Assessing Macro-Financial and Distributive Impacts of Climate Policies: a Stock-flow Consistent Model with Portfolio Choice

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Abstract

The role that green fiscal and monetary policies could play in promoting the low-carbon transition has recently attracted research and policy attention. However, deep uncertainty characterizes their implementation. In this regard, a main knowledge gap is represented by the impact of investors expectations towards the policies on economic competitiveness and financial stability. In this paper, we contribute to fill this gap by analyzing to under which conditions investors expectations of climate policies could affect market fundamentals in the economy and finance sectors of a high-income country. We consider two types of climate policies, i.e. the announcement of a carbon tax and of green sovereign bonds. In particular, we analyze to what extent banks anticipation (lack of anticipation) of the climate policies could foster (hinder) low-carbon investments and affect assets' evaluation and portfolio's performance. To do so, we enrich the Eirin Stock-Flow Consistent behavioural model with a financial market, an energy market and investors portfolio choice of financial contracts (equity, bonds, loans). We find that investors anticipation of the climate policies contributes to foster new low-carbon investments and stabilize banks balance sheet. However, the green macroeconomic effects are more pronounced in the case of green sovereign bonds, while the introduction of a carbon tax has rather negative implications on firms capital accumulation and workers wages. Our results contribute to the discussion on what role sustainable finance and financial regulation could play in the European Sustainable Finance agenda.

Keywords: investors' expectations, carbon tax, green sovereign bonds, monetary policy, Stock-Flow Consistent macroeconomic model, financial market, portfolio choice.

1. Introduction

There is growing awareness of the fact that achieving the climate and sustainability targets requires to align finance to sustainability. A deep decarbonization of production and consumption activities requires

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both a massive scaling-up of investments in low-carbon firms and sectors, as well as the phasing out of investments in fossil-fuel plants and high-carbon sectors (New Climate Economy, 2018). It has been recognized that public investments alone will not be enough and that private finance and capital markets are needed to fill the green investment gap estimated into Eur 180 bn per year by 2030 in the EU (HLEG, 2018) and in USD 90 trillion (trn) at the global scale by 2030. However, financial portfolios are still largely allocated into economic activities that are not aligned with the climate targets and are at odds with the definition of sustainable finance. The Climate Stress-test of the financial system showed that investors in the Euro Area and in the US are considerably exposed to assets issued by companies whose revenues are directly or indirectly related to fossil fuels extraction and combustion (Battiston et al., 2017). The value of carbon stranded assets in financial markets was evaluated in USD 20 trn, and for 1 to 4trn in the economy (Mercure et al., 2016) if institutions and companies fail to align now (Breeden, 2019). Due to the interconnected nature of todays business and financial activities, the losses generated in one sector could cascade via chains of economic and financial exposures to other sectors, with implications on economic performance and financial stability (Battiston and Monasterolo, 2019).

Thus, ambitious green fiscal and monetary policies have been increasingly advocated to align investors' incentives to the climate and sustainability targets. Fiscal policies gained so far the largest attention (see Dafermos and Nikolaidi (2019) for a review of green fiscal policies in both conventional and post-Keynesian approaches). These include the introduction of a global carbon tax, i.e. a tax imposed by governments on the combustion and use of fossil fuels that cause CO2 emissions (Stiglitz et al., 2017); feed-in tariff policy mechanism aimed to foster investments in renewable energy production capacity (Ponta et al., 2018); a public subsidizing mechanism on the abatement cost to enhance the speed of the energy shift (Bovari et al., 2018); the phasing out of fossil fuel subsidies (Coady et al. 2017; Gerasimchuk et al. 2017; Monasterolo and Raberto 2019). More recently, the issuance of green bonds (issued either by corporations and governments and/or connected to green monetary policies, see e.g. Ehlers and Packer (2017); Dafermos et al. (2018); Monasterolo and Raberto (2017, 2018)) and a differentiation of banks capital requirements and regulatory reform to promote green lending (Raberto et al., 2019; Thomä and Hilke, 2018) have been discussed.

Nevertheless, the climate policy implementation is characterized by deep uncertainty. Contradictory messages (e.g. the US withdrawing from the Paris Agreement) prevent investors to price the risk and opportunities of green or brown investments (i.e. their investments in low-carbon or high carbon assets) in their portfolios management strategy (Battiston, 2019). Despite the sense of urgency and the relevance of this topic in the policy agenda, important gaps remain in the academic research in finance and economics in this area. In particular, the conditions under which investors could foster or, in contrast, delay the low-carbon transition still need to be analysed. In this context, a main knowledge gap is represented by the analysis of investors expectations of the climate policies, and their macroeconomic and financial implications of investors' anticipation of the policies. At this regard, macroeconomic models able to account for climate change and policies risk transmission channels on the economy and finance, and the potential amplification effects led by reinforcing feedbacks between economic and finance agents are needed. In particular, Stock Flow Consistent-Agent Based (SFC-AB) Macro-ecological models represent a complementary approach to traditional models in so far, they allow to analyse the models behaviour under out-of-equilibrium state, the drivers of non-linearity, and the change in models characteristics after reaching boundaries and tipping points (see Monasterolo et al. 2019 for a review). Non-linearity and tipping points are characteristics of both modern financial markets and climate change impacts (see e.g. Ackerman 2017).

In this paper, we contribute to fill this gap by analysing to under which conditions investors expectations of climate policies could affect market fundamentals in the economy and finance sectors. In particular, we analyse to what extent banks anticipation (lack of anticipation) of climate policies, i.e. a carbon tax and green bonds, could foster (hinder) low-carbon investments. Then, we analyse the drivers of potential trade-offs on financial instability. To do so, we enrich the Eirin Stock-Flow Consistent behavioural model (Monasterolo and Raberto, 2018) with a financial market, an energy market and investors portfolio choice of financial contracts (equity, bonds, loans). A main novelty compared to the state of the art is that with Eirin we can analyse investors climate sentiments, i.e. how investors expectations on climate policies affect brown/green assets (equity, bonds) performance and banks lending conditions. This allows us to consider the time-mismatch between mid to long-term impacts of climate change and the short time horizon of investors and policy makers, as well as the presence of forward-looking governments and financial actors, in the analysis of real and financial markets reaction to climate change.

The paper is organized as follows. Section 2 presents the new features of the Eirin model, i.e. a novel energy market and an equity market. Section 3 describes the four scenarios characterized by different climate policies and investors' reactions. Section 4 discusses the preliminary results and section 5 concludes with a discussion on the opportunities to coordinate fiscal and monetary policies to timely implement a low-carbon transition.

2. Methodology and model description

In this section, we briefly recall the main characteristics of the Eirin model and we focus on the two main novelties of this enriched version, i.e. i) climate transition risk (considered both in relation to the introduction of climate policy as well as to a shift in investors climate sentiments), and ii) the equity and the bond market. For a detailed description of all the other sectors, market interactions and behavioural equations, please refer to previous papers Monasterolo and Raberto (2018, 2019).

Eirin is a Stock-Flow Consistent behavioural model based on the characteristics of high-income countries of the EU economy. The model is composed by heterogeneous agents which can be identified as sectors either of the real and the financial side of the economy. Agents/sectors are modelled as a nexus of inter-

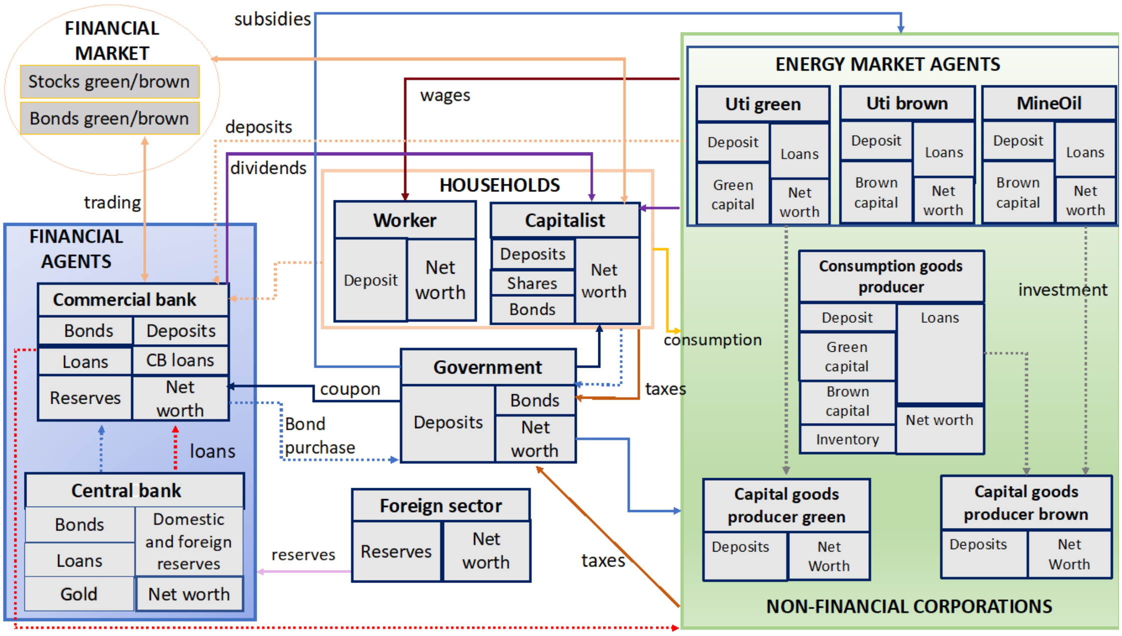

Figure 1: **The Eirin model framework:** Capital and current account flows of the Eirin economy. For each sector and agent, a representation in terms of assets and liabilities is provided. The dotted lines represent the capital account flows; the solid lines represent the current account flows. The green sovereign bonds and the carbon taxs revenues can be used by the government to finance subsidies to the renewable energy sector for employing additional capacity (solid light blue line). Climate policies impact on the flows in the financial sector and the financial market. First, reduced firms profits influence investors evaluation of equity prices and bonds yields of the sovereign, due to their climate sentiments. Second, commercial banks adapt their lending conditions (interest rates) with respect to debt to equity ratios of firms (dotted red lines), which are affected either by the impact of climate transition risk.

