The Dynamic Ecosystem-FINance-Economy (DEFINE) model: Manual

Version 1.1

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1. Introduction

This document describes the technical details of version 1.1 of the DEFINE (Dynamic Ecosystem-FINance-Economy) model. DEFINE is a global ecological stock-flow consistent (E-SFC) model that analyses the interactions between the ecosystem, the financial system and the macroeconomy. It incorporates explicitly the laws of thermodynamics, the impact of carbon emissions on climate change, the implications of climate damages, the waste generation process, the endogeneity of money and the impact of finance on economic activity. DEFINE produces various scenarios for the future of the ecosystem and the global economy. It is also used to evaluate the long-run effects of various types of environmental policies and strategies, paying particular attention to the role of finance.

DEFINE combines the post-Keynesian SFC approach developed by Godley and Lavoie (2012) with the flow-fund model of Georgescu-Roegen (1971, Chapter 9), Georgescu-Roegen (1979) and Georgescu-Roegen (1984). The key innovation of the post-Keynesian SFC approach is the integration of accounting into dynamic macro modelling. This integration permits the detailed exploration of the links between the real and the financial spheres of the macroeconomy. The flow-fund model of Georgescu-Roegen encapsulates the fundamental propositions of ecological economics. His model relies on a multi-process matrix that depicts the physical inflows and outflows that take place during the various economic processes, drawing explicitly on the First and the Second Law of Thermodynamics.

The combination of the SFC approach with the flow-fund model of Georgescu-Roegen provides an integrated approach to the combined analysis of physical and monetary stocks and flows. In DEFINE this analysis relies on four matrices: 1) the physical flow matrix; 2) the physical stock-flow matrix; 3) the transactions flow matrix; and 4) the balance sheet matrix. The first matrix is a simplification of the matrix that Georgescu-Roegen's used in his flow-fund model. The second matrix captures the dynamic interaction between physical stocks and flows and is a natural extension of the physical flow matrix. The third matrix and the fourth matrix describe the changes in the stocks and flows of the macroeconomic and the financial system, following the traditional formulations in the SFC literature.

In line with the post-Keynesian tradition, output in the model is determined by aggregate demand. However, supply-side constraints might arise primarily due to environmental problems. This is formalised by using a Leontief-type production function that specifies the supply-determined output drawing on Georgescu-Roegen's distinction between stock-flow and fund-service resources.[1] It is assumed that environmental problems affect in a different way each type of resources. Depletion problems affect the stock-flow resources (i.e. fossil fuels and material resources can be exhausted) while degradation problems, related to climate change and the accumulation of hazardous waste, damage the fund-service resources (by destroying them directly or by reducing their productivity). Climate change and its damages are modelled using similar specifications as in the integrated assessment modelling literature (see Weitzman, 2012; Dietz and Stern, 2015). However, a key departure from this literature is that climate damages do not affect an output determined via a neoclassical production function. Instead, they influence the fund-service resources of our Leontief-type production function and the components of aggregate demand.

DEFINE 1.1 differs from DEFINE 1.0 mainly in the following ways. *First*, an explicit distinction is made between conventional investments with a different 'degree of dirtiness'. 'Dirtiness' is defined based on data about the carbon emissions of different sectors of the economy. By making such a distinction we are able to assess financial policies that might impose higher capital requirements on bank loans provided for dirty investment. *Second*, version 1.1 incorporates explicitly carbon taxes and green subsidies. These green fiscal policies affect both the profitability of firms and their decision about the level of green investment. *Third*, green public investment is introduced. This implies that

[1] The stock-flow resources (fossil energy and material resources) are transformed into what they produce (including by-products), can theoretically be used at any rate desired and can be stockpiled for future use. The fund-service resources (labour, capital and Ricardian land) are not embodied in the output produced, can be used only at specific rates and cannot be stockpiled for future use. Crucially, these two types of resources are not substitutable: they are both necessary for the production process.

in this version of the model the government accumulates public capital, part of which is green. Hence, government investment decisions have an important impact on ecological sustainability. *Fourth*, the loan spread is now endogenous, and not exogenous as in the previous version. Hence, banks decide not only about the proportion of demanded loans that they reject, but also about the interest rate imposed on these loans. In this decision they take into account their financial position. Crucially, the parameters for the credit rationing and the lending spread functions are determined based on econometric estimations. Overall, these changes allow us to analyse in detail the effects of the so-called green differentiated capital requirements, whereby capital requirements are adjusted based on the greenness and the dirtiness of the assets of banks. They also allow us to investigate the effects of green fiscal policies, like carbon taxes, green subsidies and green public investment.

An additional major change in this version of the model is the way that carbon emissions are linked to changes in atmospheric temperature. We have replaced the formulation that draws on the DICE model (see Nordhaus, 2018) with a more simplified approach which takes explicitly into account the finding that global warming is approximately proportional to cumulative carbon emissions (see Matthews et al., 2021). This makes the model more consistent with recent advances in climate science. It also allows us to analyse low-emission scenarios more accurately, given that the way that the carbon cycle has been formulated in the DICE model produces an unrealistically tight short-term emissions budget (see Rickels et al., 2018).

The document is structured as follows. *Section 2* describes the matrices and the equations of the model. *Section 3* presents the key features of the baseline scenario used in this version. *Section 4* reports all the symbols of the model, the data sources and the values used for variables and parameters.

2. Structure of the model

DEFINE consists of two big blocks. The first block is the ecosystem block which includes equations about (i) matter, recycling and waste, (ii) energy, (iii) emissions and climate change and (iv) ecological efficiency and technology. The second block is the macroeconomy and financial system block which includes equations about (i) output determination, (ii) firms, (iii) households, (iii) banks, (iv) the government sector and (v) the central banks.

It is assumed that there is one type of material good that can be used for durable consumption and (conventional and green) investment purposes. Four matter/energy transformation processes are necessary for the production of this good and all of them require capital and labour. First, matter has to be extracted from the ground and has to be transformed into a form that can be used as an input in the production. Second, useful energy has to be generated based on fossil sources (e.g. oil, gas and coal) or non-fossil sources (e.g. sun, wind).[2] Third, recycling has to take place. Every year a part of the capital stock and the durable consumption goods that have been accumulated in the socio-economic system are demolished/discarded; the material content of these accumulated capital goods and durable consumption goods is called socio-economic stock.[3] A proportion of this demolished/discarded socio-economic stock is recycled and is used as an inflow in the production of the final good. This means that not all of the matter that is necessary for the production of the good has to be extracted from the ground. Fourth, the final good needs to be produced using material and energy inflows from the other processes.

Crucially, all these four processes, in combination with the functioning of the whole socio-economic system, generate by-products. In particular, industrial CO_2 emissions are produced as a result of the combustion of fossil fuels. Energy is dissipated in all transformation processes; this energy cannot be

[2] For brevity, the energy produced from fossil sources is henceforth referred to as fossil energy. For simplicity, the model does not incorporate energy and matter from biomass. However, the figure used for the share of non-fossil energy in our calibrations includes bioenergy to facilitate comparison with other studies.

[3] This is a term used in material flow analysis (see e.g. Krausmann et al., 2014). In general, socio-economic stock also includes animal livestock and humans. However, these stocks (whose mass remains relatively stable over time) are not included in our analysis. Note that socio-economic stock is measured in Gigatonnes (Gt).

used again. In addition, the demolished/discarded socio-economic stock that is not recycled becomes waste. Part of this waste is hazardous and can have adverse effects on the health of the population.

Since the model focuses on the aggregate effects of production, all the above-mentioned processes have been consolidated and are presented as part of the total production process. An unconsolidated formulation of the production process would make the model and its calibration much more complicated without changing the substance of our analysis. However, such an unconsolidated version would be useful for the analysis of intra-firm dynamics and could be the subject of future extensions of the model.

Although capital, labour, energy and matter are all necessary in the transformation processes, these resources do not directly determine the level of production as long as they are not scarce: in the absence of scarcity, the level of production is demand-determined, in line with the post-Keynesian tradition. However, if any of these resources is not sufficient to satisfy demand, production is directly affected by resource scarcity. In particular, we assume that, under supply-side constraints, consumption and private investment demand might decline. Moreover, although all these resources are necessary for the production of goods based on our Leontief-type production function (i.e. there is imperfect substitutability), their relative use changes because of technological progress.

In this version of DEFINE we have made a distinction between four broad sectors: 'mining and utilities' (*S1*), 'manufacturing and construction' (*S2*), 'transport' (*S3*) and 'other sectors' (*S4*).[4] The main purpose of the disaggregation into these four sectors is to identify different degrees of dirtiness for the loans given to these sectors based on the carbon emissions that they generate compared to their gross value added.

As mentioned above, there are two types of capital: green capital and conventional capital. In each sector, both energy and non-energy investment is undertaken. Energy investment has to do, for example, with investment in power plants, fossil fuel supply and the energy efficiency of buildings. Non-energy investment includes the rest of the investment which affects, amongst others, material efficiency and recycling. Therefore, green and conventional capital can be energy or non-energy capital. An increase in green energy capital compared to conventional energy capital leads, ceteris paribus, to higher energy efficiency and to a higher non-fossil energy share. Moreover, an increase in green non-energy capital compared to conventional non-energy capital tends to increase material efficiency and the recycling rate. The model also includes investment in carbon sequestration technologies. The higher the investment in these technologies, the lower the emissions produced for a given level of output.

Firms invest in conventional and green capital by using retained profits, loans and bonds. Banks accumulate capital and distribute part of their profits to households. They impose credit rationing on firm loans and they decide about the level of the lending interest rates. This means that they play an active role in the determination of output and the accumulation of green capital. Households receive labour income, buy durable consumption goods and accumulate wealth in the form of deposits, corporate bonds and government securities (there are no household loans). Corporate bonds can be either green or conventional. When the demand for green bonds increases, the price of these bonds tends to go up, leading to a lower cost of borrowing for green projects.

Central banks determine the policy interest rate, provide liquidity to the banks and purchase government securities and corporate bonds. The government sector collects taxes (including carbon taxes), decides about the level of government consumption and government investment (which can be green or conventional) and can implement bailout programmes, if there are financial problems in the banking sector. Inflation has been assumed away and, for simplicity, the price of goods is equal to unity. We

[4] This disaggregation relies on ISIC (International Standard Industrial Classification of All Economic Activities) rev. 3.1. The 'mining and utilities' sector includes ISIC C ('mining and quarrying') and ISIC E ('electricity, gas and water supply'), the 'manufacturing and construction' sector includes ISIC D ('manufacturing') and ISIC F ('construction'), the 'transport' sector corresponds to ISIC I ('transport, storage and communications') and the 'other sectors' include ISIC A, B, G, H and J-P.

use the US dollar ($) as a reference currency.

2.1. Ecosystem

Table 1 depicts the physical flow matrix of our model. This matrix captures the First and the Second Law of Thermodynamics. The First Law of Thermodynamics implies that energy and matter cannot be created or destroyed when they are transformed during the economic processes. This is reflected in the material and energy balance. The first column in Table 1 depicts the material balance in Gigatonnes (Gt).[5] According to this balance, the total inputs of matter into the socio-economic system over a year (extracted matter, the carbon mass of fossil energy and the oxygen included in CO_2 emissions) should be equal to the total outputs of matter over the same year (fossil CO_2 emissions and waste) plus the change in socio-economic stock. The second column in Table 1 depicts the energy balance in Exajoules (EJ). According to this balance, the total inputs of energy into the socio-economic system over a year should be equal to the total outputs of energy over the same year. Symbols with a plus sign denote inputs into the socio-economic system. Symbols with a minus sign denote outputs or changes in socio-economic stock. The Second Law of Thermodynamics is captured by the fact that the economic processes transform low-entropy energy (e.g. fossil fuels) into high-entropy dissipated energy (e.g. thermal energy).

Table 1: Physical flow matrix

	Material balance	Energy balance
Inputs		
Extracted matter	$+M_t$	
Non-fossil energy		$+E_{NFt}$
Fossil energy	$+CEN_t$	$+E_{Ft}$
Oxygen used for fossil fuel combustion	$+O2_t$	
Outputs		
Fossil CO_2 emissions	$-EMIS_{Ft}$	
Waste	$-W_t$	
Dissipated energy		$-ED_t$
Change in socio-economic stock	$-\Delta SES_t$	
Total	0	0

Note: The table refers to annual global stocks and flows. Matter is measured in Gt and energy is measured in EJ.

Table 2 displays the physical stock-flow matrix of our model.[6] This matrix presents the dynamic change in some key physical stocks. These are the material and fossil energy reserves, the cumulative CO_2 emissions, the socio-economic stock and the cumulative hazardous waste. The first row of the matrix shows the stocks of the previous year. The last row presents the stocks at the end of the current year after the additions to stocks and the reductions of stocks have taken place. Additions are denoted by a plus sign. Reductions are denoted by a minus sign.

The reserves of matter and fossil energy are those volumes expected to be produced economically using the existing technology. The reserves stem from the resources – the latter are the volumes presenting technical difficulties, are costly to extract or have not yet been discovered. When resources are converted into reserves, it means that people have a higher stock of matter and energy to rely on for economic processes. Note that although this conversion is important for human activities, it does not represent a physical transformation.

Tables 1 and 2 imply that in our model the laws of thermodynamics are important for three reasons. First, the First Law of Thermodynamics allows us to incorporate explicitly the harmful by-products of

[5] For the use of the material balance in material flow accounting, see Fischer-Kowalski et al. (2011).
[6] For a similar presentation of the physical stock-flow interactions see United Nations (2014).

Table 2: Physical stock-flow matrix

	Material reserves	Fossil energy reserves	Cumulative CO_2 emissions	Socio-economic stock	Cumulative hazardous waste
Opening stock	REV_{Mt-1}	REV_{Et-1}	$CO2_{CUMt-1}$	SES_{t-1}	HW_{CUMt-1}
Additions to stock					
Resources converted into reserves	$+CON_{Mt}$	$+CON_{Et}$			
CO_2 emissions			$+EMIS_t$		
Production of material goods				$+MY_t$	
Non-recycled hazardous waste					$+hazW_t$
Reductions of stock					
Extraction/use of matter or energy	$-M_t$	$-E_{Ft}$			
Demolished/disposed socio-economic stock				$-DEM_t$	
Closing stock	REV_{Mt}	REV_{Et}	$CO2_{CUMt}$	SES_t	HW_{CUMt}

Note: The table refers to annual global stocks and flows. Matter is measured in Gt and energy is measured in EJ.

energy and matter transformation (CO_2 emissions and hazardous material waste). As will be explained below, these by-products cause the degradation of the ecosystem with feedback effects on the economy. Second, the Second Law of Thermodynamics implies that in the very long run the economic processes cannot rely on the energy produced from fossil fuels. Since the fossil fuel resources are finite and the economic processes transform the low-entropy energy embodied in these resources into high-entropy energy, sustainability requires the reliance of economic processes on non-fossil energy sources (even if there was no climate change). Third, by combining the laws of thermodynamics with Georgescu-Roegen's analysis of material degradation, it turns out that recycling might not be sufficient to ensure the long-run availability of the material resources that are necessary for the economic processes. Hence, the depletion of matter needs to be checked separately.

We procced to describe the equations of the model that refer to the ecosystem.

2.1.1. Matter, recycling and waste

The goods produced every year, denoted by Y_t, embody a specific amount of matter, MY_t (Eq. (1)), which is necessary for their production.[7] Material intensity (μ_t) is defined as the matter included in each output produced. The socio-economic stock (SES_t) is the material content of the total capital goods (K_t) and durable consumption goods (DC_t) that remain in the socio-economic system. Thus, $SES_t = \mu_t(K_t + DC_t)$. As shown in Eq. (2), the matter embodied in goods comes from extraction (M_t denotes the extracted matter that is used every year in the production of goods) and the demolished/discarded socio-economic stock that is recycled (REC_t). The latter is defined in Eq. (3); ρ_t denotes the recycling rate, which is defined as the ratio of recycled matter to the total amount of demolished/discarded socio-economic stock (DEM_t). The demolished/discarded socio-economic stock is equal to the material content of the depreciated capital goods and the end-of-life durable consumption goods (Eq. (4)); δ_t is the depreciation rate of capital goods and ξ is the proportion of durable consumption goods discarded every year. Eq. (5) shows that socio-economic stock (SES_t) increases as a result of the production of new goods and decreases due to the demolition/discard of old material goods.

