Alessandro, S., 2023. Introduction of the carbon tax in Italy: Is there room for a quadruple-dividend effect? Energy Econ. 120, 106578.

Distefano, T., D'Alessandro, S., Campigotto, N., 2025. Climate adaptation and fiscal sustainability: when timing matters. Ital. Econ. J.

Doda, B., 2014. Evidence on business cycles and CO_2 emissions. J. Macroecon. 40, 214–227.

Gallo, E., 2025. Reduction of CO_2 emissions, climate damage and the persistence of business cycles: A model of (de)coupling. Struct. Change Econ. Dyn. 74, 725–737.

Gallo, E., Serra, G.P., 2024. A stock-flow consistent model of inventories, debt financing and investment decisions. Struct. Change Econ. Dyn. 68, 17–29.

Herzer, D., 2025. The impact of government-funded renewable energy R&D on its consumption. J. Policy Model. 47 (5), 903–918.

IPCC, 2022. Climate Change 2022: Impacts, Adaptation, and Vulnerability, Summary for Policymakers. IPCC Sixth Assessment Report.

IRENA, 2024. Renewable power generation costs in 2023. (Accessed 31 May 2025).

Jackson, T., Victor, P.A., 2020. The transition to a sustainable prosperity-a stock-flow-consistent ecological macroeconomic model for Canada. Ecol. Econom. 177, 106787.

Kalecki, M., 1971. Selected essays on the dynamics of the capitalist economy 1933–1970. CUP Archive.

King, C.W., 2020. An integrated biophysical and economic modeling framework for long-term sustainability analysis: the HARMONEY model. Ecol. Econom. 169, 106464.

Minsky, H.P., 1982. The financial instability hypothesis: a restatement. In: Minsky, H.P. (Ed.), Can It Happen Again. M. E. Sharpe.

Nalin, L., Pérez-Caldentey, E., Torres, G., 2023. A stock-flow ecological model from a latin American perspective. Levy Economics Institute of Bard College, Working Paper No. 1031.

Network for Greening the Financial System (NGFS), 2024. Nature-Related Financial Risks: A Conceptual Framework to Guide Action by Central Banks and Supervisors. NGFS Publication.

Nordhaus, W., 2013. Chapter 16 - Integrated economic and climate modeling. In: Dixon, P.B., Jorgenson, D.W. (Eds.), Handbook of Computable General Equilibrium Modeling SET, Vols. 1A and 1B. In: Handbook of Computable General Equilibrium Modeling, vol. 1, Elsevier, pp. 1069–1131.

Oliveira, G.d., Lima, G.T., 2020. A green lewis development model. Metroeconomica 71 (2), 431–448.

Oliveira, G.d., Lima, G.T., 2022. Economic growth as a double-edged sword: The pollution-adjusted Kaldor–Verdoorn effect. Ecol. Econom. 199, 107449.

Rezai, A., Taylor, L., Foley, D., 2018. Economic growth, income distribution, and climate change. Ecol. Econom. 146, 164–172.

Rezai, A., Taylor, L., Mechler, R., 2013. Ecological macroeconomics: An application to climate change. Ecol. Econom. 85, 69–76.

Schoder, C., 2017. Estimating Keynesian models of business fluctuations using Bayesian maximum likelihood. Rev. Keynes. Econ. 5 (4), 586–630.

Semmler, W., Braga, J.P., Lichtenberger, A., Toure, M., Hayde, E., 2021. Fiscal Policies for a Low-Carbon Economy. World Bank Publications, World Bank, Washington, DC.

Serra, G.P., Gallo, E., 2023. Food and energy inventory management, fiscal policy and the quest for strategic quantity controls: A stock-flow consistent model. Bull. Political Econ. 17, 91–110.

Steindl, J., 1979. Stagnation theory and stagnation policy. Camb. J. Econ. 3 (1), 1–14.

Tavani, D., Zamparelli, L., 2017. Endogenous technical change in alternative theories of growth and distribution. J. Econ. Surv. 31 (5), 1272–1303.

Taylor, L., Rezai, A., Foley, D.K., 2016. An integrated approach to climate change, income distribution, employment, and economic growth. Ecol. Econom. 121, 196–205.