connected balance sheets, see Table 1. Figure 1 shows the scheme of the Eirin economy along with the capital and current account flows among sectors. This modelling approach allow for a rigorous accounting framework where equilibrium conditions are substituted by accounting identities that hold irrespective of any behavioural assumption. The accounting identities are reported in tables from 1 to 3, which also provide a complete description of the structure of the model along the lines of representation of stock-flow consistent models provided by Godley and Lavoie (2007); see also Ponta et al. (2018); Mazzocchetti et al. (2018) for an application to agent based models. In particular, the so-called balance-sheet matrix, reported in Table 1, shows a snapshot of all assets and liabilities of the sectors of the Eirin economy. The matrix representation with the sum in last column, which is zero in most cases, highlights that what hat is a financial asset for a sector is a liability for another one. These accounting identities are structural specifications that have to be fulfilled at any time step, then providing relevant binding constraints for the dynamics of the model. It is worth noting that these constraints can be used as relevant references for the validation of both the model and the code. Similar structural constraints are showed by Table 2 which reports what we call the cash-flow matrix, also known as transactions flow matrix in the stock-flow consistent modelling literature (Godley and Lavoie, 2007). In particular, Table 2 highlights how cash flows among sectors need to cancel out (see the zeros in the last column) and the determinants of the liquidity changes for each sector. Finally, Table 3 reports what we call the Net Worth Change Matrix, also known as revaluation matrix in the stock-flow consistent modelling literature (Godley and Lavoie, 2007), which shows how sectors' net worth changes due to both net cash flows and the price changes of financial assets. Generally speaking, tables from 1 to 3 provides the accounting equations of the model. For a detailed description of behavioural equations, please refer to previous papers Monasterolo and Raberto (2018, 2019). For the sake of compactness, in the following paragraphs we will provide a general and qualitative description of our key modelling assumptions. Section 3 will report a detailed description of both the accounting and behavioral equations of the financial market, which is the new modelling feature presented in this paper.

The stock-flow consistent modelling approach also allows us to integrate financial and climate-related shocks on financial actors, computed with network-based stress-tests (Battiston et al., 2012; Castrén and Rancan, 2014) and climate-stress-tests (Battiston et al., 2017) to assess their transmission effects on agents and sectors of the real economy, government reactions (via fiscal policies) and central banks reactions (via conventional and unconventional monetary policies). Other advantages consist in relaxing strong assumptions on agents expectations formation and behaviour, such as rational expectations and utility maximization, as well as financial markets informational efficiency in the case of climate physical and transition risks, and thus to consider first and second-best policy solutions that involve central banks policies. In EIRIN, firms set prices via cost mark-ups at every time-step of the simulation. Agents investment decisions are influenced by their Net Present Value (NPV), which is influenced not only by production factor costs but also by monetary policies of central banks and the fiscal policies introduced by governments. Furthermore, we

consider heterogeneous households (capitalist/worker) according to their consumption and saving behaviour (Goodwin, 1967) and to their differential access to financial markets and yields.
The distinction between credit/bond/capital market to fund green investments is functional not only to compare conventional monetary policies (via interest rate) with unconventional ones (via bonds prices/yields), and to assess monetary policys effects on banks stability and green bonds market, but also to look at policies distributive effects in terms of income inequality and wealth concentration.

2.1. Composition of the Eirin economy

2.1.1. Agents and sectors

The Eirin economy is populated by heterogeneous sectors and agents. In particular, we can distinguish twelve different agents which represent twelve different sectors of the economy, namely a working class sector (H_w), a capitalist household sector (H_k), a consumption good producer (CGP, abbrev. by C), a brown capital goods producer (K_b), a green capital goods producer (K_g), a mining company (mi), a brown utility (U_b), a green utility (U_g), a bank (BA), a central bank (CB), a government (G) and a foreign sector (ROW).
A number of distinguishing features of our agents/sector deserves special attention. In particular, we would like to highlight the following properties:

- Heterogeneous households: by building on Goodwin (1967) and the Lotka-Volterra's predator-prey model, households are divided into two classes, a working class (H_w) and a capitalist (H_k) income class, respectively. H_w lives on wages, while H_k earns his income out of financial markets through government bonds' coupons and equity shares' dividends. The two household classes' consumption plans are based on the buffer-stock theory of savings (Deaton, 1991; Carroll, 2001). Such income class heterogeneity is functional to analyse the role that different access to financial markets played on inequality in the last two decades, and its effects on missing aggregate demand in high-income economies and on financial instability. Second, it allows to assess the distributive effects of single or suites of policies on the channels of inequality in the EU.

- Heterogeneous capital goods characterized by different resource and emissions intensity. Capital goods set the consumption goods producer (CGP) productions capacity and technology endowment, reflecting different levels of resource efficiency. Green capital goods allow a more resource-efficient, low-carbon production process than brown capital goods. We introduce a variable α of resource intensity that depends on the raw materials intensity of the production process. In so doing, we explicitly model the role of raw materials cost on CGPs investments decisions.

- A consumption goods producer (CGP) and a renewable energy producer (U_g) who make investments decisions, the former in either brown (resource and carbon intense) or green (resource and carbon saving) capital goods, the latter only in green capital goods, say solar panels, to increase its renewable production capacity. Both investments decisions are based on the NPV, which is in turn influenced by the interest rate set by the central bank, and by the governments fiscal policy and subsidies. This point is particularly important because (i) it allows us to understand agents intertemporal behaviour by comparing short-term costs with long- term benefits, (ii) it supports the representation of endogenous decision-making (e.g. the NPV of brown versus green investment decisions) and endogenous money creation in the credit market. We use NPV calculations to compare the present cost of investments, which are higher in the case of green capital goods (reflecting higher initial cost of capital and salaries of the more skilled workers), with the present value of future expected positive or negative cash flows. In so doing, we display endogenously generated GDP and the shifting to low-carbon investments.

- Heterogeneous skills for workers employed in the brown/green sectors. We assume that skills are uniformly distributed among workers, and that the green sector always employs the workers with the highest skills, in exchange of higher salaries, to support initial R&D investments. Wages in the brown and green capital goods production sectors are endogenous and set according to the average workers skills in each sector.

- An energy sector based on the Global Change Assessment Model (GCAM) (Calvin et al., 2013) that has a granular representation of energy and electricity producers (fossil fuel, renewable energy). The energy sector is composed by a mining company that extracts fossil fuels, a brown utility company that produces electricity out of fossil fuels, and a green utility company that produces electricity out of renewable energy sources. Agents produce to meet the internal demand for energy/electricity either through fossil fuels or renewable energy sources (i.e. solar and wind). Green energy coming from the renewable energy producer has grid priority whereas brown energy generated from fossil fuels by the brown one covers energy not met by green currently employed capacity. Energy production is demand driven. Energy demand is driven by two main factors, i.e. i) the inelastic energy needs of H_w and H_k (i.e. the daily uses of heat and transportation) and ii) the industrys energy requirements that are not linear but depend from the sectors market share in the economy and the overall economic business cycle. We then assume fixed HHs demand for daily uses such as heating and transportation. Industry demands energy as an input for production. The electricity price is unique and endogenously set by the brown utility company based on a mark-up on its unit costs. H_w and H_k subtract the energy bill from their wage bill as shown by their disposable income. Industry transfers the costs of energy via mark-ups on its unit costs to $H - w$ and H_k. Brown energy consumption by the industry induces emissions, which add to the stock of emissions in the atmosphere. Higher emissions increase climate change and potential negative feedback effects in the economy. As such, energy consumption contributes to the climate physical risk, as discussed in more detail in the following section.

- A credit sector represented by a commercial bank (BA) that provides loans to the firms, the mining and the utility companies. The bank has a leverage target (ratio between risk weighted assets and equity) to meet Basel III requirements and a Capital Adequacy Ratio to build resilience against borrowers defaults as a consequence on non-performing loans.

- A foreign sector (RoW) that provides raw materials to the domestic economy in infinite supply and at a given (constant) price to meet the production needs in the brown sector.

- A government that decides on the fiscal policy with the purpose to keep the budget balance aligned to the Maastricht criteria and the EU financial stability pact. The government issues brown bonds to cover its regular expenses and issues green bonds to support capital investments in renewable energy production. Also, the government can issue a carbon tax that targets the production and use of fossil fuels in the Eirin economic value chain.

- A Central Bank (CB) engaging in conventional and unconventional monetary policy. The CB sets the interest rate according to a Taylor like rule. The interest rate depends on the inflation and output gaps, measured as employment gap (i.e. the distance to a target level of employment), and influences agents expectations and investments through NPV. The CB provides liquidity to BA in case of shortage of liquid assets and accepts green/brown bonds as eligible asset in case of Quantitative Easing (QE).