Eq. (6) reflects the material balance depicted in Table 1. The waste (W_t) generated during the production process is used as a residual. Regarding fossil energy, only its carbon mass, CEN_t, has been included as input in the material balance. As shown in Eq. (7), this mass is estimated from the fossil emissions ($EMIS_{Ft}$) by using the conversion rate of Gt of carbon into Gt of CO_2 (car). Carbon exits the socio-economic system in the form of CO_2 emissions. Oxygen ($O2_t$) is introduced as an input in the material balance because it is necessary in the fossil fuel combustion process. Eq. (8) gives the mass of the oxygen that is part of the CO_2 emissions. Note that by combining Eqs. (2), (5), (6) and (8) it can be easily shown that $W_t = DEM_t - REC_t$; in other words, waste is equal to the

[7] For simplicity, we have assumed away the material content of the goods related with government consumption spending ($C_{(GOV)t}$).

demolished/discarded socio-economic stock that is not recycled.

Only a small proportion (haz) of the waste produced every year is hazardous, i.e. it is harmful to human health or the environment.[8] This hazardous waste is added to cumulative hazardous waste, HW_{CUMt} (Eq. (9)). Eq. (10) defines the per capita cumulative hazardous waste ($hazratio_t$) which is equal to the cumulative hazardous waste in Gt divided by the population (POP_t).

$$MY_t = \mu_t \left(Y_t - C_{(GOV)t}\right) \tag{1}$$

$$M_t = MY_t - REC_t \tag{2}$$

$$REC_t = \rho_t DEM_t \tag{3}$$

$$DEM_t = \mu_t \left(\delta_t K_{t-1} + \xi DC_{t-1}\right) \tag{4}$$

$$SES_t = SES_{t-1} + MY_t - DEM_t \tag{5}$$

$$W_t = M_t + CEN_t + O2_t - EMIS_{Ft} - \Delta SES_t \tag{6}$$

$$CEN_t = \frac{EMIS_{Ft}}{car} \tag{7}$$

$$O2_t = EMIS_{INt} - CEN_t \tag{8}$$

$$HW_{CUMt} = HW_{CUMt-1} + hazW_t \tag{9}$$

$$hazratio_t = \frac{HW_{CUMt}}{POP_t} \tag{10}$$

The material stock-flow dynamics are presented in Eqs. (11)-(14). Eq. (11) shows that the material reserves (REV_{Mt}) decline when matter is extracted (in order to be used in the production of goods) and increase when resources are converted into reserves. The annual conversion (CON_{Mt}) is given by Eq. (12). An exogenous conversion rate, denoted by con_M, has been assumed. Eq. (13) describes the change in material resources (RES_{Mt}). To capture the scarcity of matter we define the matter depletion ratio (dep_{Mt}), which is the ratio of matter that is extracted every year relative to the remaining material reserves (Eq. (14)). The higher this ratio the greater the matter depletion problems.

$$REV_{Mt} = REV_{Mt-1} + CON_{Mt} - M_t \tag{11}$$

$$CON_{Mt} = con_M RES_{Mt-1} \tag{12}$$

$$RES_{Mt} = RES_{Mt-1} - CON_{Mt} \tag{13}$$

$$dep_{Mt} = \frac{M_t}{REV_{Mt-1}} \tag{14}$$

2.1.2. Energy

The energy required for production (E_t) is a function of output (Eq. (15)). When energy intensity (ε_t) declines, the energy required per unit of output becomes lower. As shown in Eqs. (16) and (17), energy is generated either from non-fossil sources (E_{NFt}) or fossil sources (E_{Ft}). The share of non-fossil energy in total energy is denoted by θ_t. The dissipated energy (ED_t) is determined based on the energy balance (Eq. (18)).

$$E_t = \varepsilon_t Y_t \tag{15}$$

$$E_{NFt} = \theta_t E_t \tag{16}$$

$$E_{Ft} = E_t - E_{NFt} \tag{17}$$

[8] Asbestos, heavy metals and fluoride compounds are examples of hazardous waste. For an analysis of hazardous waste and its impact on health and the environment, see Misra and Pandey (2005).

$$ED_t = E_{Ft} + E_{NFt} \tag{18}$$

Eqs. (19)-(22) represent the stock-flow dynamics of the energy produced from fossil fuels. Eq. (19) shows the change in fossil energy reserves (REV_{Et}). CON_{Et} denotes the amount of resources converted into reserves every year. This amount is determined by Eq. (20), where con_E is the conversion rate. The resources of fossil energy (RES_{Et}) change every year according to Eq. (21). The energy depletion ratio (dep_{Et}), which captures scarcity problems, shows the fossil energy that is extracted and is used every year, relative to the remaining reserves (Eq. (22)).

$$REV_{Et} = REV_{Et-1} + CON_{Et} - E_{Ft} \tag{19}$$

$$CON_{Et} = con_E RES_{Et-1} \tag{20}$$

$$RES_{Et} = RES_{Et-1} - CON_{Et} \tag{21}$$

$$dep_{Et} = \frac{E_{Ft}}{REV_{Et-1}} \tag{22}$$

2.1.3. Emissions and climate change

Every year fossil CO_2 emissions ($EMIS_{Ft}$) are produced due to the generation of energy from fossil fuels. However, a proportion, seq_t, of these emissions are sequestrated via the use of Carbon Capture and Storage (CCS) technologies and do not enter the atmosphere (Eq. (23)). CO_2 intensity (ω_t) is defined as the emissions produced per unit of fossil energy. Every year land-use CO_2 emissions ($EMIS_{Lt}$) are also generated because of changes in the use of land. These emissions are assumed to decline exogenously at a rate g_{EMISLt} (Eq. (24) and Eq. (25)). Eq. (26) gives the total CO_2 emissions ($EMIS_t$) and Eq. (27) gives the cumulative emissions ($CO2_{CUMt}$).

The link between emissions and climate change is formulated according to Matthews et al. (2021). The surface temperature compared to the 1850-1900 reference period ($TEMP_t$) becomes higher as cumulative carbon emissions increase (Eq. (28)). The Transient Climate Response to cumulative carbon Emissions (TCRE) captures the effect of cumulative carbon emissions on temperature. The parameter f_{nc} is the non-CO_2 fraction of total anthropogenic forcing which captures the impact of non–CO_2 greenhouse gas emissions on temperature.

$$EMIS_{Ft} = \omega_t \left(1 - seq_t\right) E_{Ft} \tag{23}$$

$$g_{EMISLt} = g_{EMISLt-1} \left(1 - \zeta_9\right) \tag{24}$$

$$EMIS_{Lt} = EMIS_{Lt-1} \left(1 - g_{EMISLt}\right) \tag{25}$$

$$EMIS_t = EMIS_{Ft} + EMIS_{Lt} \tag{26}$$

$$CO2_{CUMt} = CO2_{CUMt-1} + EMIS_t \tag{27}$$

$$TEMP_t = \frac{1}{1 - f_{nc}} TCRE \times CO2_{CUMt} \tag{28}$$

2.1.4. Ecological efficiency and technology

The ecological efficiency of production is considered to be higher the lower is the energy, material and CO_2 intensity and the higher is the recycling rate. Ecological efficiency also increases when the share of non-fossil energy in total energy goes up. CO_2 intensity changes in an exogenous way. As shown in Eqs. (29) and (30), CO_2 intensity is reduced with a declining rate ($g_{\omega t} < 0$ and $\zeta_1 > 0$).[9] This reduction is, for example, related to the replacement of coal with other fossil fuels that generate less carbon emissions.

[9] See Nordhaus and Sztorc (2013) for a similar assumption.

As mentioned above, green energy capital is conducive to a lower energy intensity and to a higher use of renewables. Hence, we postulate that the efficiency related to these indicators increases when the ratio of green energy capital (K_{GEt}) to conventional energy capital (K_{CEt}) rises. Green non-energy capital contributes to a lower material intensity and to a higher recycling rate. Therefore, we hypothesise that the efficiency linked to these indicators increases when the ratio of green non-energy capital (K_{GNEt}) to the conventional non-energy capital (K_{CNEt}) rises. The sequestration rate increases when there is a rise in the ratio of private sequestration capital ($K_{SEQ)t}$) to the private conventional energy capital of the relevant sectors, which are sectors S1 ('mining and utilities') and S2 ('manufacturing and construction') (i.e. $K_{CE(PRI)1t} + K_{CE(PRI)2t}$).

The ecological efficiency indicators are shown in Eqs. (31)-(35). μ_t, ρ_t, ε_t, θ_t and seq_t denote, respectively, the material intensity, recycling rate, energy intensity, the share of non-fossil energy in total energy and sequestration rate. $\varepsilon^{\min}$ and $\mu^{\min}$ are the minimum potential values of energy intensity and material intensity respectively. These minimum values are approached when green (energy or non-energy) capital becomes sufficiently high compared to the conventional (energy or non-energy) capital. $\rho^{\max}$ is the maximum potential value of recycling rate which is approached when K_{GNEt}/K_{CNEt} becomes sufficiently high. $\varepsilon^{\max}$, $\mu^{\max}$ are, respectively, the maximum potential values of energy intensity and material intensity which are approached when green (energy or non-energy) capital is equal to zero.

The use of logistic functions in Eqs. (31)-(35) allows us to take into account learning processes which play a key role in the diffusion and efficiency of new technologies.[10] It also allows us to derive patterns about the future trajectories of energy intensity and renewable energy that are similar with those of other studies that examine the use of energy in the next decades (see, for instance, Jones and Warner, 2016; Peters et al., 2017).

$$\omega_t = \omega_{t-1}\left(1 + g_{\omega t}\right) \tag{29}$$

$$g_{\omega t} = g_{\omega t-1}\left(1 - \zeta_1\right) \tag{30}$$

$$\mu_t = \mu^{\max} - \frac{\mu^{\max} - \mu^{\min}}{1 + \pi_1 e^{-\pi_2\left(K_{GNE_{t-1}}/K_{CNEt-1}\right)}} \tag{31}$$

$$\rho_t = \frac{\rho^{\max}}{1 + \pi_3 e^{-\pi_4\left(K_{GNEt-1}/K_{CNEt-1}\right)}} \tag{32}$$

$$\varepsilon_t = \varepsilon^{\max} - \frac{\varepsilon^{\max} - \varepsilon^{\min}}{1 + \pi_5 e^{-\pi_6\left(K_{GEt-1}/K_{CEt-1}\right)}} \tag{33}$$

$$\theta_t = \frac{1}{1 + \pi_7 e^{-\pi_8\left(K_{GEt-1}/K_{CEt-1}\right)}} \tag{34}$$

$$seq_t = \frac{1}{1 + \pi_9 e^{-\pi_{10}\left(K_{SEQt-1}/\left(K_{CE(PRI)1t-1} + K_{CE(PRI)2t-1}\right)\right)}} \tag{35}$$

2.2. Macroeconomy and financial system

Table 3 and Table 4 portray the transactions flow matrix and the balance sheet matrix of our macroeconomy. The transactions flow matrix shows the transactions that take place between the various sectors of the economy (each row represents a category of transactions). For each sector inflows are denoted by a plus sign and outflows are denoted by a minus sign. The upper part of the matrix shows transactions related to the revenues and expenditures of the various sectors. The bottom part of the matrix indicates changes in financial assets and liabilities that arise from transactions. The columns represent the budget constraints of the sectors. A distinction is made between current and capital

[10] For the importance of these processes in energy systems and renewable energy technologies, see e.g. Kahouli-Brahmi (2009) and Tang and Popp (2016).

accounts: the current accounts register payments made or received while the capital accounts show how the investment in real and financial assets is funded. At the aggregate level, monetary inflows are equal to monetary outflows.

Table 3: Transactions flow matrix

	Households		Firms		Banks		Government sector		Central banks		Total
	Current	Capital	Current	Capital	Current	Capital	Current	Capital	Current	Capital	
Private consumption expenditures		$-C_{(PRI)t}$	$+C_{(PRI)t}$								0
Government consumption expenditures			$+C_{(GOV)t}$				$-C_{(GOV)t}$				0
Conventional investment			$+\Sigma I_{C(PRI)it}+I_{C(GOV)t}$	$-\Sigma I_{C(PRI)it}$				$-I_{C(GOV)t}$			0
Green investment			$+\Sigma I_{G(PRI)it}+I_{G(GOV)t}$	$-\Sigma I_{G(PRI)it}$				$-I_{G(GOV)t}$			0
Green subsidies			$+SUB_t$				$-SUB_t$				0
Household disposable income net of depreciation	$-Y_{HDt}$	$+Y_{HDt}$									0
Wages	$+w_tN_t$		$-w_tN_t$								0
Government net saving							$-GNS_t$	$+GNS_t$			0
Taxes	$-T_{Ht}$		$-T_{Ft}-T_{Ct}$				$+T_t$				0
Firms' profits	$+DP_t$		$-TP_t$	$+RP_t$							0
Banks' profits	$+BP_{Dt}$				$-BP_t$	$+BP_{Ut}$					0
Interest on deposits	$+int_DD_{t-1}$				$-int_DD_{t-1}$						0
Depreciation of green capital			$-\delta_t\Sigma K_{G(PRI)it-1}$	$+\delta_t\Sigma K_{G(PRI)it-1}$			$-\delta_tK_{G(GOV)t-1}$	$+\delta_tK_{G(GOV)t-1}$			0
Depreciation of conventional capital			$-\delta_t\Sigma K_{C(PRI)it-1}$	$+\delta_t\Sigma K_{C(PRI)it-1}$			$-\delta_tK_{C(GOV)t-1}$	$+\delta_tK_{C(GOV)t-1}$			0
Interest on conventional loans			$-\Sigma int_{Cit-1}L_{Cit-1}$		$+\Sigma int_{Cit-1}L_{Cit-1}$						0
Interest on green loans			$-\Sigma int_{Gt-1}L_{Git-1}$		$+\Sigma int_{Gt-1}L_{Git-1}$						0
Interest on conventional bonds	$+coupon_{Ct-1}b_{CHt-1}$		$-coupon_{Ct-1}b_{Ct-1}$						$+coupon_{Ct-1}b_{CCBt-1}$		0
Interest on green bonds	$+coupon_{Gt-1}b_{GHt-1}$		$-coupon_{Gt-1}b_{Gt-1}$						$+coupon_{Gt-1}b_{GCBt-1}$		0
Interest on government securities	$+int_SSEC_{Ht-1}$				$+int_SSEC_{Bt-1}$		$-int_SSEC_{t-1}$		$+int_SSEC_{CBt-1}$		0
Interest on advances					$-int_A\ A_{t-1}$				$+int_A\ A_{t-1}$		0
Depreciation of durable consumption goods	$-\xi DC_{t-1}$	$+\xi DC_{t-1}$									0
Central bank's profits							$+CBP_t$		$-CBP_t$		0
Bailout of banks						$+BAILOUT_t$		$-BAILOUT_t$			0
Δdeposits		$-\Delta D_t$				$+\Delta D_t$					0
Δconventional loans				$+\Sigma\Delta L_{Cit}$		$-\Sigma\Delta L_{Cit}$					0
Δgreen loans				$+\Sigma\Delta L_{Git}$		$-\Sigma\Delta L_{Git}$					0
Δconventional bonds		$-\bar{p}_C\Delta b_{CHt}$		$+\bar{p}_C\Delta b_{Ct}$						$-\bar{p}_C\Delta b_{CCBt}$	0
Δgreen bonds		$-\bar{p}_G\Delta b_{GHt}$		$+\bar{p}_G\Delta b_{Gt}$						$-\bar{p}_G\Delta b_{GCBt}$	0
Δgovernment securities		$-\Delta SEC_{Ht}$				$-\Delta SEC_{Bt}$		$+\Delta SEC_t$		$-\Delta SEC_{CBt}$	0
Δadvances						$+\Delta A_t$				$-\Delta A_t$	0
Δhigh-powered money						$-\Delta HPM_t$				$+\Delta HPM_t$	0
Defaulted loans				$+DL_t$		$-DL_t$					0
Total	0	0	0	0	0	0	0	0	0	0	0

Note: The table refers to annual global flows in US$ trillion.

Table 4 shows the assets and the liabilities of the sectors. We use a plus sign for the assets and a minus sign for the liabilities. Accounting requires that at the aggregate level financial assets are equal to financial liabilities. Hence, the net worth of the global economy is equal to the real assets which include the capital stock of firms and the government as well as the durable consumption goods of households.

Table 4: Balance sheet matrix

	Households	Firms	Banks	Government sector	Central banks	Total
Conventional capital		$+\Sigma K_{C(PRI)it}$		$+K_{C(GOV)t}$		$+K_{Ct}$
Green capital		$+\Sigma K_{G(PRI)it}$		$+K_{G(GOV)t}$		$+K_{Gt}$
Durable consumption goods	$+DC_t$					$+DC_t$
Deposits	$+D_t$		$-D_t$			0
Conventional loans		$-\Sigma L_{Cit}$	$+\Sigma L_{Cit}$			0
Green loans		$-\Sigma L_{Git}$	$+\Sigma L_{Git}$			0
Conventional bonds	$+\bar{p}_C b_{CHt}$	$-\bar{p}_C b_{Ct}$			$+\bar{p}_C b_{CCBt}$	0
Green bonds	$+\bar{p}_G b_{GHt}$	$-\bar{p}_G b_{Gt}$			$+\bar{p}_G b_{GCBt}$	0
Government securities	$+SEC_{Ht}$		$+SEC_{Bt}$	$-SEC_t$	$+SEC_{CBt}$	0
High-powered money			$+HPM_t$		$-HPM_t$	0
Advances			$-A_t$		$+A_t$	0
Total (net worth)	$+V_{Ht}$	$+V_{Ft}$	$+CAP_t$	$-SEC_t+K_{C(GOV)t}+K_{G(GOV)t}$	$+V_{CBt}$	$+K_{Ct}+K_{Gt}+DC_t$

Note: The table refers to annual global flows in trillion US$.

In the next subsections we present the equations for the macroeconomy and the financial system.

2.2.1. Output determination and climate damages

We assume a Leontief-type production function that incorporates Georgescu-Roegen's distinction between stock-flow and fund-service resources. The stock-flow resources are matter and fossil energy. The fund-service resources are labour and capital.[11] We define four different types of potential output. The matter-determined potential output (Y^*_{Mt}) is defined in Eq. (36) and is higher the higher are the material reserves, the higher is the recycled matter and the lower is the material intensity. The energy-determined potential output (Y^*_{Et}) is defined in Eq. (37) and is higher the higher are the fossil energy reserves, the lower is the energy intensity and the higher is the share of non-fossil energy in total energy. The capital-determined potential output (Y^*_{Kt}) is defined in Eq. (38) and is higher the higher is the private capital stock ($K_{(PRI)t}$) and the productivity of capital (v_t). Lastly, the labour-determined potential output (Y^*_{Nt}) is defined in Eq. (39) and is higher the higher is the labour force (LF_t), the hourly labour productivity (λ_t) and the annual working hours per employee (h_t). The overall potential output (Y^*_t) is the minimum of all these potential outputs (Eq. (40)).[12]

In line with the post-Keynesian tradition, actual output (Y_t) is demand-determined (Eq. (41)): it is equal to the sum of private consumption ($C_{(PRI)t}$), private investment ($I_{(PRI)t}$), government investment ($I_{(GOV)t}$) and government consumption ($C_{(GOV)t}$). However, demand is not independent of supply. When actual output approaches potential output, demand tends to decline as a result of supply-side constraints. This is captured by our investment and consumption functions described below. We define four ratios which capture the extent to which potential output is utilised (Eqs. (42)-(45)). The first two ratios are the matter utilisation rate (um_t) and the energy utilisation rate (ue_t), which refer to the use of stock-flow resources.[13] When these ratios increase, the output produced approaches the potential output determined by the material and fossil energy reserves. The last two ratios are the utilisation rate (u_t) and the rate of employment (re_t), which refer to the use of fund-service resources. A rise in these ratios reflects a higher scarcity of capital and labour.

[11] We assume away Ricardian land.

[12] To avoid simultaneity problems, in our simulations the labour-determined potential output is replaced with an 'expected' labour-determined potential output that is determined based on the lagged labour-determined potential output

[13] Recall that we have assumed away the material content of the goods related with government consumption.

$$Y^*_{Mt} = \frac{REV_{Mt-1} + REC_t}{\mu_t} \tag{36}$$

$$Y^*_{Et} = \frac{REV_{Et-1}}{(1-\theta_t)\,\varepsilon_t} \tag{37}$$

$$Y^*_{Kt} = v_t K_{(PRI)t} \tag{38}$$

$$Y^*_{Nt} = \lambda_t h_t LF_t \tag{39}$$

$$Y^*_t = \min\left(Y^*_{Mt}, Y^*_{Et}, Y^*_{Kt}, Y^*_{Nt}\right) \tag{40}$$

$$Y_t = C_{(PRI)t} + I_{(PRI)t} + I_{(GOV)t} + C_{(GOV)t} \tag{41}$$

$$um_t = \frac{Y_t - C_{(GOV)t}}{Y^*_{Mt}} \tag{42}$$

$$ue_t = \frac{Y_t}{Y^*_{Et}} \tag{43}$$

$$u_t = \frac{Y_t}{Y^*_{Kt}} \tag{44}$$

$$re_t = \frac{Y_t}{Y^*_{Nt}} \tag{45}$$

Climate change causes damages to the fund-service resources (capital and labour), reducing thereby the potential output determined by them. There are two types of damages: the damages that affect directly the funds (capital stock and labour force) and the damages that affect the productivities of the funds (capital productivity and labour productivity). Capital stock is affected because climate change can destroy infrastructure by causing storms or inundations, or because it can trigger the abandonment of capital in coastal areas by causing a rise in the sea level (see Dietz and Stern, 2015; Naqvi, 2015; Taylor et al., 2016). The proportion of the population that participates in the labour force might decline as a result of global warming. The reason is that climate change has an adverse impact on the health of the population (see e.g. Watts et al., 2017) and poor health reduces labour force participation. Capital productivity can be driven down since climate change might create a hostile environment that can reduce the ability of firms to use capital effectively (Stern, 2013; Dietz and Stern, 2015). Finally, by affecting the health of the workers, the conditions in workplaces and the accumulation of knowledge, climate change might decrease the ability of people to perform work tasks, reducing labour productivity (Kjellstrom et al., 2009; Dell et al., 2014; Dietz and Stern, 2015; Taylor et al., 2016).

Aggregate demand is affected by these damages in two ways. First, the catastrophes caused by climate change might increase the fears of entrepreneurs that their capital will be destroyed or that it will have very low returns. This reduces their desired private investment.[14] Moreover, experiencing or observing the natural disasters and the health problems, households might be induced to save more for precautionary reasons.[15] This can lead to less consumption. Measures that restrict consumption directly might also be adopted as climate damages become more significant. Second, since global warming damages tend to reduce Y^*_{Kt} and Y^*_{Nt}, they place upward pressures on u_t and re_t. As mentioned above, this rise in the scarcity of capital and labour can reduce private consumption and investment demand.

Importantly, societies do not react passively to the climate change-related effects on fund-service resources. They take adaptation measures that limit climate damages. Drawing on De Bruin et al.

[14] Taylor et al. (2016) have postulated a negative impact of climate change on investment demand by assuming that greenhouse gas concentration reduces the profit share.

[15] For some empirical evidence about the impact of natural disasters on the saving behaviour of households, see Skidmore (2001).

(2009), we thereby make a distinction between gross damages and net damages. Gross damages are the initial damages caused by climate change if there were no adaptation measures and net damages are the damages that remain after the implementation of adaptation measures.[16]

Eq. (46) is the damage function, which shows how atmospheric temperature and damages are linked. D_{Tt} is the proportional gross damage which lies between 0 (no damage) and 1 (complete catastrophe). The form of Eq. (46) has been suggested by Weitzman (2012), who argues that the quadratic forms of damage functions used in the traditional literature of integrated assessment models do not adequately capture high-temperature damages. This issue is tackled by inserting the term $\eta_3 TEMP_t^{6.754}$ where η_3 and the corresponding exponent have been selected such that $D_{Tt} = 0.5$ when $TEMP_t = 4^o$C, in line with Dietz and Stern (2015).

In most integrated assessments models D_{Tt} affects directly the supply-determined output. On the contrary, as mentioned above, in our model D_{Tt} affects the potential output and the aggregate demand. Hence, the variable D_{Tt} enters into both (i) the determination of funds and their productivities (see Eqs.(92), (93), (96) and (138)) and (ii) the investment and consumption demand (see Eqs. (54) and (124)). It is also necessary to partition the gross damage between the fund (D_{TFt}) and its productivity (D_{TPt}), so as to warrant that when $D_{Tt} = x\%$ the capital-determined potential output and the labour-determined potential output would be reduced by $x\%$ if there were no adaptation measures. This is done by Eqs. (47) and (48).[17]

The impact of adaptation is captured by the parameters ad_P, ad_K and ad_{LF} that represent the proportion of the gross damage (of productivity, capital stock and labour force respectively) which is eliminated due to adaptation measures. We have that $0 \leq ad_P, ad_K, ad_{LF} \leq 1$. This means that, for example, the proportional net damage to productivity is given by $(1 - ad_P)D_{TPt}$. We assume that adaptation does not affect private investment and consumption demand: firms and households make decisions based on gross damages.

$$D_{Tt} = 1 - \frac{1}{1 + \eta_1 TEMP_t + \eta_2 TEMP_t^2 + \eta_3 TEMP_t^{6.754}} \tag{46}$$

$$D_{TPt} = pD_{Tt} \tag{47}$$

$$D_{TFt} = 1 - \frac{1 - D_{Tt}}{1 - D_{TPt}} \tag{48}$$

2.2.2. Firms

Although we use a consolidated version of the firm sector, we make a distinction between key stocks and flows that have to do with specific sectors of the economy. As mentioned above, these sectors are 'mining and utilities' (*S1*), 'manufacturing and construction' (*S2*), 'transport' (*S3*) and 'other sectors' (*S4*). Each sector takes a different decision about the mix of conventional and green investment and has thereby a different demand for conventional and green loans. Crucially, under green financial regulation, the conditions under which each sector has access to bank credit are different as well.

The total gross profits of firms (TP_{Gt}) are given by Eq. (49); w_t is the wage rate, N_t is the number of employed workers, int_{Cit} is the interest rate on conventional loans for sector i (where $i = S1, S2, S3, S4$), int_{Gt} is the interest rate on green loans (which is the same for all sectors of the economy), $coupon_{Ct}$ denotes the coupon payments on conventional bonds, $coupon_{Gt}$ denotes the coupon payments on green bonds, L_{Cit} is the amount of conventional loans for sector i, L_{Git} is the amount of green loans for sector i, b_{Ct} is the number of conventional bonds, b_{Gt} is the number of green bonds, $K_{(PRI)t}$ is the private capital stock and δ_t is the depreciation of capital stock (which is assumed to be the same for green capital and conventional capital). The net profits of firms (TP_t) are equal to gross profits plus the value of green subsidies provided by the government (SUB_t) minus

[16] We do not include the financial cost of the adaptation measures in net damages.
[17] See also Moyer et al. (2014).

the taxes on firms' profits (T_{Ft}) and the taxes on carbon emissions (T_{Ct}) (Eq. (50)). Firms' retained profits (RP_t) are a proportion (s_F) of their total profits (Eq. (51)). The distributed profits of firms (DP_t) are determined as a residual (Eq. (52)). Eq. (53) gives the total profit rate (r_t).

$$TP_{Gt} = Y_t - w_t N_t - \sum int_{Cit-1} L_{Cit-1} - \sum int_{Gt-1} L_{Git-1} \\ - \delta_t K_{(PRI)t-1} - coupon_{Ct-1} b_{Ct-1} - coupon_{Gt-1} b_{Gt-1} \tag{49}$$

$$TP_t = TP_{Gt} - T_{Ft} - T_{Ct} + SUB_t \tag{50}$$

$$RP_t = s_F TP_{t-1} \tag{51}$$

$$DP_t = TP_t - RP_t \tag{52}$$

$$r_t = TP_t / K_{(PRI)t} \tag{53}$$

Total desired net investment is affected by a number of factors (Eq. (54)). First, following the Kaleckian approach (see e.g. Blecker, 2002), it depends positively on the rate of profit (r_t) and the rate of capacity utilisation (u_t). The impact of these factors is assumed to be non-linear in general line with the tradition that draws on Kaldor (1940). This means that when the profit rate and capacity utilisation are very low or very high, their effects on investment become rather small.

Second, following Skott and Zipperer (2012), we assume a non-linear impact of the unemployment rate (ur_t) on investment: when unemployment approaches zero, there is a scarcity of labour that discourages entrepreneurs to invest. This employment effect captures Marx's and Kalecki's insights, according to which high employment strengthens the power of workers, having an adverse impact on the business climate. Theoretically, this negative effect of employment could be put into question in the presence of immigration and labour-augmenting investment. In the presence of immigration, entrepreneurs can expect that the flow of immigrants will relax the labour shortage constraint. Thus, investment might not decline when employment approaches the full employment level. However, this does not apply in our model, since we analyse the global economy and, thus, there is no immigration effect. Regarding labour-augmenting investment, it could be argued that when entrepreneurs observe an unemployment rate close to zero, they could relax the labour shortage constraint by increasing investment that enhances labour productivity. However, the adverse impact of climate change on labour productivity, that takes place in our model, makes it more difficult for the entrepreneurs to expect that more investment in labour-augmenting technologies would relax the labour shortage constraint. Therefore, in the presence of climate change, it is less likely that firms will try to invest more in order to increase productivity and reduce the employment rate.[18]

Third, the scarcity of energy and material resources can dampen investment, for example because of a rise in resource prices; ue_t and um_t capture the utilisation of energy and material resources respectively. This impact, however, is highly non-linear: energy and material scarcity affects investment only once the depletion of the resources has become very severe.

Overall, our investment function implies that demand declines (or stops increasing) when it approaches potential output. This allows us to take explicitly into account the environmental supply-side effects on aggregate demand mentioned above.

Note, that, according to Eq. (54), all capital that is depreciated is replaced when there are no climate damages. However, under the presence of climate damages, firms are assumed to be less willing to replace all the depreciated capital. Only a proportion of the depreciated capital is replaced – this proportion is lower the higher are the climate damages. An alternative approach would be to assume that firms replace all climate-damaged capital. This assumption has been used in some previous versions of DEFINE and implies that investment is kept at a relatively high level when climate damages become more severe (since higher damages lead to higher reconstruction investment).

[18] Note, though, that our model takes into account the general role of labour-augmenting technologies by using the Kaldor-Verdoorn law in the determination of labour productivity.

We take into account that within the firm sector there exist different types of investment linked with different sectors of the economy. The total desired investment is allocated to these sectors based on their relative gross value added (GVA). This is shown in Eq. (55), where the desired investment of each sector ($I^D_{(PRI)it}$) is a proportion, $sh_{(GVA)i}$, of total desired investment ($i = S1, S2, S3, S4$). In addition, in each sector a decision has to be made about the level of desired green investment ($I^D_{G(PRI)it}$). This investment is set as a proportion, β_{it}, of the total desired investment of each sector. This is shown in Eq. (56).[19]

Let us first explain how β_i in Eq. (56) is determined. The proportion of green investment depends on three factors (Eq. (57)). The first factor is captured by the term β_{0it} which reflects exogenous developments, such as environmental preferences or institutional changes linked with environmental regulation. It is assumed that β_{0it} increases every year but with a declining rate (Eqs. (58) and (59)).