2.2. Markets

Eirins representative agents and sectors interact with each other and with the foreign sector through a set of markets, i.e. consumption and capital goods markets, labour, energy, oil and raw materials markets. Eirin makes also explicit consideration of the credit, equity holdings and bonds market and their interactions with the energy sector, the real economy and the government. Demand and supply formation, as well as pricing in each market (except for the credit market) are independent from each other at any given simulation step. In the credit market, demand depends on the demand for capital goods. The demand rationing affects the effective demand of capital goods by the CGP, the oil company and the green utility company. In each market, pricing is made by the supply side as a mark-up on unit costs, with exception of the average price of labour, where the average nominal wage is determined according to a Phillips curve-like rule (Keen, 2013), and the financial market, where asset prices are determined based on the aggregate amount of financial wealth that the economic and financial agents are willing to allocate on each asset, as outlined in Section 3. The sequence of events occurring in each simulation step is the following:

1. Policy makers take their policy decisions. The CB sets the policy rate according to a Taylor-like rule. The government adjusts the tax rates on labour and capital income, and on corporate earnings, to meet its budget deficit target.
2. The credit market opens. The bank sets its maximum credit supply according to its equity base. If supply is lower than demand, proportional rationing is applied and prospective borrowers (i.e. the consumption goods producer, the mining company and the green utility producer) revise down their investment and production plans accordingly.)
3. Real markets open in parallel. Prices of the exchanged goods or services are determined, then the nominal or real demand and supply are provided by the relevant agent in each market. Finally, transactions occur generally at disequilibrium, i.e. at the minimum between demand and supply.
4. The financial market opens. The capitalist household and the bank determine their desired portfolio allocation of financial wealth on equity shares, government bonds, either brown or green, and liquid assets. The government offers newly issued brown and green bonds to finance budget deficit and green subsidies, respectively, while the central bank may perform quantitative easing policies and enter the bond market as a buyer of sovereign bonds (green or brown). New asset prices are then determined.
5. All transactions and monetary flows are recorded, and the balance sheets of the agents and sectors of the Eirin economy are updated accordingly.

2.3. Climate transition risk

Consistently with climate financial risk assessment literature (see e.g. Battiston et al. (2017)) we consider climate transition risk as a disordered introduction of climate policies that investors may not be able to anticipate and thus may not be able to price in their portfolios and risk management strategies. In this context, some investors might trust the government and assign higher risk factors to brown assets, while others might follow their respective benchmark and keep their exposures to brown assets. Thus, we consider climate transition risk in relation to:

- The introduction of a carbon tax designed according to the Stiglitz et al. (2017) recommendations on carbon markets.
- Investors reactions to the policies, i.e. their climate sentiments. We consider two types of investors reactions to climate transition risks, i.e. investors (i.e. the bank and the capitalist household) who do not react to the introduction of the climate policies (because they don't trust the government) and thus they don't change their portfolio choice evaluation; investors who react to the climate policy by

	H_w	H_k	**CGP** (C)	K_b	K_g	mi	U_b	U_g	BA	CB	G	ROW	$\sum$
Tangible capital			$p_{K_b}K_b^C + p_{K_g}K_g^C$			$p_{K_b}K_b^{mi}$	$p_{K_b}K_b^{U_b}$	$p_{K_b}K_b^{U_g}$					$p_{K_b}K_b + p_{K_g}K_g$
Inventories			$p_C I_{q_C}$										$p_C I_{q_C}$
Gold in the vault										M_{CB}			M_{CB}
Brown gov bonds		$p_{B_b}n_{B_b}^{H_k}$							$p_{B_b}n_{B_b}^{BA}$	$p_{B_b}n_{B_b}^{CB}$	$-p_{B_b}n_{B_b}$		0
Green gov bonds		$p_{B_g}n_{B_g}^{H_k}$							$p_{B_g}n_{B_g}^{BA}$	$p_{B_g}n_{B_g}^{CB}$	$-p_{B_g}n_{B_g}$		0
Bank's loans			$-L_C$			$-L_{mi}$	$-L_{U_b}$	$-L_{U_g}$	L_{BA}				0
CB's loan									$-L_{CB}$	L_{CB}			0
Bank's deposits	M_{H_w}	M_{H_k}	M_C	M_{K_b}	M_{K_g}	M_{mi}	M_{U_b}	M_{U_g}	$-D_{BA}$		M_G		0
CB's reserves									M_{BA}	$-M_{fiat}$		M_{ROW}	0
		$n_C p_{E_C}$	$-E_C$										$n_C p_{E_C} - E_C$
		$n_{K_b}p_{E_{K_b}}$		$-E_{K_b}$									$n_{K_b}p_{E_{K_b}} - E_{K_b}$
		$n_{K_g}p_{E_{K_g}}$			$-E_{K_g}$								$n_{K_g}p_{E_{K_g}} - E_{K_g}$
Traded equity shares		$n_{mi}p_{E_{mi}}$				$-E_{mi}$							$n_{mi}p_{E_{mi}} - E_{mi}$
		$n_{U_b}p_{E_{U_b}}$					$-E_{U_b}$						$n_{U_b}p_{E_{U_b}} - E_{U_b}$
		$n_{U_g}p_{E_{U_g}}$						$-E_{U_g}$					$n_{U_g}p_{E_{U_g}} - E_{U_g}$
		$n_{BA}p_{E_{BA}}$							$-E_{BA}$				$n_{BA}p_{E_{BA}} - E_{BA}$
Equity (net worth)	$-E_{H_w}$	$-E_{H_k}$								$-E_{CB}$	$-E_G$	$-E_{ROW}$	$-E_{Eirin}$
$\sum$	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1: Balance sheet matrix of the EIRIN economy. Each column represents the balance sheet of an agent/sector. Assets items are reported with a positive sign while liabilities with a negative sign. Each column always sums to zero to highlight the definition of equity (or net worth). Except for real assets, the table rows also sum to zero in most cases to highlight the financial interlinkages among sectors, i.e. that what is a financial asset for a sector is a liability for another sector. In the case of equity shares the difference between assets and it counterpart is different from zero to highlight that market value of equity is generally different from its book value.

Cash flows from:	H_w	H_k	**CGP** (C)	K_b	K_g	mi	U_b	U_g	BA	CB	G	ROW	Σ
Consumption of:													0
- goods	$-C_{H_w}$	$-C_{H_k}$	$p_C q_C$										0
- electricity	$-p_e q_e^{H_w}$	$-p_e q_e^{H_k}$					$p_e q_e^{nr}$	$p_e q_e^{r}$					0
Imports			$-p_R q_R$						$p_O q_O$			$p_O q_O + p_R q_R$	0
Wages	Y_{H_w}		$-N_b^C w_b$	$-N_b^{K_b} w_b$	$-N_b^{K_g} w_g$						$-N_b^G w_b$		0
Interests:													
- bonds' coupons		$Y_{H_k}^B$							$c_B(n_{B_b}^{BA} + n_{B_g}^{BA})$	$c_B(n_{B_b}^{CB} + n_{B_g}^{CB})$	$-c_B(n_{B_b} + n_{B_g})$		0
- bank's loans			$-r_D L_C$			$-r_D L_{mi}$	$-r_D L_{U_b}$	$-r_D L_{U_b}$	Y_{BA}				0
- CB's loan									$-r_{CB} L_{CB}$	$r_{CB} L_{CB}$			0
Income tax	$-T_{H_w}$	$-T_{H_k}$	$-T_C$	$-T_{K_b}$	$-T_{K_g}$	$-T_{mi}$					T_G		0
Carbon tax			$-T_C^O$	$-T_{K_b}^O$	$-T_{K_g}^O$	$-T_{mi}^O$	$-T_{U_b}^O$				T_G^O		0
Subsidies								$\xi p_{K_g} q_{K_g}$			$-\xi p_{K_g} q_{K_g}$		0
Dividend payout		$Y_{H_k}^E$	$-n_{E_C} d_C$	$-n_{E_{K_b}} d_{K_b}$	$-n_{E_{K_g}} d_{K_g}$	$-n_{E_{mi}} d_{mi}$	$-n_{E_{U_b}} d_{U_b}$	$-n_{E_{U_g}} d_{U_g}$	$-n_{E_{BA}} d_{BA}$				0
	=	=	=	=	=	=	=	=	=	=	=	=	
(Net Cash flow)	$+NCF_{H_w}$	$+NCF_{H_k}$	$+NCF_C$	$+NCF_{K_b}$	$+NCF_{K_g}$	$+NCF_{Mi}$	$+NCF_{U_b}$	$+NCF_{U_g}$	$+NCF_{BA}$	$+NCF_{CB}$	$+NCF_G$	$+NCF_{ROW}$	0
	+	+	+	+	+	+	+	+	+	+	+	+	
Investment in:													
- brown capital			$-p_{K_b} q_{K_b}^C$	$p_{K_b} q_{K_b}$		$-p_{K_b} q_{K_b}^{mi}$							0
- green capital			$-p_{K_g} q_{K_g}^C$		$p_{K_g} q_{K_g}$			$p_{K_g} q_{K_g}$					0
Δ Loans			ΔL_C			ΔL_{mi}	ΔL_{U_b}	ΔL_{U_g}	$-\Delta L_{BA} + \Delta L_{CB}$	$-\Delta L_{CB}$			0
brown bond issues		$-p_{B_b} \Delta n_{B_b}^{H_k}$							$-p_{B_b} \Delta n_{B_b}^{BA}$	$-p_{B_b} \Delta n_{B_b}^{CB}$	$p_{B_b} \Delta n_{B_b}$		0
green bond issues		$-p_{B_g} \Delta n_{B_g}^{H_k}$							$-p_{B_g} \Delta n_{B_g}^{BA}$	$-p_{B_g} \Delta n_{B_g}^{CB}$	$p_{B_g} \Delta n_{B_g}$		0
Δ bank's deposits	$-\Delta M_{H_w}$	$-\Delta M_{H_k}$	$-\Delta M_C$	$-\Delta M_{K_b}$	$-\Delta M_{K_g}$	$-\Delta M_{mi}$	$-\Delta M_{U_b}$	$-\Delta M_{U_g}$	ΔD_{BA}		$-\Delta M_G$		0
Δ CB's reserves									$-\Delta M_{BA}$	ΔM_{fiat}		$-\Delta M_{ROW}$	0
Σ	0	0	0	0	0	0	0	0	0	0	0	0	

Table 2: Cash flow matrix of agents/sectors in the Eirin economy. The matrix is divided into two sections; the first section refers to cash receipts or outlays of operating activities with an impact on net worth; whereas the second section refers to any cash flows generated by variations real, financial and monetary assets or liabilities.