The second factor reflects the cost of green capital compared to conventional capital. This cost differential has been proxied by the total unit cost of producing renewable energy ($tucr_t$) compared to the total unit cost of generating non-renewable energy ($tucn_t$).[20] We let $tucr_t$ be equal to $ucr_t\,(1 - gov_{SUBt})$, where ucr_t is the pre-subsidies levelised cost of producing renewable energy and gov_{SUBt} is the subsidy rate, namely the proportion of this cost that is funded by the government (Eq. (60)). $tucn_t$ consists of two components: (i) ucn_t which is the pre-taxes levelised cost of generating non-renewable energy and (ii) $\tau_{Ct}\omega_t\,(1 - seq_t)$ which is the carbon tax cost per unit of energy; τ_{Ct} is the carbon tax measured in US$/kg CO_2 (or US$ trillion/GtCO_2). We assume that ucn_t rises every year to reflect the fact that costs increase as fossil fuel reserves are depleted (Eqs. (62) and (63)).[21] On the other hand, we let ucr_t decline every year, assuming at the same time that the rate of decline is more rapid as the share of non-fossil energy goes up. This captures endogenous green technical progress (Eqs. (64) and (65)).

The importance of the relative cost of energy differs between the different sectors. We assume that this cost differential is more important for those sectors that produce a higher amount of carbon emissions. We do so by multiplying the share of each sector's carbon emissions, $sh_{(EMIS_{IN})i}$, by β_1 in Eq. (57).

The third factor, captured by the term $\beta_2\,[sh_{Lt-1}\,(int_{Gt-1} - int_{Cit-1}) + (1 - sh_{Lt-1})\,(yield_{Gt-1} - yield_{Ct-1})]$, reflects the borrowing cost of investing in green capital relative to conventional capital; $yield_{Ct}$ is the yield on conventional bonds, $yield_{Gt}$ is the yield on green bonds and sh_{Lt} is the share of loans in the total liabilities of firms (loans plus bonds). As the cost of borrowing for investing in green capital (via bank lending or bonds) declines compared to the cost of borrowing for investing in conventional capital, firms tend to increase green investment.[22]

Conventional desired private investment ($I^D_{C(PRI)it}$) is given by Eq. (66). It is equal to total investment minus green investment.

$$I^D_{(PRI)t} = \left(\frac{\alpha_{00}}{1 + e^{\left(\alpha_{01} - \alpha_1 u_{t-1} - \alpha_2 r_{t-1} + \alpha_{31} ur_{t-1}^{-\alpha_{32}} + \alpha_{41}(1 - ue_{t-1})^{-\alpha_{42}} + \alpha_{51}(1 - um_{t-1})^{-\alpha_{52}}\right)}} K_{(PRI)t-1} + \delta_t K_{(PRI)t-1} \right) (1 - D_{Tt-1}) \tag{54}$$

[19] Our formulation implicitly assumes that green investment crowds out conventional investment. This is in line with the recent empirical literature (see Weche, 2019). However, such crowding out is not assumed in the case of public green investment: government can conduct green investment on top of conventional investment.

[20] Because of the heterogeneity of both green and conventional capital, the cost differential between these two types of capital is in reality affected by a large number of factors, apart from the cost of energy. We have focused on the latter for two reasons. First, the energy cost arguably affects directly or indirectly the cost related with a large part of capital stock in the economy. In the case of energy capital, the cost of energy has a direct impact on the return on this capital; in the case of non-energy related capital (such as capital that affects material efficiency and recycling), the cost of energy is relevant because it affects indirectly the cost of raw materials. Second, the cost differential between renewables and non-renewables can be calibrated relatively easily and is likely to follow a similar trend in the next decades as the broader cost differential between green and conventional capital.

[21] See e.g. Van der Ploeg and Rezai (2019) for a similar assumption.

[22] We have implicitly not included the cost of borrowing in ucn_t and ucr_t.

$$I^{D}_{(PRI)it} = sh_{(GVA)i} I^{D}_{(PRI)t} \tag{55}$$

$$I^{D}_{G(PRI)it} = \beta_{it} I^{D}_{(PRI)it} \tag{56}$$

$$\begin{aligned}\beta_{it} = {} & \beta_{0it} - \beta_1 sh_{(EMIS_F)i} \left(tucr_{t-1} - tucn_{t-1}\right) \\ & - \beta_2 \left[sh_{Lt-1} \left(int_{Gt-1} - int_{Cit-1}\right) + \left(1 - sh_{Lt-1}\right)\left(yield_{Gt-1} - yield_{Ct-1}\right)\right]\end{aligned} \tag{57}$$

$$\beta_{0it} = \beta_{0it-1} \left(1 + g_{\beta 0t}\right) \tag{58}$$

$$g_{\beta 0t} = g_{\beta 0t-1} \left(1 - \zeta_2\right) \tag{59}$$

$$tucr_t = ucr_t \left(1 - gov_{SUBt}\right) \tag{60}$$

$$tucn_t = ucn_t + \tau_{Ct} \omega_t \left(1 - seq_t\right) \tag{61}$$

$$ucn_t = ucn_{t-1} \left(1 + g_{ucnt}\right) \tag{62}$$

$$g_{ucnt} = g_{ucrt-1} \left(1 - \zeta_8\right) \tag{63}$$

$$ucr_t = ucr_{t-1} \left(1 - g_{ucrt}\right) \frac{1 - \theta_t}{1 - \theta_{t-1}} \tag{64}$$

$$g_{ucrt} = g_{ucrt-1} \left(1 - \zeta_7\right) \tag{65}$$

$$I^{D}_{C(PRI)it} = I^{D}_{(PRI)it} - I^{D}_{G(PRI)it} \tag{66}$$

As mentioned above, retained profits are not in general sufficient to cover the desired investment expenditures. This means that firms need external finance, which is obtained via bonds and bank loans. It is assumed that firms first issue bonds and then demand new loans from banks in order to cover the rest amount of their desired expenditures. Only a proportion of the demanded new loans is provided. In other words, the model assumes that there is a quantity rationing of credit.[23]

Eq. (67) gives the desired new green loans for sector i (NL^{D}_{Git}) and Eq. (68) gives the desired new conventional loans (NL^{D}_{Cit}). The levels of green and conventional investment for each sector (after the imposition of credit rationing) are shown in Eqs. (69), (70) and (71);[24] $I_{G(PRI)it}$ is green private investment for sector i, $I_{C(PRI)it}$ is conventional investment for sector i, $\bar{p}_C$ is the par value of conventional bonds, $\bar{p}_G$ is the par value of green bonds, DL_t is the amount of defaulted loans and def_t is the rate of default. Eqs. (72), (73) and (74) show the green, conventional and total investment of the private sector. The ratio of green investment to total investment (κ_t) is given by Eq. (75). The total loans of firms (L_t) are equal to conventional loans plus green loans (Eq. (76)).

$$NL^{D}_{Git} = I^{D}_{G(PRI)it} - sh_{(GVA)i} \beta_{it} RP_t + repL_{Git-1} - \delta_t K_{G(PRI)it-1} - sh_{(GVA)i} \bar{p}_G \Delta b_{Gt} \tag{67}$$

$$NL^{D}_{Cit} = I^{D}_{C(PRI)it} - sh_{(GVA)i} \left(1 - \beta_{it}\right) RP_t + repL_{Cit-1} - \delta_t K_{C(PRI)it-1} - sh_{(GVA)i} \bar{p}_C \Delta b_{Ct} \tag{68}$$

$$I_{G(PRI)it} = sh_{(GVA)i} \beta_{it} RP_t + \Delta L_{Git} + \delta_t K_{G(PRI)it-1} + sh_{(GVA)i} \bar{p}_G \Delta b_{Gt} + def_t L_{Git-1} \tag{69}$$

$$I_{C(PRI)it} = sh_{(GVA)i} \left(1 - \beta_{it}\right) RP_t + \Delta L_{Cit} + \delta_t K_{C(PRI)it-1} + def_t L_{Cit-1} + sh_{(GVA)i} \bar{p}_C \Delta b_{Ct} \tag{70}$$

$$\begin{aligned}I_{C(PRI)S4t} = {} & RP_t + \Delta L_{Ct} + \Delta L_{Gt} + \delta_t K_{(PRI)t-1} - I_{G(PRI)t} - I_{C(PRI)S1t} \\ & - I_{C(PRI)S2t} - I_{C(PRI)S3t} + \bar{p}_G \Delta b_{Gt} + \bar{p}_C \Delta b_{Ct} + DL_t\end{aligned} \tag{71}$$

$$I_{G(PRI)t} = \sum I_{G(PRI)it} \tag{72}$$

$$I_{C(PRI)t} = \sum I_{C(PRI)it} \tag{73}$$

$$I_{(PRI)t} = I_{C(PRI)t} + I_{G(PRI)t} \tag{74}$$

$$\kappa_t = I_{G(PRI)t} / I_{(PRI)t} \tag{75}$$

[23] See also Dafermos (2012), Nikolaidi (2014) and Jakab and Kumhof (2019).

[24] Note that in Eq. (70) $i = S1, S2, S3$.

$$L_t = L_{Ct} + L_{Gt} \tag{76}$$

The change in green and conventional private capital stock of each sector is equal to gross investment minus the depreciation of capital (Eqs. (77) and (78)). Total green (conventional) private capital is the sum of green (conventional) capital of each sector (Eqs. (79) and (80)).

Eq. (81) shows that the total private capital is equal to conventional private capital ($K_{C(PRI)t}$) plus green private capital ($K_{G(PRI)t}$). The green energy capital of each sector ($K_{GE(PRI)it}$) is a proportion of total green capital (γ_{Ei}) in the sector (Eq. (82)); this proportion of energy capital stock in total capital stock is fixed and is calibrated using global data on energy investment. Eq. (83) gives the non-energy green capital for each sector ($K_{GNE(PRI)it}$). The proportion, γ_{Ei}, is the same for green and conventional capital. Eqs (84) and (85) give the energy ($K_{CE(PRI)it}$) and non-energy ($K_{CNE(PRI)it}$) conventional capital, respectively. The sequestration capital of each sector is a proportion of the green energy capital of the sector (Eq. (86)); only sectors *S1* and *S2* are assumed to undertake sequestration investment.

Eq. (87)-(91) give the total amount of green energy capital (K_{GEt}), green non-energy capital (K_{GNEt}), conventional energy capital (K_{CEt}), conventional non-energy capital (K_{CNEt}) and sequestration capital (K_{SEQt}). $K_{G(GOV)t}$ and $K_{C(GOV)t}$ denote the green and the conventional capital of the government.

$$K_{G(PRI)it} = K_{G(PRI)it-1} + I_{G(PRI)it} - \delta_t K_{G(PRI)it-1} \tag{77}$$

$$K_{C(PRI)it} = K_{C(PRI)it-1} + I_{C(PRI)it} - \delta_t K_{C(PRI)it-1} \tag{78}$$

$$K_{G(PRI)t} = \sum K_{G(PRI)it} \tag{79}$$

$$K_{C(PRI)t} = \sum K_{C(PRI)it} \tag{80}$$

$$K_{(PRI)t} = K_{C(PRI)t} + K_{G(PRI)t} \tag{81}$$

$$K_{GE(PRI)it} = \gamma_{Ei} K_{G(PRI)it} \tag{82}$$

$$K_{GNE(PRI)it} = (1 - \gamma_{Ei}) K_{G(PRI)it} \tag{83}$$

$$K_{CE(PRI)it} = \gamma_{Ei} K_{C(PRI)it} \tag{84}$$

$$K_{CNE(PRI)it} = (1 - \gamma_{Ei}) K_{C(PRI)it} \tag{85}$$

$$K_{SEQ(PRI)it} = \gamma_{SEQi} K_{GE(PRI)it} \tag{86}$$

$$K_{GEt} = \sum K_{GE(PRI)it} + \gamma_E K_{G(GOV)t} \tag{87}$$

$$K_{GNEt} = \sum K_{GNE(PRI)it} + (1 - \gamma_E) K_{G(GOV)t} \tag{88}$$

$$K_{CEt} = \sum K_{CE(PRI)it} + \gamma_E K_{C(GOV)t} \tag{89}$$

$$K_{CNEt} = \sum K_{CNE(PRI)it} + (1 - \gamma_E) K_{C(GOV)t} \tag{90}$$

$$K_{SEQt} = \sum K_{SEQ(PRI)i} \tag{91}$$

Eq. (92) shows the rate of capital depreciation. Interestingly, a higher depreciation due to climate change has two countervailing effects on economic growth. On the one hand, capital-determined potential output is reduced, placing adverse supply-side effects on economic activity (see Eq. (38)); in addition, desired investment might go down because depreciation affects the profitability of firms. On the other hand, aggregate demand tends to increase because a higher depreciation leads to higher gross investment (see Eq. (54)).

Eqs. (93) and (96) refer to capital and labour productivity respectively. As argued above, both productivities are influenced by climate change. Labour productivity is affected by exogenous technology factors reflected in the term $\sigma_{0t} + \sigma_1$ (see Eq. (94)). These factors increase productivity growth ($g_{\lambda t}$)

every year but with a declining rate. Also, in line with the Kaldor-Verdoorn law (see Lavoie, 2014 ch. 6), the growth rate of labour productivity is positively affected by the growth rate of output (g_{Yt}). Note that, although a lower labour productivity can reduce the unemployment rate for a given level of output, it has adverse effects on the supply side by driving down the labour-determined potential output (see Eq. (39)).

Eq. (97) gives the wage rate. The wage share (s_W) depends on the unemployment rate (see Eq. (98)): as the unemployment rate increases the bargaining power of workers declines leading to a reduction in the wage share (see Stirati and Paternesi Meloni, 2021 and the references therein). The number of employees is determined by Eq. (99). The unemployment rate is defined in Eq. (100).

In the baseline scenario the working hours are constant. However, in specific policy scenarios the working hours change endogenously in order to avoid an increase in the unemployment rate. The working hours are given by Eq. (101) with g_{ht} being the growth rate of working hours. Eq. (102) shows that the growth rate of working hours declines as the unemployment rate becomes higher than a specific target, ur^T. In the baselien scenario $\phi_h = 0$.

$$\delta_t = \delta_0 + (1 - \delta_0)(1 - ad_K) D_{TFt-1} \tag{92}$$

$$v_t = v_{t-1}[1 - (1 - ad_P) D_{TPt-1}] \tag{93}$$

$$g_{\lambda t} = \sigma_{0t} + \sigma_1 + \sigma_2 g_{Yt} \tag{94}$$

$$\sigma_{0t} = \sigma_{0t-1}(1 - \zeta_3) \tag{95}$$

$$\lambda_t = \lambda_{t-1}(1 + g_{\lambda t})[1 - (1 - ad_P) D_{TPt-1}] \tag{96}$$

$$w_t = s_{Wt} \lambda_t h_t \tag{97}$$

$$s_{Wt} = sw_0 - sw_1 ur_{t-1} \tag{98}$$

$$N_t = \frac{Y_t}{h_t \lambda_t} \tag{99}$$

$$ur_t = 1 - re_t \tag{100}$$

$$h_t = h_{t-1}(1 + g_{ht}) \tag{101}$$

$$g_{ht} = min[0, \phi(ur^T - ur_{t-1})] \tag{102}$$

For simplicity, the bonds issued by firms are assumed to be one-year coupon bonds.[25] Once they have been issued at their par value, their market price and yield is determined according to their demand. Firms set the coupon rate of bonds based on their yield in the previous year. This means that an increase in the market price of bonds compared to their par value causes a decrease in their yield, allowing firms to issue new bonds with a lower coupon rate.

Eqs. (103) and (104) show the proportion of firms' desired investment which is funded via conventional and green bonds respectively; x_{1t} is the proportion of firms' conventional desired investment financed via bonds, x_{2t} is the proportion of firms' green desired investment funded via bonds, $\bar{p}_C$ is the par value of conventional bonds and $\bar{p}_G$ is the par value of green bonds. Eqs. (105)-(106) show that the proportion of desired investment covered by green or conventional bonds is a negative function of the bond yield. In other words, firms fund a lower proportion of their investment via bonds when the cost of borrowing increases. Eqs. (107) and (108) show that the growth rate of the proportion of firms' green desired investment funded via bonds (g_{x20t}) increases with a declining rate ($g_{x20t} > 0$ and $\zeta_4 > 0$). This reflects the fact that the green bond market is expected to expand in the next years and firms are likely to use this market more in order to fund their green investment.

[25] This assumption, which does not change the essence of the analysis, allows us to abstract from complications that would arise from having firms that accumulate bonds with different maturities.

Eqs. (109) and (110) show the yield of conventional and green bonds, respectively. The yield of bonds is equal to the coupon payments of the bonds divided by their market price. When this yield increases, the coupon payment (for a given par value) goes up. This is captured by Eqs. (111) and (112). Note that the coupon rate is given by the coupon payment divided by the par value. Thus, when the yield increases, the coupon rate increases too. Eqs. (113) and (114) define the value of conventional bonds (B_{Ct}) and green bonds (B_{Gt}) respectively; B_{CHt} is the value of conventional bonds held by households, B_{CCBt} is the value of conventional bonds held by central banks, B_{GHt} is the value of green bonds held by households and B_{GCBt} is the value of green bonds held by central banks. We postulate a price-clearing mechanism in the bond market (see Eqs. (115) and (116)). p_{Ct} is the market price of conventional bonds and p_{Gt} is the market price of green bonds. Eq. (117) shows the value of total bonds (B_t) that is equal to the value of conventional plus the value of green bonds.

$$b_{Ct} = b_{Ct-1} + \frac{x_{1t} \sum I^D_{C(PRI)it}}{\bar{p}_C} \tag{103}$$

$$b_{Gt} = b_{Gt-1} + \frac{x_{2t} \sum I^D_{G(PRI)it}}{\bar{p}_G} \tag{104}$$

$$x_{1t} = x_{10} - x_{11} yield_{Ct-1} \tag{105}$$

$$x_{2t} = x_{20} - x_{21} yield_{Gt-1} \tag{106}$$

$$x_{20t} = x_{20t-1} \left(1 + g_{x20t}\right) \tag{107}$$

$$g_{x20t} = g_{x20t-1} \left(1 - \zeta_4\right) \tag{108}$$

$$yield_{Ct} = \frac{coupon_{Ct}}{p_{Ct}} \tag{109}$$

$$yield_{Gt} = \frac{coupon_{Gt}}{p_{Gt}} \tag{110}$$

$$coupon_{Ct} = yield_{Ct-1} \bar{p}_C \tag{111}$$

$$coupon_{Gt} = yield_{Gt-1} \bar{p}_G \tag{112}$$

$$B_{Ct} = B_{CHt} + B_{CCBt} \tag{113}$$

$$B_{Gt} = B_{GHt} + B_{GCBt} \tag{114}$$

$$p_{Ct} = \frac{B_{Ct}}{b_{Ct}} \tag{115}$$

$$p_{Gt} = \frac{B_{Gt}}{b_{Gt}} \tag{116}$$

$$B_t = B_{Ct} + B_{Gt} \tag{117}$$

Firms might default on their loans. When this happens, a part of their accumulated loans is not repaid, deteriorating the financial position of banks.[26] The amount of defaulted loans (DL_t) is a proportion (def_t) of total loans of firms (see Eq. (118)). The rate of default (def_t) is assumed to increase when firms become less liquid (see Eq. (119)); $def^{\max}$ is the maximum default rate.[27] This suggests that, as cash outflows increase compared to cash inflows, the ability of firms to repay their debt declines. The illiquidity of firms is captured by an illiquidity ratio, $illiq_t$, which expresses the cash outflows of firms relative to their cash inflows (see Eq. (120)). Cash outflows include wages, interest, taxes net of subsidies, loan repayments and maintenance capital expenditures (which are equal to depreciation). Cash inflows comprise the revenues from sales and the funds obtained from bank loans

[26] For simplicity, loan loss provisions and reserves have been assumed away.
[27] We use a logistic function, in similar lines with Caiani et al. (2016).

and the issuance of bonds.[28] CR_{Cit} is the degree of credit rationing on the conventional loans of each sector and CR_{Gt} is the degree of credit rationing on green loans. Eq. (121) defines the debt service ratio (dsr_t), which is the ratio of debt payment commitments (interest plus principal repayments) to profits before interest. Its key difference with the illiquidity ratio is that the latter takes into account the new flow of credit.

$$DL_t = def_t L_{t-1} \tag{118}$$

$$def_t = \frac{def^{\max}}{1 + def_0 e^{(def_1 - def_2 illiq_{t-1})}} \tag{119}$$

$$\begin{aligned} illiq_t = {} & \frac{\sum \left(int_{Cit-1} + rep\right) L_{Cit-1} + \sum \left(int_{Gt-1} + rep\right) L_{Git-1} + coupon_{Ct-1} b_{Ct-1}}{Y_t + \sum \left(1 - CR_{Cit}\right) NL^D_{Cit} + \sum \left(1 - CR_{Gt}\right) NL^D_{Git} + \bar{p}_C \Delta b_{Ct} + \bar{p}_G \Delta b_{Gt}} \\ & \frac{+ coupon_{Gt-1} b_{Gt-1} + w_t N_t + T_{Ft} + T_{Ct} - SUB_t + \delta_t K_{(PRI)t-1}}{Y_t + \sum \left(1 - CR_{Cit}\right) NL^D_{Cit} + \sum \left(1 - CR_{Gt}\right) NL^D_{Git} + \bar{p}_C \Delta b_{Ct} + \bar{p}_G \Delta b_{Gt}} \end{aligned} \tag{120}$$

$$dsr_t = \frac{\sum \left(int_{Cit-1} + rep\right) L_{Cit-1} + \sum \left(int_{Gt-1} + rep\right) L_{Git-1} + coupon_{Ct-1} b_{Ct-1} + coupon_{Gt-1} b_{Gt-1}}{TP_t + \sum int_{Cit-1} L_{Cit-1} + \sum int_{Gt-1} L_{Git-1} + coupon_{Ct-1} b_{Ct-1} + coupon_{Gt-1} b_{Gt-1}} \tag{121}$$

2.2.3. Households

Eq. (122) gives the gross disposable income of households (Y_{HGt}); BP_{Dt} denotes the distributed profits of banks, int_D is the interest rate on deposits, D_t is the amount of deposits, int_S is the interest rate on government securities, SEC_{Ht} is the amount of government securities held by households, b_{CHt} is the number of conventional corporate bonds held by households, b_{GHt} is the number of green bonds held by households. Eq. (123) defines the net disposable income of households (Y_{Ht}), which is equal to the gross disposable income minus the taxes on households' gross disposable income (T_{Ht}). Households' consumption ($C_{(PRI)Nt}$), adjusted for climate damages, depends on lagged income (which is a proxy for the expected one) and lagged financial wealth (Eq. (124)). However, Eq. (124) holds only when there are no supply-side constraints; in that case, $C_{(PRI)t} = C_{(PRI)Nt}$. If the overall demand in the economy is higher than the supply-determined output, Y_t^*, consumption adjusts such that the overall demand in the economy is below Y_t^*. This is shown in Eq. (125). Note that pr is slightly lower than 1.

$$Y_{HGt} = w_t N_t + DP_t + BP_{Dt} + int_D D_{t-1} + int_S SEC_{Ht-1} + coupon_{Ct-1} b_{CHt-1} + coupon_{Gt-1} b_{GHt-1} \tag{122}$$

$$Y_{Ht} = Y_{HGt} - T_{Ht} \tag{123}$$

$$C_{(PRI)Nt} = \left(c_1 Y_{Ht-1} + c_2 V_{HFt-1}\right)\left(1 - D_{Tt-1}\right) \tag{124}$$

$$\begin{aligned} C_{(PRI)t} = C_{(PRI)Nt} \text{ if } C_{(PRI)Nt} + I_{(PRI)t} + I_{(GOV)t} + C_{(GOV)t} < Y_t^*; \text{ otherwise} \\ C_{(PRI)t} = pr\left(Y_t^* - I_{(GOV)t} - I_{(PRI)t} - C_{(GOV)t}\right) \end{aligned} \tag{125}$$

Eq. (126) defines the financial wealth of households (V_{HFt}). Households invest their expected financial wealth in four different assets: government securities (SEC_{Ht}), conventional corporate bonds (B_{CHt}), green corporate bonds (B_{GHt}) and deposits (D_t). In the portfolio choice, captured by Eqs. (127)-(127n), Godley (1999)'s imperfect asset substitutability framework is adopted.[29]

Households' asset allocation is driven by three factors. The first factor is climate damages. We posit that damages affect households' confidence and increase the precautionary demand for more liquid

[28] Our formulation suggests that less access to external finance can increase the default rate. For some empirical evidence on the links between defaults and access to credit, see Farinha et al. (2019).

[29] The parameters in the portfolio choice equations satisfy the horizontal, vertical and symmetry constraints.

and less risky assets (see Batten et al., 2016).[30] Since damages destroy capital and the profitability opportunities of firms, we assume that as D_{Tt} increases, households reduce their holding of corporate conventional bonds and increase the proportion of their wealth held in deposits and government securities which are considered safer.[31] Second, asset allocation responds to alterations in the relative rates on return. The holding of each asset relies positively on its own rate of return and negatively on the other asset's rate of return. Third, a rise in the transactions demand for money (as a result of higher expected income) induces households to substitute deposits for other assets.[32]

Eqs. (131) and (132) show that the growth rate of households' portfolio choice parameter (λ_{30t}) related to the autonomous demand for green bonds ($g_{\lambda 30t}$) follows partially the growth rate of green bonds ($0 < \zeta_{10} < 1$). This captures the fact that the preference for green bonds is likely to increase as the bond market expands. Eq. (133) and (134) show the number of conventional and green bonds held by households.

Recall that all consumption goods in our economy are durable (i.e. they have a life higher than one year). Every year the stock of durable goods increases due to the production of new consumption goods and decreases due to the discard of the accumulated durable goods (Eq. (135)).

$$V_{HFt} = V_{HFt-1} + Y_{Ht} - C_{(PRI)t} + b_{CHt-1}\Delta p_{Ct} + b_{GHt-1}\Delta p_{Gt} \tag{126}$$

$$\frac{SEC_{Ht}}{V_{HFt-1}} = \lambda_{10} + \lambda'_{10}D_{Tt-1} + \lambda_{11}int_S + \lambda_{12}yield_{Ct-1} + \lambda_{13}yield_{Gt-1} + \lambda_{14}int_D + \lambda_{15}\frac{Y_{Ht-1}}{V_{HFt-1}} \tag{127}$$

$$\frac{B_{CHt}}{V_{HFt-1}} = \lambda_{20} + \lambda'_{20}D_{Tt-1} + \lambda_{21}int_S + \lambda_{22}yield_{Ct-1} + \lambda_{23}yield_{Gt-1} + \lambda_{24}int_D + \lambda_{25}\frac{Y_{Ht-1}}{V_{HFt-1}} \tag{128}$$

$$\frac{B_{GHt}}{V_{HFt-1}} = \lambda_{30t} + \lambda'_{30}D_{Tt-1} + \lambda_{31}int_S + \lambda_{32}yield_{Ct-1} + \lambda_{33}yield_{Gt-1} + \lambda_{34}int_D + \lambda_{35}\frac{Y_{Ht-1}}{V_{HFt-1}} \tag{129}$$

$$\frac{D_t}{V_{HFt-1}} = \lambda_{40} + \lambda'_{40}D_{Tt-1} + \lambda_{41}int_S + \lambda_{42}yield_{Ct-1} + \lambda_{43}yield_{Gt-1} + \lambda_{44}int_D + \lambda_{45}\frac{Y_{Ht-1}}{V_{HFt-1}} \tag{127n}$$

$$D_t = D_{t-1} + Y_{Ht} - C_{(PRI)t} - \Delta SEC_{Ht} - \bar{p}_C\Delta b_{CHt} - \bar{p}_G\Delta b_{GHt} \tag{130}$$

$$\lambda_{30t} = \lambda_{30t-1}\left(1 + g_{\lambda 30t}\right) \tag{131}$$

$$g_{\lambda 30t} = \zeta_{10}g_{bGt-1} \tag{132}$$

$$b_{CHt} = \frac{B_{CHt}}{p_{Ct}} \tag{133}$$

$$b_{GHt} = \frac{B_{GHt}}{p_{Gt}} \tag{134}$$

$$DC_t = DC_{t-1} + C_{(PRI)t} - \xi DC_{t-1} \tag{135}$$

Eqs. (136) and (137) show that the growth rate of population (g_{POPt}) increases with a declining rate ($g_{POPt} > 0$ and $\zeta_5 > 0$). As mentioned above, climate change reduces the ratio labour force to population ratio (Eq. (138)). However, there are two additional factors that drive the change in labour force. First, there are some exogenous dynamics that influence the labour force to population ratio, which are captured by the term lf_{1t} (see Eq. (139)) ($\zeta_6 > 0$). Second, the accumulation of hazardous waste creates health problems (for instance, carcinogenesis and congenital anomalies) that affect the proportion of the population that is able to work.

[30] For some empirical evidence on the link between climate risks and firms' liquidity preference, see Huang et al. (2018).

[31] It could be argued that the demand for green corporate bonds is also affected negatively by the climate change damages that harm firms' financial position. However, climate change damages might at the same time induce households to hold more green bonds in order to contribute to the restriction of global warming. Hence, the overall impact of damages on the demand of green bonds is ambiguous. For this reason, we assume that λ'_{30} =0 in our simulations.

[32] Note that balance sheet restrictions require that Eq. (127n) must be replaced by (130) in the computer simulations.

$$g_{POPt} = g_{POPt-1}\left(1 - \zeta_5\right) \tag{136}$$

$$POP_t = POP_{t-1}\left(1 + g_{POPt}\right) \tag{137}$$

$$LF_t = \left(lf_{1t} - lf_2 hazratio_{t-1}\right)\left(1 - \left(1 - ad_{LF}\right) D_{TFt-1}\right) POP_t \tag{138}$$

$$lf_{1t} = lf_{1t-1}\left(1 - \zeta_6\right) \tag{139}$$

2.2.4. Banks

The profits of banks (BP_t) are equal to the interest on both conventional and green loans plus the interest on government bonds minus the sum of the interest on deposits and the interest on advances (Eq. (140)); SEC_{Bt} stands for the government securities that banks hold, int_A is the interest rate on advances and A_t is the advances. As shown in Eq. (141), the change in the capital of banks (CAP_t) is equal to their undistributed profits (BP_{Ut}) minus the amount of defaulted loans plus the amount of bailout of the government ($BAILOUT_t$). The undistributed profits of banks are a proportion (s_B) of total profits of banks (see Eq. (142)). The distributed profits of banks are determined as the residual (see Eq. (143)). According to Eqs. (144) and (145), high-powered money (HPM_t) and the government securities held by banks are a proportion of deposits. Advances are determined as a residual from the budget constraint of banks (see Eq. (146)).[33]

$$BP_t = \sum int_{Cit-1} L_{Cit-1} + \sum int_{Gt-1} L_{Git-1} + int_S SEC_{Bt-1} - int_D D_{t-1} - int_A A_{t-1} \tag{140}$$

$$CAP_t = CAP_{t-1} + BP_{Ut} - DL_t + BAILOUT_t \tag{141}$$

$$BP_{Ut} = s_B BP_{t-1} \tag{142}$$

$$BP_{Dt} = BP_t - BP_{Ut} \tag{143}$$

$$HPM_t = h_1 D_t \tag{144}$$

$$SEC_{Bt} = h_2 D_t \tag{145}$$

$$A_t = A_{t-1} + \Delta HPM_t + \Delta L_{Gt} + \Delta L_{Ct} + \Delta SEC_{Bt} + DL_t - \Delta D_t - BP_{Ut} - BAILOUT_t \tag{146}$$

As mentioned above, banks impose credit rationing on the loans demanded by firms: they supply only a proportion of demanded loans. The degree of credit rationing (CR_t) shows this proportion of demanded loans that are provided by banks (Eq. (147)). Hence, it lies between 0 and 1. The degree of credit rationing increases as the debt service ratio of firms goes up, since banks are less willing to lend when the financial position of borrowers deteriorates. The degree of credit rationing also depends negatively on the capital adequacy ratio. In particular, credit rationing declines as the capital adequacy ratio increases relative to a minimum acceptable value, $CAR^{\min}$, which is determined by regulatory authorities. The incorporation of the capital adequacy ratio is in line with the recent empirical literature that has documented a negative effect of capital requirements and a positive effect of capital ratios on bank lending (see Bridges et al., 2014; Aiyar et al., 2016; De-Ramon et al., 2016; Meeks, 2017; Gambacorta and Shin, 2018; Gropp et al., 2019; De Jonghe et al., 2020; Fraisse et al., 2020).