	H_w	H_k	CGP (C)	K_b	K_g	mi	U_b	U_g	BA	CB	G	ROW
(Net cash flows Table 2)	$+NCF_{H_w}$	$+NCF_{H_k}$	$+NCF_C$	$+NCF_{K_b}$	$+NCF_{K_g}$	$+NCF_{Mi}$	$+NCF_{U_b}$	$+NCF_{U_g}$	$+NCF_{BA}$	$+NCF_{CB}$	$+NCF_G$	$+NCF_{ROW}$
Capital depreciation			$-\xi_k K_C$			$-\xi_K K_{mi}$						
Change of inventories			$p_C \Delta I_{q_C}$									
Price change of:												
- tangible capital			$\Delta p_{K_b} K_b^C + \Delta p_{K_g} K_g^C$			$\Delta p_{K_b} K_b^{mi}$	$\Delta p_{K_b} K_b^{U_b}$	$\Delta p_{K_b} K_b^{U_g}$				
- inventories			$\Delta p_C I_{q_C}$									
- equity share		$\sum_a \Delta p_{E_a} n_{E_a}$										
- brown gov bonds		$\Delta p_{B_b} n_{B_b}^{H_k}$							$\Delta p_{B_b} n_{B_b}^{BA}$	$\Delta p_{B_b} n_{B_b}^{CB}$	$-\Delta p_{B_b} n_{B_b}$	
- green gov bonds		$\Delta p_{B_g} n_{B_g}^{H_k}$							$\Delta p_{B_g} n_{B_g}^{BA}$	$\Delta p_{B_g} n_{B_g}^{CB}$	$-\Delta p_{B_g} n_{B_g}$	
	$-\Delta E_{H_w}$	$-\Delta E_{H_k}$	$-\Delta E_C$	$-\Delta E_{K_b}$	$-\Delta E_{K_g}$	$-\Delta E_{mi}$	$-\Delta E_{U_b}$	$-\Delta E_{U_g}$	$-\Delta E_{BA}$	$-\Delta E_{CB}$	$-\Delta E_G$	$-\Delta E_{ROW}$
$\sum$	0	0	0	0	0	0	0	0	0	0	0	0

Table 3: Net Worth Change Matrix. The matrix shows how sectors' net worth changes due to both net cash flows and the price changes of financial assets.

assigning a higher risk to the brown financial assets, applying a higher discount factor for carbon-intensive (brown) assets, and thus rebalancing their portfolio towards green assets.

First, the government introduces a carbon tax for brown goods, thus signalling producers and investors. Green firms have a lower energy intensity and thus produce less emissions per unit of output generated, and thus are not affected by the introduction of the carbon tax. The carbon tax generates additional fiscal revenues for the government, which could decide to use them for financing green subsidies aimed to decrease the costs of renewable energy investments. Second, an equity shares market is introduced in order to capture investors portfolio choices. These consider firms performance in the brown and green sectors, and investors' climate sentiments in terms of perception of climate transition risks (Section 2.3). Finally, the commercial bank adjusts its lending conditions (i.e. interest rates) to green and brown firms with respect to firms debt to equity ratios. These can vary as a result of the expected performance of firms that face two types of climate risks: climate physical risk, i.e. damages induced by climate-led natural disasters, that destroy firms capital stock and affect the value of firms' equity holdings via lower profits; climate transition risk, as a result of the climate policy introduction that makes brown production costlier and less profitable, thus reflecting in a change in the value of firms' equity holdings.

3. Financial market and asset pricing model

Building on the portfolio model by Brainard and Tobin (1968), we develop a model of bond and equity portfolio investments that is affected by the introduction of a climate policy (i.e. a carbon tax).

Financial assets are represented by government bonds, either brown or green, and by equity shares, which are issued by the capital and consumption goods producers, the two utility companies, either brown or green, the mining company and the bank. Thus, the Eirin financial market is composed of seven financial asset classes. A main characteristic of our model is that financial assets prices directly depend on the amount of financial wealth that the market players are willing to allocate on each financial asset class. The capitalist household and the bank are the active players in the market. A second important feature of our model is that the share of financial wealth that the market players are willing to allocate on each financial asset class (i.e. the seven equity asset classes and the brown/green sovereign bonds) depends on the relative capitalization of each asset class. In this regard, the capitalization is evaluated not at current market prices but considering so-called "rational" prices. In particular, the capitalization of each asset class is given by the amount of outstanding equity shares or bond units, times a "rational" value for equity shares and bonds prices. Sovereign bonds are owned by the capitalist household, the bank and by the central bank, when the QE policy is active. Equity shares are owned by the capitalist household and by the bank.[1]

[1] For the sake of simplicity, in the scenarios presented in this study, equity shares are owned only by the capitalist household.

In the case of sovereign bonds, the the government plays a role in affecting market prices by issuing new bond units, either green or brown.

Portfolio allocation by the bank and the capitalist household is based on the discounted cash flow model, see Gordon (1959). In this respect, for each asset class a, both players, which are indexed here by s where $s \in \{H_k, BA\}$, determine the so-called rational market prices. These are $\hat{p}^s_{E_a}$ with $a \in \{C, K_b, K_g, mi, U_b, U_g, BA\}$ for equity shares and $\hat{p}^s_{B_a}$ with $a \in \{b, g\}$ for bond units. Rational market prices are set considering the present value of future expected case flows, i.e. expected share dividends or bond coupons. Afterwards, based on the rational prices, both the bank and the capitalist household compute the desired fraction of their financial wealth that they want to allocate on each asset class. The rationale is the assumption that the market price should converge to the rational prices, in line with the common modelling of fundamentalist behavior in agent-based behavioral models of financial markets, see e.g. Raberto et al. (2003). In particular, under the assumption that dividends grow at the expected growth rate $\hat{g}^s_a$, the expected rational equity price $\hat{p}^s_{E_a}$ is given by the well-know formula;

$$\hat{p}^s_{E_a} = \frac{\hat{d}^s_a}{r^s_a - \hat{g}^s_a} \,, \tag{1}$$

where $\hat{d}^s_a$ is the expected next step dividend and $\hat{r}^s_a$ is average cost of capital estimated by agent s for sector a, where $a \in \{C, K_b, K_g, mi, U_b, U_g, BA\}$ denotes all business agents/sectors of the Eirin economy. Similarly, considering that government bonds are infinitely lived and pay a coupon c for both green and brown bond classes, the expected rational bond price $\hat{p}^s_{B_a}$ is given by:

$$\hat{p}^s_{B_a} = \frac{c}{r^s_a} \,, \tag{2}$$

where $\hat{r}^s_a$ is the discount rate assessed by agent s and $s \in \{H_k, BA\}$ to denote either green or brown bonds. It is worth noting that market players have *adaptive expectations*. The expected values[2] of both dividends and growth rates are estimated as the average of past values of the variable in a moving time window of fixed length. The average cost of capital of business sectors and the discount rate applied to government bonds are estimated as the central banks policy rate, plus a given risk premium δ. This is differentiated with respect to bond and equity asset classes and depends on whether investors react to the climate policy announcement (i.e. their climate sentiments). In particular, in case climate sentiments are considered and carbon tax is introduced, the risk premium is assumed to be higher for brown equity asset classes (i.e. the consumption goods producer, the brown capital goods producer, the mining company and the brown utility). This feature aims to account for investors' anticipation of higher risk associated to brown assets in the case of carbon tax because of expected lower future profits and dividends.

The rational prices determined according to Eqs 1 and 2 are central in the portfolio allocation decisions by the two investors. We assume that the two investors are willing to allocate to each asset class (i.e. the

[2] The symbol ˆ over a variable denotes that it is an expected value.

seven equity asset classes and the brown/green sovereign bonds) a share of their financial wealth W^s that is identical to the share of the overall market capitalization that each asset class would get if market prices $p^s_{E_a}$ and $p^s_{B_a}$ would be identical to expected rational ones $\hat{p}^s_{E_a}$ and $\hat{p}^s_{B_a}$. Accordingly, for investor s, the desired weights (or fraction) of financial wealth $\hat{\omega}^s_{E_a}$ and $\hat{\omega}^s_{B_a}$ of equity shares and bond units of class a, respectively, are given by:

$$\hat{\omega}^s_{E_a} = \frac{n_{E_a}\hat{p}^s_{E_a}}{\sum_a n_{E_a}\hat{p}^s_{E_a} + \sum_a n_{B_a}\hat{p}^s_{B_a} + M^{H_k} + M^{BA}} + \sigma_\epsilon \epsilon \,, \tag{3}$$

$$\hat{\omega}^s_{B_a} = \frac{n_{B_a}\hat{p}^s_{B_a}}{\sum_a n_{E_a}\hat{p}^s_{E_a} + \sum_a n_{B_a}\hat{p}^s_{B_a} + M^{H_k} + M^{BA}} + \sigma_\epsilon \epsilon \,, \tag{4}$$

where $a \in \{C, K_b, K_g, mi, U_b, U_g, BA\}$ for stocks, $a \in \{b, g\}$ for bonds, and n_{E_a} (or n_{B_a}) is the number of outstanding equity shares (or bond units) of class a. The term $\sigma\epsilon$ is intended to provide a small idiosyncratic random shock to any weight calculation, being ϵ a random draw from a normal distribution, and σ_ϵ a scale parameter. This is the only source of stochasticity in the model, and can affect reactions and performance of agents and sectors in the real economy. The amounts of financial wealth $\hat{W}^s_{E_a}$ and $\hat{W}^s_{B_a}$ each investor s is willing to allocate to equity and bond asset classes are then respectively given by:

$$\hat{W}^s_{E_a} = \hat{\omega}^s_{E_a} W^s \,, \tag{5}$$

$$\hat{W}^s_{B_a} = \hat{\omega}^s_{B_a} W^s \,, \tag{6}$$

where W^s is the actual financial wealth given by actual market prices of financial assets, i.e.

$$W^s = \sum_a n^s_{E_a} p_{E_a} + \sum_a n^s_{B_a} p_{B_a} + M^s_0. \tag{7}$$

where $n^s_{E_a}$ (or $n^s_{B_a}$) is the number of outstanding equity shares (or bond units) of class a held by investor s and M^s_0 is the liquidity available to agent s before the financial market opens.

Accordingly, the expected liquidity $\hat{M}^s$ at the end of financial market trading for any investor is given as a residual, i.e. by the difference between initial total financial wealth and the amounts allocated to equity shares and bond units. This can be written as:

$$\hat{M}^s = W^s - \sum_a \hat{W}^s_{E_a} - \sum_a \hat{W}^s_{B_a} \,. \tag{8}$$

The actual end-of-period liquidity of the capitalist household M^{H_k} and of the bank M^{BA} will depend also on financial market operations of both the government and the central bank. The government may affect liquidity of amount $\Delta M^G_{B_b} + \Delta M^G_{B_g}$ by issuing new units of sovereign bonds, either brown $\Delta n^G_{B_b}$ or green $\Delta n^G_{B_g}$. In contrast, the central bank may inject liquidity $\Delta M^{CB}_{B_b} + \Delta M^{CB}_{B_g}$ by purchasing units of sovereign bonds, either brown $\Delta n^{CB}_{B_b}$ or green $\Delta n^{CB}_{B_g}$. In particular, assuming the the two policy makers will always fulfill their liquidity drawing and injection plans in the bond market, the total liquidity to be shared by the bank and the capitalist household at the closure of the market, i.e. $\sum_s M^s$ shall be given by their initial liquidity plus government and central bank money drawing or injections. This is equal to:

$$\sum_s M^s = \sum_s M_0^s - \Delta M_{B_b}^G - \Delta M_{B_g}^G + \Delta M_{B_b}^{CB} + \Delta M_{B_g}^{CB} \tag{9}$$

Eq. 9 shall then be considered as a binding constraint to determine the actual liquidity M^s at disposal to each investor s, i.e. the capitalist household and the bank in our case. We assume that the end-of-period liquidity of each investor is a share of the total actual liquidity available to investors. The share is set by the ratio between the desired investor liquidity and total desired liquidity of all investors, i.e. $\hat{M}^s / \sum_s \hat{M}^s$, as follows:

$$M^s = \frac{\hat{M}^s}{\sum_s \hat{M}^s} \Big(\sum_s M_0^s - \Delta M_{B_b}^G - \Delta M_{B_g}^G + \Delta M_{B_b}^{CB} + \Delta M_{B_g}^{CB} \Big) \, . \tag{10}$$

The actual end-of-period liquidity sets the actual amounts of financial wealth, $W_{E_a}^s$ and $W_{B_a}^s$, allocated to equity shares and bond units by each investor s, i.e.,

$$W_{E_a}^s = \frac{\hat{\omega}_{E_a}^s}{\hat{\omega}_M^s} M^s \, , \tag{11}$$

$$W_{B_a}^s = \frac{\hat{\omega}_{B_a}^s}{\hat{\omega}_M^s} M^s \, . \tag{12}$$

The rationale of Eqs. 11 and 12 is to keep the desired proportion between the share of financial wealth held in liquidity, i.e. $\hat{\omega}_M^s$, and the share of wealth invested in each asset as determined by Eqs. 3 and 4. This goal is mathematically achieved by re-normalizing the desired weights of financial assets by the desired weight of liquidity so to set the relative proportions between the actual invested amounts $W_{E_a}^s$, $W_{E_a}^s$ and liquidity M^s equal to the desired ones, i.e. $\frac{\hat{\omega}_{E_a}^s}{\hat{\omega}_M^s}$ or $\frac{\hat{\omega}_{B_a}^s}{\hat{\omega}_M^s}$.

The financial asset prices are the degrees of freedom that allow for Eqs. 11 and 12 to be fulfilled. Accordingly, we consider a pricing rule that sets the new price of each financial asset as the ratio between the amount of financial wealth invested in it and the number of outstanding shares or units. The new market share price p_{E_a} of stock a is given by:

$$p_{E_a} = \frac{\sum_s W_{E_a}^s}{n_{E_a}} \, , \tag{13}$$

while the new market prices p_{B_b} and p_{B_g} of the brown and green bonds are given by:

$$p_{B_b} = \frac{\sum_s W_{B_b}^s - \Delta M_{B_b}^G + \Delta M_{B_b}^{CB}}{n_{B_b}} \, , \tag{14}$$

$$p_{B_g} = \frac{\sum_s W_{B_g}^s - \Delta M_{B_g}^G + \Delta M_{B_g}^{CB}}{n_{B_g}} \, . \tag{15}$$

Finally, it is worth noting that the rationale of Eqs. 14 and 15 is the same as the one of Eq. 13. An additional complication emerges in the case of bonds and is due to government and central bank operations.

If Δn_{B_a}, where $a \in \{b, g\}$, denotes the net increase (or decrease) of the number of bond units outstanding in the market, following new issues by the government and bond purchases by the central bank, then the analogue of Eq.13 for bonds is:

$$(n_{B_a} + \Delta n_{B_a})p_{B_a} = \sum_s W^s_{B_a} \qquad a \in \{b, g\} \tag{16}$$

Then, considering that by definition $\Delta n_{B_a} p_{B_a} = \Delta M^G_{B_a} - \Delta M^{CB}_{B_a}$, from Eq. 16 we can derive Eqs. 14 and 15.

4. Scenarios: climate policies, investors' reaction and risk perception

We assess how the government may contribute to scale up private capital investments in renewable energy by providing green subsidies for capital investments in renewable energy. We consider a government that faces budgetary constraints, i.e. it has to meet certain budget and public debt targets (see Section 2). In addition, it wants to prevent potential trade-offs on country's economic competitiveness and inequality. Thus, the government can choose to finance the green subsidies either through the introduction of a *carbon tax* (fiscal policy) according to the recommendations of Stiglitz et al. (2017), or through the issuance of green bonds (that are then conditioned to the capital investments in renewable energy, (Monasterolo and Raberto, 2018)). In addition, we consider the role of investors' reactions in the analysis of climate policies' implementation. Investors could trust the government and thus react (in a mild or steep way) by changing their risk perception associated to brown assets (i.e. by applying an higher discount rate to brown investments to mirror the higher risk associated). Thus, the three climate policy scenarios (*Sc*) differ for the way the government decides to finance the green subsidies, and in investors' reaction to the policies.

We simulate three climate policy scenarios characterized by different types of government intervention and investors' reaction, and we compare them with a Business as Usual scenario (BAU) of government's climate inaction. The BAU and the three climate policy scenarios are defined as follows:

- *Sc1*: The government doesn't react to the EU2030 targets or Paris Agreement's climate targets, i.e. Business as Usual (black).

- *Sc2*: The government provides green subsidies, which are financed via the introduction of a carbon tax. The tax targets the production and use of fossil fuels in the economic value chain (blue).

- *Sc3*: The government provides green subsidies, which are financed with the introduction of a carbon tax. Investors in the financial market (i.e. capitalist household and the bank) react to the policy by changing their expectations on future profitability of the brown companies revising their risk pricing of brown financial assets. (green).

- *Sc4*: The government provides green subsidies, which are financed with the issuance of green bonds (i.e. conditionality)(red).

In the scenario characterized by the introduction of a carbon tax scenario, we explicitly consider investors' reactions, i.e. what we call "climate sentiments". The definition of investors' climate sentiments is based on experts' opinions collected via interviews, through a transdisciplinary knowledge co-production approach (Howarth and Monasterolo, 2016). The characteristics of the four scenarios are summed up in Table 4.

Table 4: Main characteristics of the four model's scenarios

Scenario N.	**Colour**	**Green Subsidy**	**Carbon Tax**	**Climate Sentiment**	**Green Bonds**
1/BAU	Black	No	No	No	No
2	Blue	Yes	Yes	No	No
3	Green	Yes	Yes	Yes	No
4	Red	Yes	No	No	Yes

5. Discussion of results

We present and discuss the main results of the model's simulation in Figure 2 to Figure 7. Figure 2 and Figure 3 show the results of the four scenarios in terms of real economy, i.e. real GDP and total unemployment (Figure 2), firms' capital and the ratio of utilized green capital stock over total physical capital endowment of the consumption goods producer (Figure 3).

We notice that by moving from the BAU scenario (*Sc1*) to scenarios characterized by the introduction of a carbon tax (*Sc2* and *Sc3*) and green bonds (*Sc4*), real GDP (Figure 3, top panel) grows as a result of new green investments. The (green) growth path is sustained by the reaction of financial investors (*Sc3*), i.e., when investors believe that government climate policy is credible, they react accordingly by increasing their risk perception of brown financial assets (Figure 6). Higher real GDP growth and lower unemployment take place in the climate policy scenario characterized by the introduction of green bonds (Figure 2, bottom panel), compared to the other scenarios.

Figure 3 shows the trend in firms' capital investments and green capital stock across the four scenarios. Firms' capital (top panel) remains at the lowest levels in the scenarios characterized by the BAU (*Sc1*) and by the introduction of the carbon tax (*Sc2*), in particular when investors don't start to internalize the climate policy in their portfolios' strategies. In contrast, firms' capital grows the most in the policy scenario characterized by the introduction of green sovereign bonds (*Sc4*).

The introduction of green subsidies fosters the production of renewable energy and thus its share on total energy produced in the economy, with negligible differences across the three climate policy scenarios (Fig.