Eq. (147) refers to total credit rationing on firm loans; $CR^{\max}$ is the maximum degree of credit rationing. In our baseline scenario banks do not treat green and conventional loans differently, so total credit rationing coincides with the credit rationing on different types of loans. However, credit rationing on green and conventional loans can become different once green differentiated capital requirements are introduced. This is captured by Eqs. (148), (149), and (150); CR_{Gt} is the degree of credit rationing on green loans, CR_{Cit} is the degree of credit rationing on conventional loans for each sector, $sh_{(NLG)t}$ is the share of desired green loans in total desired loans and $sh_{(NLC)it}$ is the share of desired

[33] Note that if the amount of advances turns out to be negative, the role of residual is played by the government securities.

conventional loans in total desired loans. When $w_{Cit} = w_{LTt}$ and $w_{Gt} = w_{LTt}$, the credit rationing on green loans and conventional loans is the same with the total credit rationing. When $w_{Gt} < w_{LTt}$, the credit rationing on green loans becomes lower than the total credit rationing and when $w_{Cit} > w_{LTt}$, the credit rationing on conventional loans is more likely to be higher than the total credit rationing. The parameter l_1 captures the responsiveness of credit rationing to changes in relative risk weights.

The conventional loans and the green loans for each sector are defined in Eqs. (151) and (152). Eqs. (153) and (154) show the total conventional and green loans. Eq. (155) and (156) show the bank leverage ratio (lev_{Bt}) and the capital adequacy ratio of banks; w_H, w_S, w_{Gt} and w_{Cit} are the risk weights on high-powered money, government securities, green and conventional loans respectively. We assume that when the bank leverage ratio becomes higher than its maximum value and/or the capital adequacy ratio falls below its minimum value, the government steps in and bails out the banking sector in order to avoid a financial collapse. The bailout takes the form of a capital transfer. This means that it has a negative impact on the fiscal balance and the government acquires no financial assets as a result of its intervention (see Popoyan et al., 2017 for a similar assumption). The bailout funds are equal to the amount that is necessary for the banking sector to restore the capital needed in order to comply with the regulatory requirements.

$$CR_t = \frac{CR^{\max}}{1 + r_0 e^{(r_1 - r_2 dsr_{t-1} + r_3 (CAR_{t-1} - CAR^{\min}))}} \tag{147}$$

$$CR_{Gt} = \left[1 + l_1 \left(w_{Gt-1} - w_{LTt-1}\right)\right] CR_t \tag{148}$$

$$CR_{Cit} = \left[1 + l_1 \left(w_{Cit-1} - w_{LTt-1}\right)\right] CR_t \tag{149}$$

$$CR_{CS4t} = \frac{CR_t - sh_{(NLG)t-1} CR_{Gt} - sh_{(NLC)S1t-1} CR_{CS1t} - sh_{(NLC)S2t-1} CR_{CS2t} - sh_{(NLC)S3t-1} CR_{CS3t}}{sh_{(NLC)S4t-1}} \tag{150}$$

$$L_{Cit} = L_{Cit-1} + \left(1 - CR_{Cit}\right) NL^D_{Cit} - repL_{Cit-1} - def_t L_{Cit-1} \tag{151}$$

$$L_{Git} = L_{Git-1} + \left(1 - CR_{Gt}\right) NL^D_{Git} - repL_{Git-1} - def_t L_{Git-1} \tag{152}$$

$$L_{Ct} = \sum L_{Cit} \tag{153}$$

$$L_{Gt} = \sum L_{Git} \tag{154}$$

$$lev_{Bt} = \left(L_{Ct} + L_{Gt} + SEC_{Bt} + HPM_t\right) / CAP_t \tag{155}$$

$$CAR_t = CAP_t \Big/ \left[w_{Gt} L_{Gt} + \sum w_{Cit} L_{Cit} + w_S SEC_{Bt} + w_H HPM_t\right] \tag{156}$$

The weight of conventional loans is a function of the degree of dirtiness (dd_i) of each sector. We calibrate the degree of dirtiness of conventional investment by utilising global data for carbon emissions and GVA in different sectors of the economy. An investment is considered to be 'dirtier' when it is undertaken by a sector that has a higher carbon emissions-to-GVA ratio. We estimate carbon emissions-to-GVA ratios for different sectors using data from UNCTAD (for GVA) and IEA (for carbon emissions). The higher the carbon emissions-to-GVA ratio of a specific sector compared to the carbon emissions-to-GVA ratio of the total economy, the higher the degree of dirtiness. If a sector has a carbon emissions-to-GVA ratio equal to the carbon emissions-to-GVA ratio of the total economy, the degree of dirtiness of the loan provided to this sector is set equal to 1. The degree of dirtiness (dd_i) is thereby given by:

$$dd_i = \frac{\frac{carbon_i}{GVA_i}}{\frac{carbon}{GVA}}$$

where $carbon_i$ denotes the carbon emissions of sector i, $carbon$ stands for the carbon emissions of the total economy, GVA_i is the gross value added of a specific sector and GVA is the gross value added of the total economy.[34]

The weight on total loans is shown in Eq. (157); $sh_{(LG)t}$ is the share of green loans in total loans and $sh_{(LC)it}$ is the share of conventional loans in total loans of each sector i. The lending interest rate on green and conventional loans is set as a spread over the policy interest rate which is determined by central banks; spr_{Gt} is the lending spread on green loans and spr_{Cit} is the lending spread on conventional loans for each sector. The total lending spread (spr_t) depends on the capital adequacy ratio and firms; debt service ratio (see Eq. (160)). The negative impact of the capital adequacy ratio on the lending spread is in line with the empirical literature on the determinants of lending interest rates (see Slovik and Cournède, 2011; Akram, 2014). The inclusion of the debt service ratio in Eq. (160) reflects the fact that, as firms become more financially fragile, banks impose a higher spread to capture the higher risk of default (see e.g. Juselius and Drehmann, 2020 for related empirical evidence). As in the case of credit rationing, in our baseline scenario the lending spread is the same for all types of loans. However, the introduction of green differentiated capital requirements can affect that. This is shown in Eqs. (161), (162) and (163).

$$w_{LTt} = sh_{(LG)t-1}w_{Gt} + \sum sh_{(LC)it-1}w_{Cit} \tag{157}$$

$$int_{Gt} = spr_{Gt} + int_A \tag{158}$$

$$int_{Cit} = spr_{Cit} + int_A \tag{159}$$

$$spr_t = spr_0 - spr_1\left(CAR_{t-1} - CAR^{\min}\right) + spr_2 dsr_{t-1} \tag{160}$$

$$spr_{Gt} = \left[1 + spr_3\left(w_{Gt-1} - w_{LTt-1}\right)\right] spr_t \tag{161}$$

$$spr_{Cit} = \left[1 + spr_3\left(w_{Cit-1} - w_{LTt-1}\right)\right] spr_t \tag{162}$$

$$spr_{CS4t} = \frac{spr_t - sh_{(LG)t-1}spr_{Gt} - sh_{(LC)S1t-1}spr_{CS1t} - sh_{(LC)S2t-1}spr_{CS2t} - sh_{(LC)S3t-1}spr_{CS3t}}{sh_{(LC)S4t-1}} \tag{163}$$

2.2.5. Government sector

The revenues of the government sector include taxes on household income, taxes on firms' profits and taxes on carbon. They also include the profits that the government sector receives from central banks. Current government expenditures comprise government consumption, green subsidies and the interest paid on government debt. The government net saving (GNS_t) is equal to revenues minus current expenditures and capital depreciation (Eq. (164)); net saving does not include the investment expenditures of the government and capital transfers linked to bailouts.

The government sector issues securities (SEC_t) in order to finance its deficit. The government debt is therefore equal to the outstanding amount of securities. The change in securities equals investment spending ($I_{(GOV)t}$) (adjusted for depreciation) minus net saving plus the capital transfers linked to bailouts (Eq. (165)). Government investment includes both green investment ($I_{G(GOV)t}$) and conventional investment ($I_{C(GOV)t}$), which are determined as an exogenous proportion of output, gov_{IG} and gov_{IC}, respectively (see Eqs. (166) and (167)). Total government investment is the sum of green and conventional investment (see Eq. (168)). Eqs. (169) and (170) are the law of motion of green capital and conventional capital. The capital of the government sector is given by Eq. (171). Total capital stock is the sum of the private and government capital stock (see Eq. (172)). Eqs. (173) and (174) show the total green and conventional capital; $K_{G(GOV)t}$ is green government capital, $K_{C(GOV)t}$ is conventional government capital, $K_{(GOV)t}$ is total capital of the government, K_{Gt} is green total

[34] An extension of this analysis would be to estimate a 'degree of greenness' for the investment of different sectors. In the current version of DEFINE this has not been pursued since, based on the existing available data, it is not straightforward which variable should be used to capture how 'green' the investment of a sector is.

capital, K_{Ct} is conventional total capital, SUB_t are the green subsidies of the government and CBP_t are the central bank profits.

Government consumption expenditures are also set exogenously as a fraction, gov_C, of output (Eq. (175)). We assume carbon revenue 'recycling'. In particular, all carbon taxes are assumed to be distributed back to firms in the form of green subsidies that are used to finance the production of renewable energy (Eq. (176)). The subsidy rate (gov_{SUBt}) is equal to the total amount of subsidies over the total cost of generating non-fossil energy (see Eq. (177)). The taxes on households' disposable income are a proportion (τ_H) of the gross disposable income (Eq. (178)), the taxes on firms' profits are a proportion (τ_F) of total gross profits (see Eq. (179)) and the revenues from carbon taxes are given by the carbon tax (τ_C) times the fossil carbon emissions (Eq. (180)). The total taxes are equal to the sum of taxes on households, the taxes on firms and the revenues from carbon taxes (Eq. (181)).

$$GNS_t = T_t + CBP_t - C_{(GOV)t} - SUB_t - int_S SEC_{t-1} - \delta_t K_{(GOV)t-1} \tag{164}$$

$$SEC_t = SEC_{t-1} + I_{(GOV)t} - GNS_t - \delta_t K_{(GOV)t-1} + BAILOUT_t \tag{165}$$

$$I_{G(GOV)t} = gov_{IG} Y_{t-1} \tag{166}$$

$$I_{C(GOV)t} = gov_{IC} Y_{t-1} \tag{167}$$

$$I_{(GOV)t} = I_{G(GOV)t} + I_{C(GOV)t} \tag{168}$$

$$K_{G(GOV)t} = K_{G(GOV)t-1} + I_{G(GOV)t} - \delta_t K_{G(GOV)t-1} \tag{169}$$

$$K_{C(GOV)t} = K_{C(GOV)t-1} + I_{C(GOV)t} - \delta_t K_{C(GOV)t-1} \tag{170}$$

$$K_{(GOV)t} = K_{C(GOV)t} + K_{G(GOV)t} \tag{171}$$

$$K_t = K_{(PRI)t} + K_{(GOV)t} \tag{172}$$

$$K_{Gt} = K_{G(PRI)t} + K_{G(GOV)t} \tag{173}$$

$$K_{Ct} = K_{C(PRI)t} + K_{C(GOV)t} \tag{174}$$

$$C_{(GOV)t} = gov_C Y_{t-1} \tag{175}$$

$$SUB_t = T_{Ct} \tag{176}$$

$$gov_{SUBt} = \frac{SUB_t}{E_{NFt-1} ucr_{t-1}} \tag{177}$$

$$T_{Ht} = \tau_H Y_{HGt-1} \tag{178}$$

$$T_{Ft} = \tau_F TP_{Gt-1} \tag{179}$$

$$T_{Ct} = \tau_C EMIS_{Ft-1} \tag{180}$$

$$T_t = T_{Ht} + T_{Ft} + T_{Ct} \tag{181}$$

2.2.6. Central banks

Central banks determine the policy interest rate, provide liquidity to banks (via advances) and buy government securities (acting as residual purchasers). Moreover, in the context of quantitative easing (QE) programmes, they buy bonds issued by the firm sector.[35] Currently, central banks do not

[35] These bonds are bought on the primary market (the essence of our analysis does not change if we also consider purchases on the secondary market). The purchase of corporate bonds by central banks leads to a temporary increase in the deposits of firms, which is matched by an increase in the excess reserves of banks; the latter are used as intermediaries for the transactions between firms and the central bank. However, firms use all these deposits in order to fund their investment. This means that excess reserves do not appear on the end-of-period balance sheet of banks. Moreover, an implicit assumption that is made is that the temporary increase in the excess reserves of banks does not disrupt the ability of central banks to control the policy interest rate, for example because there is a floor system in place (for the role of such a system in central bank interest rate setting, see Lavoie, 2014, ch. 4).

explicitly distinguish between the holdings of conventional and green bonds. However, in order to analyse the implications of a green QE programme, we assume that central banks announce separately the amount of conventional bond and green bond holdings.

The profits of the central bank are defined in Eq. (182); b_{CCBt} is the number of conventional corporate bonds held by central banks, b_{GCBt} is the number of green bonds held by central banks and SEC_{CBt} are the government securities held by central banks.

The value of green corporate bonds held by central banks (B_{GCBt}) is a share (s_G) of total outstanding green bonds (see Eq. (183)). The value of conventional corporate bonds held by central banks (B_{CCBt}) is a share (s_C) of total outstanding conventional bonds (see Eq. (184)).

Eqs. (185) and (186) define the number of conventional corporate bonds held by central banks and the number of green bonds held by central banks respectively. Eq. (187) shows the government securities held by central banks. Eq. (188-red) reflects the capital account of banks and is the redundant equation of the system described in Table 3 and Table 4: it is logically implied by all the other equations of this system.

$$CBP_t = coupon_{Ct-1} b_{CCBt-1} + coupon_{Gt-1} b_{GCBt-1} + int_A A_{t-1} + int_S SEC_{CBt-1} \tag{182}$$

$$B_{GCBt} = s_G B_{Gt-1} \tag{183}$$

$$B_{CCBt} = s_C B_{Ct-1} \tag{184}$$

$$b_{CCBt} = \frac{B_{CCBt}}{p_{Ct}} \tag{185}$$

$$b_{GCBt} = \frac{B_{GCBt}}{p_{Gt}} \tag{186}$$

$$SEC_{CBt} = SEC_t - SEC_{Ht} - SEC_{Bt} \tag{187}$$

$$SEC_{CBt} = SEC_{CBt-1} + \Delta HPM_t - \Delta A_t - \bar{p}_C \Delta b_{CCBt} - \bar{p}_G \Delta b_{GGBt} \tag{188-red}$$

3. Baseline scenario

For the identification of our baseline scenario we draw on the combined Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) framework (see Riahi et al., 2017). In particular, we use as a reference the SSP2 and SSP3 mitigation scenarios that correspond to radiative forcing levels of 6.0 W/m^2 in 2100 (these levels give an atmospheric temperature slightly higher than 3^{o}C at the end of the century).[36] In both scenarios there is a transition to a low-carbon economy, but this transition is slow. In the SSP2, social, economic, and technological trends do not shift significantly from historical patterns and there is a moderate growth in global population. The SSP3 is characterised by a resurgent nationalism and regional conflicts that have a negative impact on global economic growth; population growth is low in high-income countries and high in low-income countries.