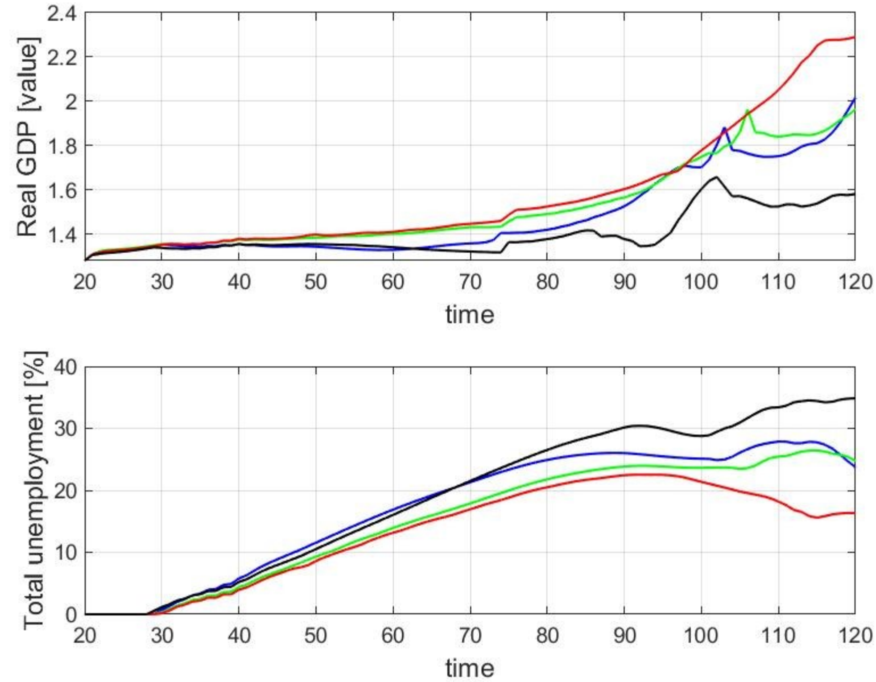

Figure 2: Real GDP and total unemployment's trends in the EIRIN economy

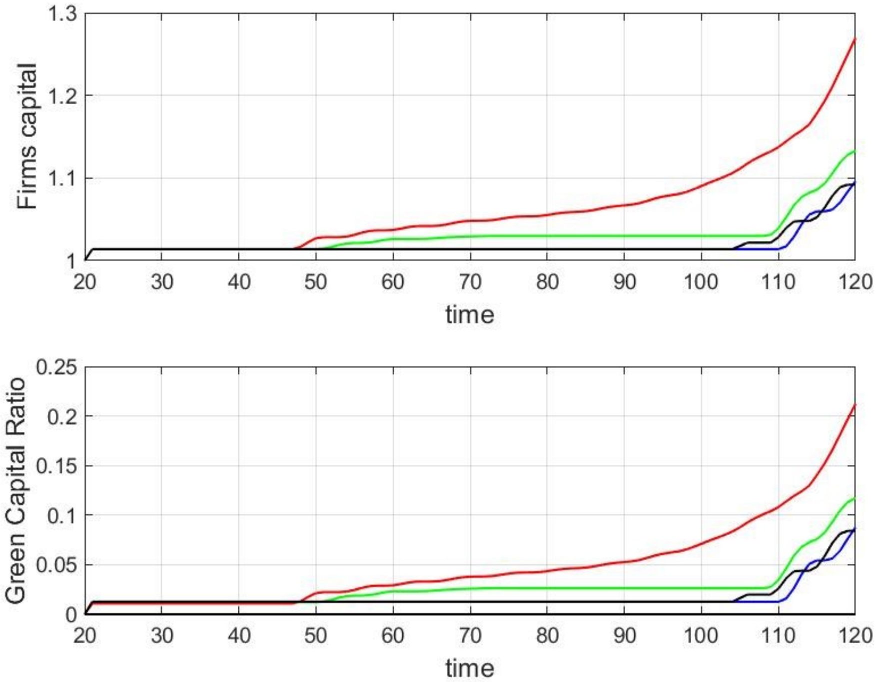

Figure 3: Firms'capital investments and Green capital ratio

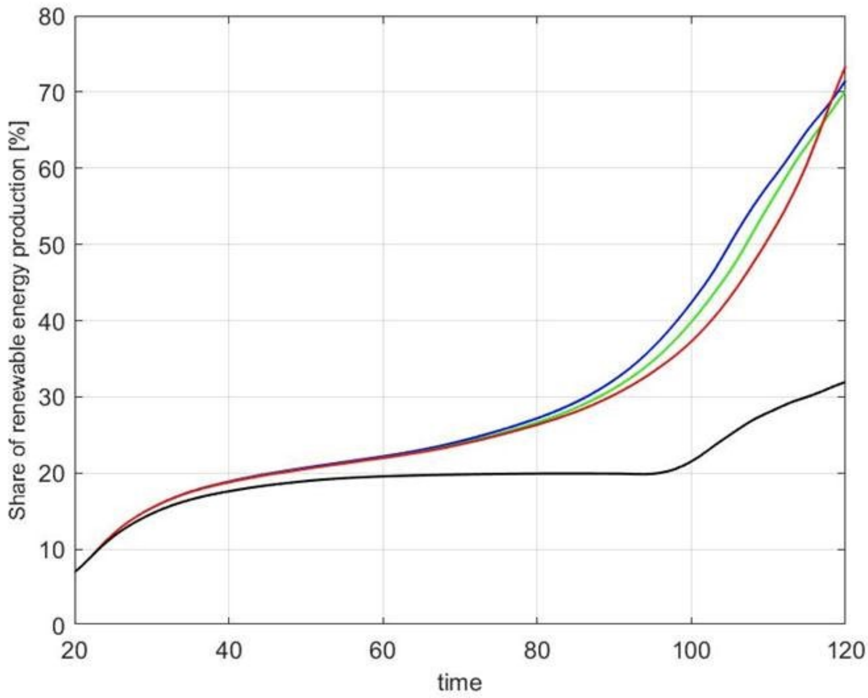

Figure 4: Share of renewable energy production (in percentage of total)

4). All the scenarios characterized by climate policies perform better than the BAU due to the performance of investments, consumption and of the labour market.

Figure 5 shows the effects of the four scenarios on the relative performance of worker and capitalist households in the economy, i.e. what we consider the distributive effects of the policies. The scenario characterized by the introduction of a carbon tax (*Sc2*) has the highest distributive effects on the worker households. In contrast, the green sovereign bonds' scenario (*Sc4*) shows the lowest distributive effects, in particular at the end of the simulation period. This is due to the fact that workers' income share in the economy decreases when energy producers apply higher energy prices to cover the cost of the carbon tax. Thus, the carbon tax is transmitted by capital and consumption goods producers to the final consumers. This, in turn, contributes to decrease the aggregate consumption in the economy (demand side channel), negatively affecting GDP growth, investments and employment (see Figure 2). Distributive effects of the carbon tax are smoothed when investors' reactions emerge. In the green sovereign bonds scenario (*Sc4*), the distributive effects of the policy are low due to the performing (green) real economy, which fosters new green investments and jobs (i.e. a green multiplier effect occurs). However, we notice that all the scenarios characterized by climate policies show lower distributive effects than the BAU (*Sc1*). This is due to the steep increase in total unemployment in the BAU.

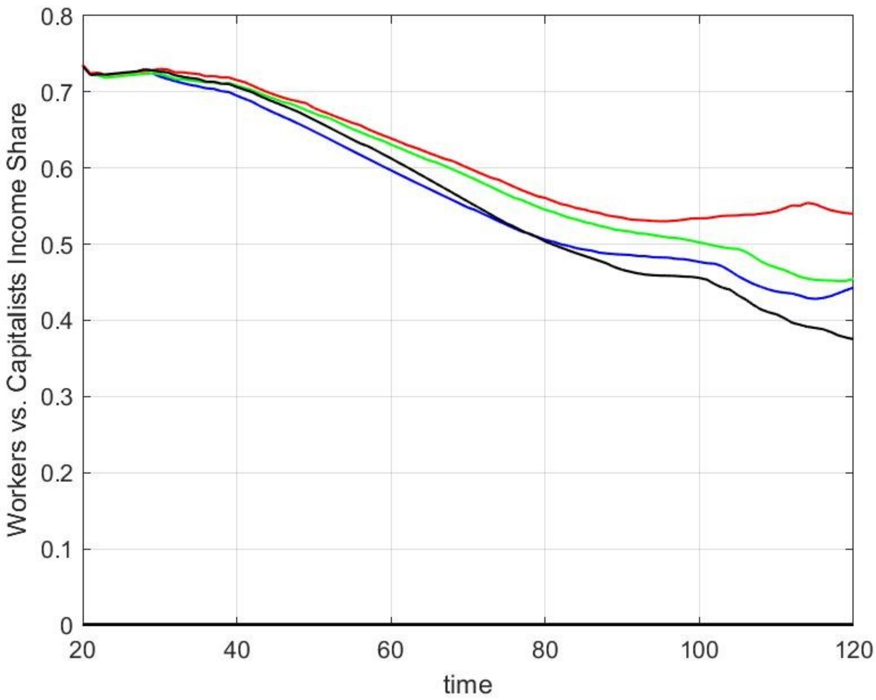

Figure 5: Distributive impacts of government's policies

Figure 6 shows the prices of equity holdings of the mining company and of the green utility company (respectively top right and top left panels), and of brown and green capital goods producers (respectively bottom right and left panels). We notice that investors' reactions to the climate policy (*Sc3*) affect the decrease in the price of mining company's equity shares (top right panel). As a result, investors' portfolio shifts to green assets, contributing to increase the price of the equity shares of the green utility company (top left panel). Consistently with the model's results and narrative, in the BAU scenario (*Sc1*), the equity prices of the mining company and brown capital goods company show the best performance, while green utility and green capital goods companies' equity prices show the worst performance. The equity prices of green capital goods gain the most in the scenarios characterized by strong investors' reaction and green sovereign bonds, as a result of investors' brown risk perception and portfolio reallocation.

Finally, Figure 7 shows the trend of green sovereign bonds' prices across the four scenarios. Highest green bonds' prices are related to the scenario characterized by investors' reactions to the carbon tax (*Sc3*) as a consequence of investors portfolio's shift to green assets. In contrast, and as expected, green bonds' prices are the lowest in the BAU and carbon tax scenarios.