In our baseline scenario (see Table **??**), the population growth, the energy intensity improvement, and the increase in the share of non-fossil energy until 2050 are in line with the SSP3. Global economic growth is consistent with the SSP2: it gradually declines over the next decades causing an increase in the unemployment rate. At the end of the century the temperature is equal to 3.2^{o}C, as is the case both in the 6.0 W/m^2 SSP2 and SSP3. Annual green energy investment (both private and public) is on average equal to about 0.8% of GDP over the period 2018-2050.[37]

[36] The higher the levels of radiative forcing the higher the temperature.

[37] This is slightly lower than the figure for green energy investment in the Nationally Determined Contributions (NDC) scenario in McCollum et al. (2018). Our baseline scenario is a bit more pessimistic about the path of carbon emissions compared to the NDC scenario.

The carbon tax pathway for the period 2030-2100 is the same as in the SSP3 6.0 W/m^2 scenario.[38] The carbon tax revenues are recycled: they are provided to firms in the form of green subsidies, covering part of the cost of generating non-fossil energy.[39] Our model is calibrated such that the elasticity of the industrial carbon emissions intensity with respect to the carbon tax in the baseline scenario is close to the elasticity derived in the SSP3 6.0 W/m^2 scenario.[40]

Variable	**2021 value**	**2050 value**	**Mean (2021-2050)**	**St. deviation (2021-2050)**
Economic growth (%)	5.80	2.41	2.60	0.62
Unemployment rate (%)	6.20	6.61	6.45	0.16
Population (billion people)	7.70	9.96	8.86	0.69
Share of non-fossil energy in total energy (%)	15.00	23.02	18.63	2.72
Energy intensity as a ratio of 2021 energy intensity	1.00	0.71	0.86	0.10
Material intensity as a ratio of 2021 material intensity	1.00	0.90	0.96	0.04
Carbon emissions (GtCO_2/year)	39.30	47.89	44.17	2.03
Carbon tax (2021 US$/t$CO_2$)	2.37	38.67	23.09	11.27
Annual green energy investment (% of GDP)	0.58	0.92	0.80	0.10
Default rate on corporate loans (%)	2.60	2.86	2.77	0.10
Yield of conventional bonds (%)	5.00	5.58	5.26	0.24
Yield of green bonds (%)	5.00	4.84	4.72	0.15

The R code used for the simulations of the model is available at: https://github.com/DEFINE-model (DEFINE 1.1 August 2022 version).

[38] The data for the SSP2 and the SSP3 have been downloaded from the International Institute for Applied System Analysis (IIASA); for the period 2020-2100 the data are provided with a 10-year time step. In the SSP3 6.0 W/m^2 scenario the carbon tax value that is implicitly given for 2020 is too high compared to its actual value (the latter has been estimated by dividing carbon tax revenues by emissions at the global level). Thus, we have used the actual value of the carbon tax for 2021 and the SSP3 value for 2030 and have interpolated the values between 2021 and 2030.

[39] In the SSP3 scenario the carbon tax revenues are recycled as well, but this happens via lump-sum transfers to households (see Fujimori et al., 2017) not via green subsidies as is the case in our model.

[40] Over the period 2030-2100, this elasticity is 0.68% in the SSP3 6.0 W/m^2 scenario, while it is 0.72% in our model. The desired elasticity is primarily achieved by adjusting the value of β_1 in Eq. (57).

4. Symbols, data sources and values for variables and parameters

Table 5: Symbols and initial values for endogenous variables (baseline scenario)

Symbol	Description	Value	Remarks/sources
A	Advances (US$ trillion)	15.7	Calculated from the identity $CAP=L_C+L_G+HPM+SEC_B-A-D$ using the initial values of CAP, L_C, L_G, HPM, SEC_B and D
B	Value of total corporate bonds (US$ trillion)	14.4	Based on S&P Global Ratings (2022)
$BAILOUT$	Bailout funds provided to the banking system from the government sector	0	No bailout is assumed in 2021 since $lev_B<lev_B^{max}$ and $CAR>CAR^{min}$
B_C	Value of conventional corporate bonds (US$ trillion)	14.0	Calculated from Eq. (117) using the initial values of B and B_G
b_C	Number of conventional corporate bonds (trillions)	0.140	Calculated from Eq. (115) using the initial values of p_C and B_C
B_{CCB}	Value of conventional corporate bonds held by central banks (US$ trillion)	0.5	Calculated from the identity $B_{CCB}=B_{CB}-B_{GCB}$ where B_{CB} is the estimated amount of corporate sector holdings
b_{CCB}	Number of conventional corporate bonds held by central banks (trillions)	0.005	Calculated from Eq. (185) using the initial values of p_C and B_{CCB}
B_{CH}	Value of conventional corporate bonds held by households (US$ trillion)	13.5	Calculated from Eq. (113) using the initial values of B_{CCB} and B_C
b_{CH}	Number of conventional corporate bonds held by households (trillions)	0.1	Calculated from Eq. (133) using the initial values of p_C and B_{CH}
B_G	Value of green corporate bonds (US$ trillion)	0.45	Based on Climate Bonds Initiative (2017, 2022); we use the value of the green bonds that has been issued by the financial and the non-financial corporate sector
b_G	Number of green corporate bonds (trillions)	0.005	Calculated from Eq. (116) using the initial values of p_G and B_G
B_{GCB}	Value of green corporate bonds held by central banks (US$ trillion)	0.04	Calculated from the identity $B_{GCB}=prop_{GCB}*B_{CB}$ where $prop_{GCB}$ is the proportion of green bonds in the total corporate bolds held by central banks and B_{CB} is the estimated amount of central banks' corporate sector holdings
b_{GCB}	Number of green corporate bonds held by central banks (trillions)	0.0004	Calculated from Eq. (186) using the initial values of p_G and B_{GCB}
B_{GH}	Value of green corporate bonds held by households (US$ trillion)	0.41	Calculated from Eq. (114) using the initial values of B_G and B_{GCB}
b_{GH}	Number of green corporate bonds held by households (trillions)	0.0041	Calculated from Eq. (134) using the initial values of p_G and B_{GH}
BP	Profits of banks (US$ trillion)	3.13	Calculated from Eq. (140) using the initial values of int_{Ci}, int_G, L_{Ci}, L_{Gi}, SEC_B, D and A
BP_D	Distributed profits of banks (US$ trillion)	0.74	Calculated from Eq. (140) using the initial values of BP and BP_U
BP_U	Retained C230profits of banks (US$ trillion)	2.39	Calculated from Eq. (142) using the initial value of BP
$C_{(GOV)}$	Government expenditures (US$ trillion)	15.9	Calculated from Eq. (175) using the initial value of Y
$C_{(PRI)}$	Consumption (US$ trillion)	55.2	No supply-side constraints are assumed in 2021 since $C_{(PRI)N}+I_{(PRI)}+I_{(GOV)}+C_{(GOV)}<Y^*$; therefore $C_{(PRI)}=C_{(PRI)N}$
$C_{(PRI)N}$	Consumption when no supply-side constraints exist (US$ trillion)	55.2	Calculated from Eq. (41) using the initial values of Y, $C_{(GOV)}$, $I_{(PRI)}$ and $I_{(GOV)}$ (since $C_{(PRI)}=C_{(PRI)N}$)
CAP	Capital of banks (US$ trillion)	10.8	Calculated from Eq. (155) using the initial values of lev_B, L_C, L_G, SEC_B and HPM
CAR	Capital adequacy ratio	0.1	Calculated from Eq. (156) using the initial values of CAP, L_C, L_G, w_C, w_G, SEC_B and HPM
CBP	Central banks' profits (US$ trillion)	0.9	Calculated from Eq. (182) using the initial values of $coupon_C$, b_{CCB}, $coupon_G$, b_{GCB}, A and SEC_{CB}
CEN	Carbon mass of fossil energy sources (Gt)	9.9	Calculated from Eq. (7) using the initial value of $EMIS_{IN}$
$CO2_{CUM}$	Cumulative CO_2 emissions ($GtCO_2$)	2365	Calculated from the formula $CO2_{CUM}=T_{AT}/(t_2*\varphi)$ using the initial value of T_{AT}
CON_E	Amount of fossil energy resources converted into reserves (EJ)	1514.4	Calculated from Eq. (20) using the initial value of RES_E
CON_M	Amount of material resources converted into reserves (Gt)	174	Calculated from Eq. (12) using the initial value of RES_M
$coupon_C$	Fixed coupon paid per conventional corporate bond (US$)	5	Calculated from Eq. (111) using the initial values of p_C and $yield_C$
$coupon_G$	Fixed coupon paid per green corporate bond (US$)	5	Calculated from Eq. (112) using the initial values of p_G and $yield_G$
CR	Degree of total credit rationing on loans	0.2	Calculated from Eq. (147) using the initial values of dsr and CAR
CR_{CS1}	Degree of credit rationing on conventional loans of the 'mining and utilities' sector	0.2	Calculated from Eq. (149) using the initial values of w_{C1}, w_{LT} and CR
CR_{CS2}	Degree of credit rationing on conventional loans of the 'manufacturing and construction' sector	0.2	Calculated from Eq. (149) using the initial values of w_{C2}, w_{LT} and CR
CR_{CS3}	Degree of credit rationing on conventional loans of the 'transport' sector	0.2	Calculated from Eq. (149) using the initial values of w_{C3}, w_{LT} and CR
CR_{CS4}	Degree of credit rationing on conventional loans of the 'other sectors'	0.2	Calculated from Eq. (150) using the initial values of sh_{NLG}, sh_{NLCi}, CR, CR_G, CR_{CS1}, CR_{CS2} and CR_{CS3}
CR_G	Degree of credit rationing on green loans	0.2	Calculated from Eq. (148) using the initial values of w_G, w_{LT} and CR
D	Deposits (US$ trillion)	90.0	Based on Carrera (2021)
DC	Stock of durable consumption goods (US$ trillion)	1463	Calculated from Eq. (4) using the initial values of K, DEM, δ and μ
def	Firms' rate of default	0.026	Based on World Bank

(continued from the previous page)

Symbol	Description	Value	Remarks/sources
DEM	Demolished/discarded socio-economic stock (Gt)	19.6	Taken from Wiedenhofer et al. (2019); the figure refers to the end-of-life waste from stocks
dep_E	Energy depletion ratio	0.012	Calculated from Eq. (22) using the initial values of E_F and REV_E
dep_M	Matter depletion ratio	0.026	Based on Jowitt et al. (2020)
DL	Amount of defaulted loans (US$ trillion)	2.1	Calculated from Eq. (118) using the initial values of *L* and *def*
DP	Distributed profits of firms (US$ trillion)	17.7	Calculated from Eq. (52) using the initial values of *TP* and *RP*
dsr	Debt service ratio of firms	0.57	Calculated from Eq. (121) using the initial values of int_{CI}, int_G, L_{CI}, L_{GI}, $coupon_C$, b_C, $coupon_G$, b_G and *TP*
D_T	Total proportional damage caused by climate change	0.0044	Calculated from Eq. (46) using the initial value of T_{AT}
D_{TF}	Part of damage that affects directly the fund-service resources	0.0040	Calculated from Eq. (48) using the initial values of D_T and D_{TP}
D_{TP}	Part of damage that reduces the productivities of fund-service resources	0.0004	Calculated from Eq. (47) using the initial value of D_T
E	Energy used for the production of output (EJ)	598	Based on IEA (International Energy Agency); total primary energy supply is used
ED	Dissipated energy (EJ)	598	Calculated from Eq. (18) using the initial values of E_F and E_{NF}
EMIS	Total CO_2 emissions ($GtCO_2$)	39.3	Calculated from Eq. (26) using the initial values of $EMIS_{IN}$ and $EMIS_L$
$EMIS_F$	Fossil CO_2 emissions ($GtCO_2$)	36.4	Taken from CDIAC (Carbon Dioxide Information Analysis Center)
$EMIS_L$	Land-use CO_2 emissions ($GtCO_2$)	2.9	Taken from CDIAC (Carbon Dioxide Information Analysis Center)
E_F	Energy produced from fossil sources (EJ)	508.3	Calculated from Eq. (17) using the initial values of *E* and E_{NF}
E_{NF}	Energy produced from non-fossil sources (EJ)	89.7	Calculated from Eq. (16) using the initial values of θ and *E*
GNS	Government net saving (US$ trillion)	-0.3	Calculated from Eq. (164) using the initial values of $C_{(GOV)}$, *SUB*, *T*, *SEC*, *CBP*, δ and $K_{(GOV)}$
g_{EMISL}	Growth rate of land emissions	0.020	Based on SSP3, 6.0 W/m^2 (see Riahi et al., 2017)
g_h	Growth rate of working hours	0	In the baseline scenario the working hours are assumed to be constant
g_{POP}	Growth rate of population	0.011	Based on SSP3, 6.0 W/m^2 (see Riahi et al., 2017)
gov_{SUB}	Green subsidy rate	0.04	Calculated from Eq. (177) using the initial values of *SUB*, E_{NF} and *ucr*
g_{ucn}	Growth rate of pre-taxes levelised cost of generating non-renewable energy	0.005	Selected from a reasonable range of values
g_{ucr}	Growth rate of pre-subsidies levelised cost of generating renewable energy	0.010	Selected from a reasonable range of values
g_{x20}	Growth rate of the autonomous proportion of desired green investment funded via bonds	0.020	Calibrated such that the model generates the baseline scenario
g_Y	Growth rate of output	0.058	Based on World Bank
$g_{\beta 0}$	Growth rate of the autonomous share of green investment in total investment	0.0002	Calibrated such that the model generates the baseline scenario
g_λ	Growth rate of labour productivity	0.043	Calculated from Eq. (97) using the initial values of g_Y and σ_o
$g_{\lambda 30}$	Growth rate of the households' portfolio choice parameter related to the autonomous demand for green bonds	0.005	Calculated from Eq. (132) using the initial value of g_{bG}
g_ω	Growth rate of CO_2 intensity	-0.001	Calibrated such that the model generates the baseline scenario
h	Annual working hours per employee	1893	Based on Penn World Table 10.0 (see Feenstra et al., 2015)
hazratio	Hazardous waste accumulation ratio (tonnes per person)	2.08	Calculated from Eq. (10) using the initial values of HW_{CUM} and *POP*
HPM	High-powered money (US$ trillion)	18.90	Calculated from Eq. (144) using the initial value of *D*
HW_{CUM}	Cumulative hazardous waste (Gt)	16.0	Calculated assuming a constant ratio of hazardous waste to GDP since 1960
$I_{(GOV)}$	Investment of the government sector (US$ trillion)	6.25	Calculated from the identity $I_{(GOV)}=(1\text{-}prop)*(I/Y)*Y$ where *prop* is the proportion of private investment in total investment (based on data from IMF), *I*/*Y* is the proportion of total investment in GDP (taken from World Bank) and *Y* is the initial value of output
$I_{(PRI)}$	Investment of the private sector (US$ trillion)	18.74	Calculated from the identity $I_{(PRI)}=prop*(I/Y)*Y$ where *prop* is the proportion of private investment in total investment (based on data from IMF), *I*/*Y* is the proportion of total investment in GDP (taken from World Bank) and *Y* is the initial value of output
$I_{C(GOV)}$	Conventional investment of the government sector (US$ trillion)	6.06	Calculated from Eq. (168) using the initial values of $I_{(GOV)}$ and $I_{G(GOV)}$
$I_{C(PRI)}$	Conventional investment of the private sector (US$ trillion)	18.17	Calculated from Eq. (74) using the initial values of $I_{(PRI)}$ and $I_{G(PRI)}$
$I_{C(PRI)S1}$	Conventional investment of the 'mining and utilities' sector (US$ trillion)	0.76	Calculated from the identity $I_{C(PRI)S1}=I_{(PRI)S1}-I_{G(PRI)S1}$; we use the initial values of $I_{(PRI)S1}$ and $I_{G(PRI)S1}$
$I_{C(PRI)S2}$	Conventional investment of the 'manufacturing and construction' sector (US$ trillion)	4.13	Calculated from the identity $I_{C(PRI)S2}=I_{(PRI)S2}-I_{G(PRI)S2}$; we use the initial values of $I_{(PRI)S2}$ and $I_{G(PRI)S2}$
$I_{C(PRI)S3}$	Conventional investment of the 'transport' sector (US$ trillion)	1.58	Calculated from the identity $I_{C(PRI)S3}=I_{(PRI)S3}-I_{G(PRI)S3}$; we use the initial values of $I_{(PRI)S3}$ and $I_{G(PRI)S3}$
$I_{C(PRI)S4}$	Conventional investment of the 'other' sectors (US$ trillion)	11.70	Calculated from the identity $I_{C(PRI)S4}=I_{(PRI)S4}-I_{G(PRI)S4}$; we use the initial values of $I_{(PRI)S4}$ and $I_{G(PRI)S4}$