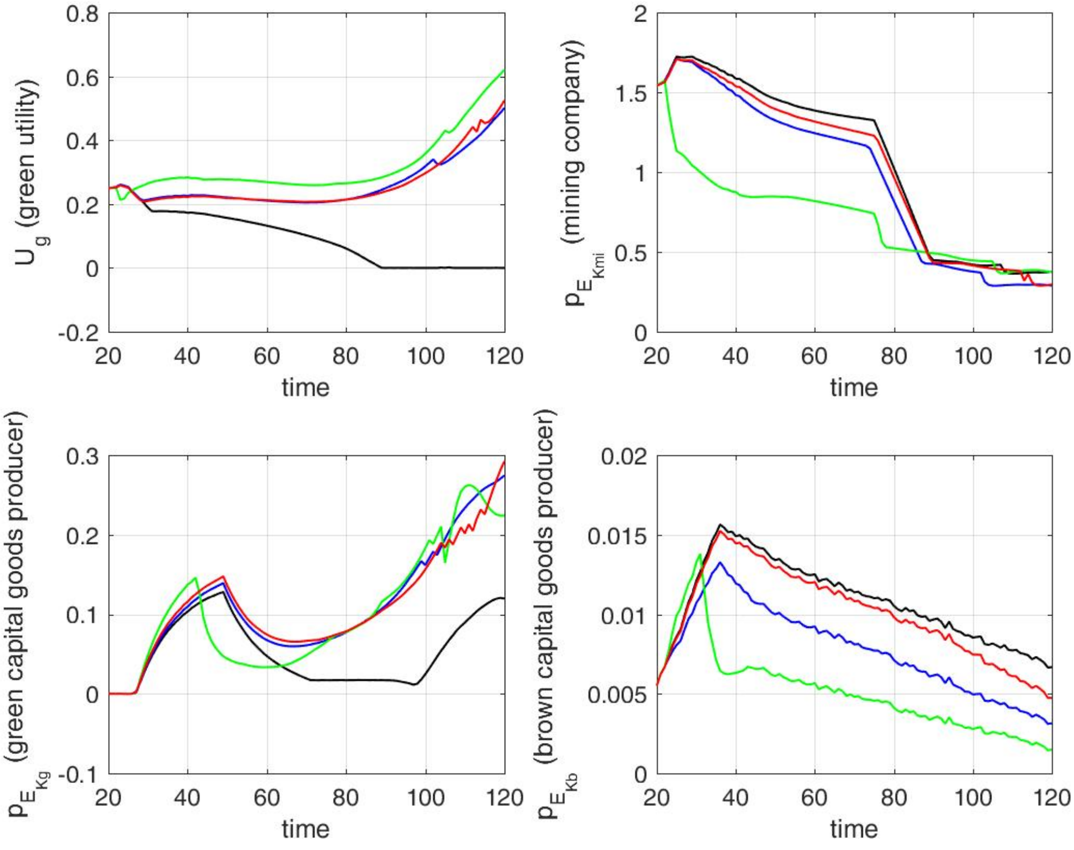

Figure 6: Equity prices in green and brown sectors

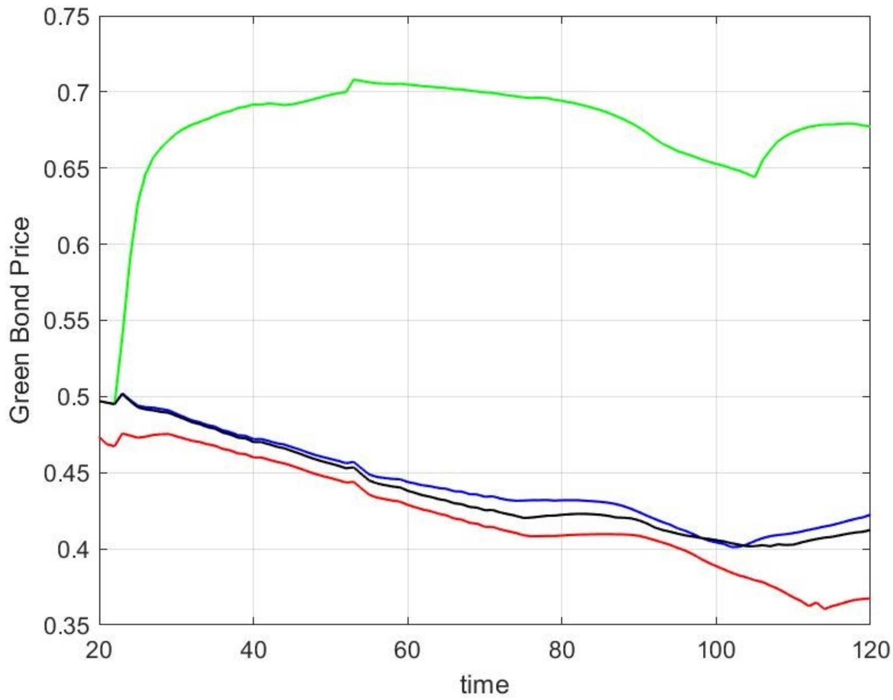

Figure 7: Green bonds' prices

6. Conclusions

In this paper, we have analyzed how a EU government subject to budget and public debt constraints could foster investors' capital allocation in renewable energy with the introduction of green subsidies, which can be financed either with a carbon tax or green sovereign bonds. We have also analyzed to what extent the climate policies could induce a change in investors' risk perception of brown financial assets, affect financial markets' fundamentals for green/brown equity and bonds, and investors' portfolio's allocation. We then studied the cascading effects generated on investments and employment in the real economy, and on income inequality across households.

We have compared the scenarios characterized by climate policies and by investors' reactions with a scenario of government's climate inaction. Results are discussed in terms of effects on green/brown investments, unemployment, salaries, and financial assets' prices. The analysis was performed by further extending the Eirin SFC behavioural model (Monasterolo and Raberto (2018, 2019)).

Our results are summed up in Table 5, which compares the four scenarios in terms of impacts - positive/negative, low/medium/high - on the real economy, on green capital and renewable energy investments, on the equity market, and on income inequality (capitalist/worker households).

We find that the design of climate policies could critically influence their economic and financial result, and in particular the pace and magnitude of new renewable energy investments. Moreover, the way climate policies are implemented could generate distributive effects that drive down demand. In particular, the scenario characterized by the introduction of a carbon tax (*Sc2*) has high distributive effects that contribute to slow down the economy. Indeed, in absence of market regulations or conditionality, the cost of the tax is mostly transmitted from the fossil fuel energy and electricity companies through the production value chain (i.e., brown capital goods producer and consumption good producer) to households. These have to face higher energy prices that contribute to decrease their income share, and as a consequence their overall consumption in the real economy, with negative feedback effects on investments and GDP.

This result has three main implications. First, the possibility to pass the cost of the carbon tax on final consumers allows the non-financial sector to remain in a carbon-intensive path, with very limited effects on the low-carbon transition. Second, a limited reallocation of investments toward renewable energy means a limited impact on the decarbonization of the economy, which is the goal of the climate policies introduced by the government. Third, the introduction of the carbon tax alone and in the conditions analysed by the model doesn't seem to consistently prize green companies vs. brown companies in the financial market, by looking at the trend in the relative prices of equity holdings.

The macroeconomic situation improves when the government starts to issue green bonds. In this scenario (*Sc4*), the distributive effects of the carbon tax are mitigated (but don't disappear) by an overall sustained growth of the green real economy, i.e. renewable energy investments, employment, green capital accumulation. A green multiplier effect takes place. Further, we notice that investors' climate sentiments in reaction to the climate policies affect the price of equity shares of fossil fuel and carbon-intensive companies, as a result of portfolios' shift to green assets. This, in turn, contributes to increase the price of equity shares of the green utility company. Real and financial markets' reactions have overall positive effects on emissions' decrease, which is more successful in *Sc3* and *Sc4* in comparison to the other scenarios due to the highest green capital stock and green energy capacity.

In conclusion, we have provided what is to our knowledge the first SFC macroeconomic dynamic model that allows to assess the impact of two types of climate policies on real and financial markets' expectations, as well as the conditions for investors' climate sentiments to emerge and to play a role in the decarbonization of investors' portfolios and of the economy. This is a first attempt subject to further developments. Nevertheless, our analysis is already able to provide some meaningful insights to policy makers, central banks and regulators who aim to assess potential direct and indirect economic and financial implications of climate policies, in order to define targeted and timely risk mitigation policies. However, potential unintended distributive effects should be considered in the policy design, and properly counteracted.

Further, our results show that investors' climate sentiments could emerge as a result of the policies and could play a key role in the decarbonization of financial markets and of the real economy. Thus, it is in the interest of policy makers, central banks and financial regulators to discuss if and to what extent synergies between sustainable finance initiatives and actors could be identified and exploited to provide strong signals to the markets and promote a greening of real and financial markets.

In the discussion on the introduction of a new sustainable finance architecture and sustainable finance agenda in Europe, identifying the opportunities and challenges of the government-led sustainable finance initiatives under discussion, as well as the potential role of central banks, could be key to still allow the achievement of the climate targets.

Table 5: Policy Scenario Impacts

Impacts		**Carbon tax with climate sentiments (SC2)**	**Carbon tax with climate sentiments (SC3)**	**Green Bonds (SC4)**
Real economy & distributive effects		↑	↑↑	↑↑↑
Green capital		∼	↑	↑↑↑
Renewable capacity investment		↑↑	↑↑	↑↑
Equity market	Brown stock prices	↓↓	↓↓↓	↓
	Green stock prices	↑↑	↑↑↑	↑↑
Green bond price		↑	↑↑↑	↓

Note: Government-led sustainable finance initiatives classified according to their impacts on the real economy, on green capital investments, on the bonds and equity market.

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Appendix A. Sensitivity Analysis

We provide here a sensitivity analysis of climate policy parameter values of the two climate policy scenarios, i.e. the carbon tax and green sovereign bonds (*Sc2 & Sc4*) and investors climate sentiments *(Sc3)* with respect to their effects on the main model variables. We analyze the effects of the policies and investors climate sentiments on real GDP and unemployment, on government debt levels as well as debt to GDP ratios. As we are interested in analyzing the change in core model variables in response to altered policy parameters, we show the results indexed to the above presented baseline policy and climate sentiment parameters.

Figure A.8 shows the effects of different green subsidy shares for green investments, when financed by raising a carbon tax (*Sc2*). The range of the green subsidy share ranges between low shares of 2.5% to high shares of 25% and are plotted as an index against the baseline *Sc2* share of 15%. A higher green subsidy share tends to increase GDP, lower emissions and unemployment. However, government debt also slightly increases. The increasing volatility of green subsidy shares with greater distance to the baseline share of 15% shows that the timing of the impacts of the policy varies with different shares of green subsidies.

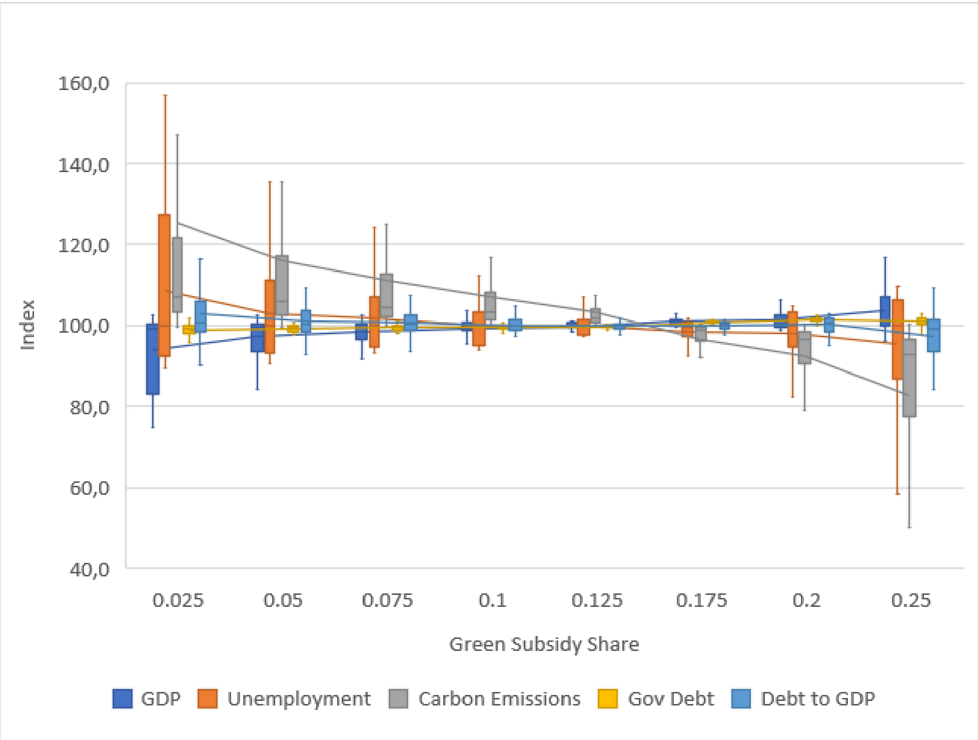

Figure A.8: Macroeconomic and financial variables' response to different green subsidy shares **financed by the carbon tax (Sc2)** (0.25 = 25%)

Figure A.9 shows different levels of investors climate sentiments (*Sc3*), ranging from very low levels that barely differ from the carbon tax scenario *Sc2* to levels of entirely climate sensitive investors (full reaction, = 1). We generally observe positive impacts on GDP, unemployment and emissions, as well as slightly higher government debt levels and debt to GDP ratios, the stronger investors climate sentiments. Two points emerge. First, the volatility of GDP, unemployment and government debt with respect to the baseline climate sensitivity level of (0.08) increases, indicating a different timing effects in response to climate sentiment levels compared to the baseline scenario. Second, changes in investors climate sentiments have stronger effects at lower levels, whereas a saturation effect appears at levels (> 0.2).

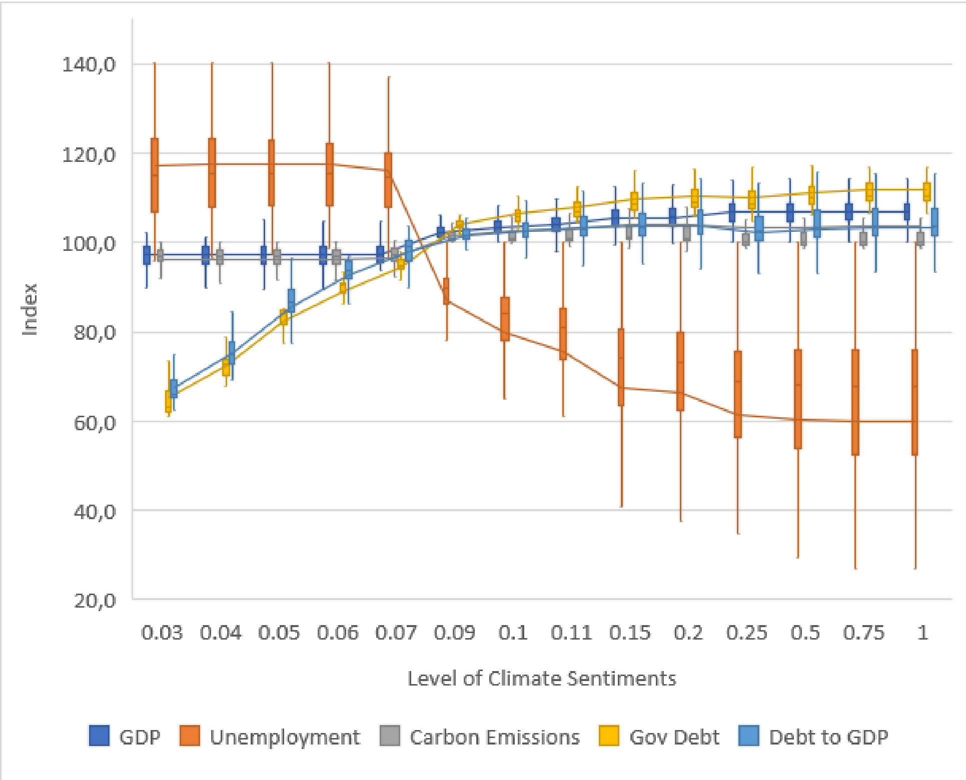

Figure A.9: Macroeconomic and financial variables' response to different levels investor's climate sentiments (SC3) (0.03 = 3%)

Figure A.10 shows the effects of different green subsidy shares for green investment, financed by the issuance of green government bonds (*Sc4*). The range of the green subsidy share ranges from 2.5% to 25%. Compared to the carbon tax scenario, we notice more pronounced positive effects of the green bond issuance on GDP, lower emissions and lower unemployment. Government debt non-surprisingly increases but at a much smaller pace than GDP growth, making new debt sustainable. Volatility increases with greater distance to the baseline green subsidy share scenario of 15%, showing the different timing of effects compared to the baseline scenario.

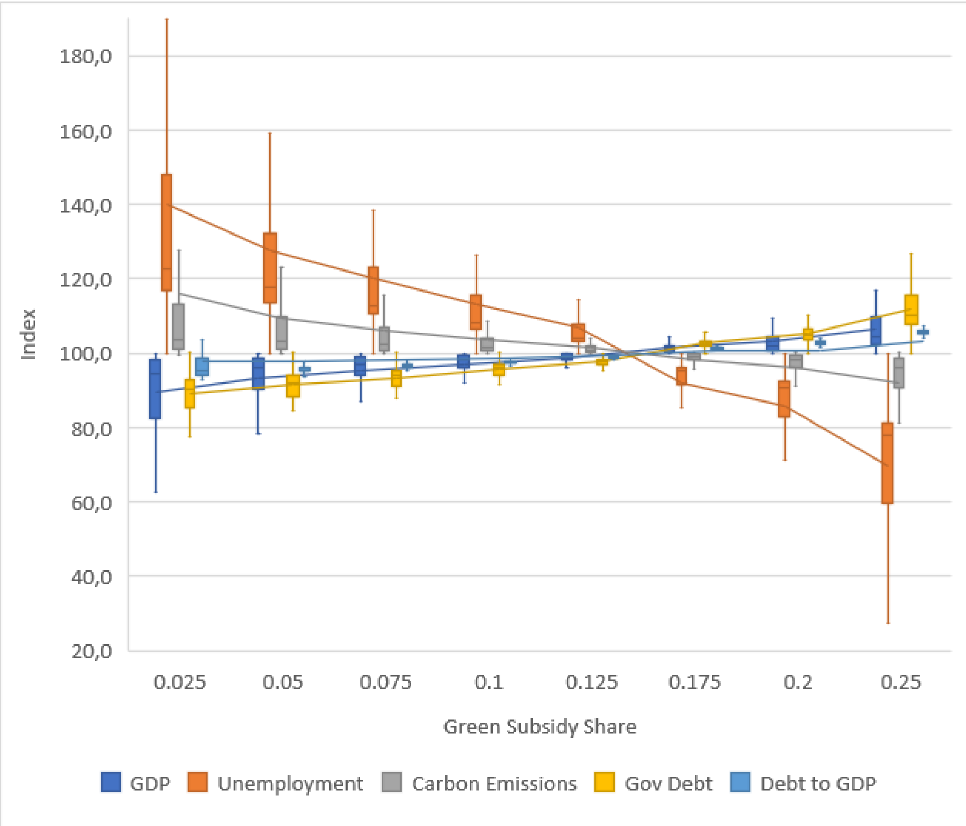

Figure A.10: Macroeconomic and financial variables' response to different green subsidy shares **financed by green bond issuance (SC4)** (0.25 = 25%)