(continued from the previous page)

Symbol	Description	Value	Remarks/sources
$I_{G(GOV)}$	Green investment of the government sector (US$ trillion)	0.19	Calculated from the identity $I_{G(GOV)}$ =(1-*prop*)**green investment* ; *prop* is the proportion of private investment in total investment based on data from IMF; *green investment* refers to total green investment based on CPI (2021); we use a slightly higher value than the one reported in CPI (2021) since green investment in our model is not confined to investment in energy efficiency and renewables (it also includes investment in recycling and material efficiency)
$I_{G(PRI)}$	Green investment of the private sector (US$ trillion)	0.6	Calculated from the identity $I_{G(PRI)}$ =*prop* **green investment*; *prop* is the proportion of private investment in total investment based on data from IMF; *green investment* refers to total green investment based on CPI (2021); we use a slightly higher value than the one reported in CPI (2021) since green investment in our model is not confined to investment in energy efficiency and renewables (it also includes investment in recycling and material efficiency)
$I_{G(PRI)S1}$	Green investment of the 'mining and utilities' sector (US$ trillion)	0.3	Calculated from the identity $I_{G(PRI)S1}=sh_{(GREEN)S1}*I_{G(PRI)}$; we use the initial value of $I_{G(PRI)}$
$I_{G(PRI)S2}$	Green investment of the 'manufacturing and construction' sector (US$ trillion)	0.05	Calculated from the identity $I_{G(PRI)S2}=sh_{(GREEN)S2}*I_{G(PRI)}$; we use the initial value of $I_{G(PRI)}$
$I_{G(PRI)S3}$	Green investment of the 'transport' sector (US$ trillion)	0.15	Calculated from the identity $I_{G(PRI)S3}=sh_{(GREEN)S3}*I_{G(PRI)}$; we use the initial value of $I_{G(PRI)}$
$I_{G(PRI)S4}$	Green investment of the 'other sectors' (US$ trillion)	0.10	Calculated from the identity $I_{G(PRI)S4}=sh_{(GREEN)S4}*I_{G(PRI)}$; we use the initial value of $I_{G(PRI)}$
$I^D_{(PRI)}$	Desired total investment (US$ trillion)	22.1	Calibrated such that the model generates the baseline scenario
$I^D_{(PRI)S1}$	Desired total investment of the 'mining and utilities' sector (US$ trillion)	1.2	Calculated from Eq. (55) *using* the initial value of $I^D_{(PRI)}$
$I^D_{(PRI)S2}$	Desired total investment of the 'manufacturing and construction' sector (US$ trillion)	4.93	Calculated from Eq. (55) *using* the initial value of $I^D_{(PRI)}$
$I^D_{(PRI)S3}$	Desired total investment of the 'transport' sector (US$ trillion)	2.03	Calculated from Eq. (55) *using* the initial value of $I^D_{(PRI)}$
$I^D_{(PRI)S4}$	Desired total investment of the 'other sectors' (US$ trillion)	13.91	Calculated from Eq. (55) *using* the initial value of $I^D_{(PRI)}$
$I^D_{C(PRI)S1}$	Desired conventional investment of the 'mining and utilities' sector (US$ trillion)	0.90	Calculated from Eq. (66) using the initial values of $I^D_{(PRI)S1}$ *and* $I^D_{G(PRI)S1}$
$I^D_{C(PRI)S2}$	Desired conventional investment of the 'manufacturing and construction' sector (US$ trillion)	4.9	Calculated from Eq. (66) using the initial values of $I^D_{(PRI)S2}$ *and* $I^D_{G(PRI)S2}$
$I^D_{C(PRI)S3}$	Desired conventional investment of the 'transport' sector (US$ trillion)	1.86	Calculated from Eq. (66) using the initial values of $I^D_{(PRI)S3}$ *and* $I^D_{G(PRI)S3}$
$I^D_{C(PRI)S4}$	Desired conventional investment of the 'other sectors' (US$ trillion)	13.79	Calculated from Eq. (66) using the initial values of $I^D_{(PRI)S4}$ *and* $I^D_{G(PRI)S4}$
$I^D_{G(PRI)S1}$	Desired green investment of the 'mining and utilities' sector (US$ trillion)	0.32	Calculated such that it is reasonably higher than $I_{G(PRI)S1}$
$I^D_{G(PRI)S2}$	Desired green investment of the 'manufacturing and construction' sector (US$ trillion)	0.07	Calculated such that it is reasonably higher than $I_{G(PRI)S2}$
$I^D_{G(PRI)S3}$	Desired green investment of the 'transport' sector (US$ trillion)	0.18	Calculated such that it is reasonably higher than $I_{G(PRI)S3}$
$I^D_{G(PRI)S4}$	Desired green investment of the 'other sectors' (US$ trillion)	0.12	Calculated such that it is reasonably higher than $I_{G(PRI)S4}$
illiq	Firms' illiquidity ratio	0.77	Calculated from Eq. (120) using the initial values of int_{Ci}, int_G, L_{Ci}, L_{Gi}, $coupon_C$, b_C, $coupon_G$, b_G, w, N, T_F, T_C, SUB, δ, $K_{(PRI)}$, Y, CR_{Ci}, NL_{Ci}^D, CR_G and NL_{Gi}^D
int_{CS1}	Interest rate on the conventional loans of the 'mining and utilities'	0.09	Calculated from Eq. (159) using the initial value of spr_{CS1}
int_{CS2}	Interest rate on the conventional loans of the 'manufacturing and construction' sector	0.09	Calculated from Eq. (159) using the initial value of spr_{CS2}
int_{CS3}	Interest rate on the conventional loans of the 'transport' sector	0.09	Calculated from Eq. (159) using the initial value of spr_{CS3}
int_{CS4}	Interest rate on the conventional loans of the 'other sectors'	0.09	Calculated from Eq. (159) using the initial value of spr_{CS4}
int_G	Interest rate on green loans	0.09	Calculated from Eq. (158) using the initial value of spr_G
K	Total capital stock	333.9	Calculated from the identity $K=(K/Y)*Y$; we use the initial value of Y and the capital-to-output has been selected such that the model generates the baseline scenario
$K_{(GOV)}$	Capital stock of the government	83.5	Calculated from the identity $K_{(GOV)}$ =(1-*prop*) *K where *prop* is the proportion of private investment in total investment (based on data from IMF); we use the initial value of K
$K_{(PRI)}$	Capital stock of firms (US$ trillion)	250.4	Calculated from the identity $K_{(PRI)}$ =*prop* *K where *prop* is the proportion of private investment in total investment (based on data from IMF); we use the initial value of K
K_C	Conventional capital stock (US$ trillion)	323.8	Calculated from Eq. (174) using the initial values of $K_{C(PRI)}$ and $K_{C(GOV)}$
$K_{C(GOV)}$	Conventional capital stock of the government sector (US$ trillion)	81.0	Calculated from Eq. (171) using the initial values of $K_{(GOV)}$ and $K_{G(GOV)}$
$K_{C(PRI)}$	Conventional capital stock of firms (US$ trillion)	242.8	Calculated from Eq. (81) using the initial values of $K_{(PRI)}$ and $K_{G(PRI)}$
$K_{C(PRI)S1}$	Conventional capital stock of the 'mining and utilities' sector (US$ trillion)	13.3	Calculated from the identity $K_{C(PRI)S1}=sh_{(GVA)S1}*K_{C(PRI)}$; we use the initial value of $K_{C(PRI)}$

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Symbol	Description	Value	Remarks/sources
$K_{C(PRI)S2}$	Conventional capital stock of the 'manufacturing and construction' sector (US$ trillion)	54.2	Calculated from the identity $K_{C(PRI)S2}=sh_{(GVA)S2}*K_{C(PRI)}$; we use the initial value of $K_{C(PRI)}$
$K_{C(PRI)S3}$	Conventional capital stock of the 'transport' sector (US$ trillion)	22.3	Calculated from the identity $K_{C(PRI)S3}=sh_{(GVA)S3}*K_{C(PRI)}$; we use the initial value of $K_{C(PRI)}$
$K_{C(PRI)S4}$	Conventional capital stock of the 'other sectors' (US$ trillion)	152.9	Calculated from the identity $K_{C(PRI)S4}=sh_{(GVA)S4}*K_{C(PRI)}$; we use the initial value of $K_{C(PRI)}$
K_{CE}	Conventional energy capital stock (US$ trillion)	125.2	Calculated from Eq. (89) using the initial values of $K_{CE(PRI)}$ and $K_{C(GOV)}$
$K_{CE(PRI)S1}$	Conventional energy capital stock of the 'mining and utilities' sector (US$ trillion)	12.9	Calculated from Eq. (84) using the initial value of $K_{C(PRI)S1}$
$K_{CE(PRI)S2}$	Conventional energy capital stock of the 'manufacturing and construction' sector (US$ trillion)	21.0	Calculated from Eq. (84) using the initial value of $K_{C(PRI)S1}$
$K_{CE(PRI)S3}$	Conventional energy capital stock of the 'transport' sector (US$ trillion)	20.2	Calculated from Eq. (84) using the initial value of $K_{C(PRI)S1}$
$K_{CE(PRI)S4}$	Conventional energy capital stock of the 'other sectors' (US$ trillion)	11.4	Calculated from Eq. (84) using the initial value of $K_{C(PRI)S1}$
K_{CNE}	Conventional non-energy capital stock (US$ trillion)	198.6	Calculated from Eq. (90) using the initial values of $K_{CNE(PRI)i}$ and $K_{C(GOV)}$
$K_{CNE(PRI)S1}$	Conventional non-energy capital stock of the 'mining and utilities' sector (US$ trillion)	0.4	Calculated from Eq. (85) using the initial value of $K_{C(PRI)S1}$
$K_{CNE(PRI)S2}$	Conventional non-energy capital stock of the 'manufacturing and construction' sector (US$ trillion)	33.3	Calculated from Eq. (85) using the initial value of $K_{C(PRI)S1}$
$K_{CNE(PRI)S3}$	Conventional non-energy capital stock of the 'transport' sector (US$ trillion)	2.1	Calculated from Eq. (85) using the initial value of $K_{C(PRI)S1}$
$K_{CNE(PRI)S4}$	Conventional non-energy capital stock of the 'other sectors' (US$ trillion)	141.5	Calculated from Eq. (85) using the initial value of $K_{C(PRI)S1}$
K_{G}	Green capital stock (US$ trillion)	10.1	Calculated from Eq. (173) using the initial values of $K_{G(PRI)}$ and $K_{G(GOV)}$
$K_{G(GOV)}$	Green capital stock of the government sector (US$ trillion)	2.5	Calibrated such that the model generates the baseline scenario
$K_{G(PRI)}$	Green capital stock of firms (US$ trillion)	7.6	Calculated from the formula $K_{G(PRI)}=\varkappa*K_{(PRI)}$ using the initial values of $\varkappa$ and $K_{(PRI)}$
$K_{G(PRI)S1}$	Green capital stock of the 'mining and utilities' sector (US$ trillion)	3.5	Calculated from the identity $K_{G(PRI)S1}=sh_{(GREEN)S1}*K_{G(PRI)}$; we use the initial value of $K_{G(PRI)}$
$K_{G(PRI)S2}$	Green capital stock of the 'manufacturing and construction' sector (US$ trillion)	0.7	Calculated from the identity $K_{G(PRI)S2}=sh_{(GREEN)S2}*K_{G(PRI)}$; we use the initial value of $K_{G(PRI)}$
$K_{G(PRI)S3}$	Green capital stock of the 'transport' sector (US$ trillion)	2.0	Calculated from the identity $K_{G(PRI)S3}=sh_{(GREEN)S3}*K_{G(PRI)}$; we use the initial value of $K_{G(PRI)}$
$K_{G(PRI)S4}$	Green capital stock of the 'other sectors' (US$ trillion)	1.4	Calculated from the identity $K_{G(PRI)S4}=sh_{(GREEN)S4}*K_{G(PRI)}$; we use the initial value of $K_{G(PRI)}$
K_{GE}	Green energy capital stock (US$ trillion)	7.5	Calculated from Eq. (87) using the initial values of $K_{GE(PRI)i}$ and $K_{G(GOV)}$
$K_{GE(PRI)S1}$	Green energy capital stock of the 'mining and utilities' sector (US$ trillion)	3.4	Calculated from Eq. (82) using the initial value of $K_{G(PRI)S1}$
$K_{GE(PRI)S2}$	Green energy capital stock of the 'manufacturing and construction' sector (US$ trillion)	0.3	Calculated from Eq. (82) using the initial value of $K_{G(PRI)S1}$
$K_{GE(PRI)S3}$	Green energy capital stock of the 'transport' sector (US$ trillion)	1.8	Calculated from Eq. (82) using the initial value of $K_{G(PRI)S1}$
$K_{GE(PRI)S4}$	Green energy capital stock of the 'other sectors' (US$ trillion)	0.1	Calculated from Eq. (82) using the initial value of $K_{G(PRI)S1}$
K_{GNE}	Green non-energy capital stock (US$ trillion)	2.7	Calculated from Eq. (88) using the initial values of $K_{GNE(PRI)i}$ and $K_{G(GOV)}$
$K_{GNE(PRI)S1}$	Green non-energy capital stock of the 'mining and utilities' sector (US$ trillion)	0.1	Calculated from Eq. (83) using the initial value of $K_{G(PRI)S1}$
$K_{GNE(PRI)S2}$	Green non-energy capital stock of the 'manufacturing and construction' sector (US$ trillion)	0.4	Calculated from Eq. (83) using the initial value of $K_{G(PRI)S2}$
$K_{GNE(PRI)S3}$	Green non-energy capital stock of the 'transport' sector (US$ trillion)	0.2	Calculated from Eq. (83) using the initial value of $K_{G(PRI)S3}$
$K_{GNE(PRI)S4}$	Green non-energy capital stock of the 'other sectors' (US$ trillion)	1.3	Calculated from Eq. (83) using the initial value of $K_{G(PRI)S4}$
K_{SEQ}	Sequestration capital (US$ trillion)	0.0	Calculated from Eq. (91) using the initial values of $K_{SEQ(PRI)S1}$ and $K_{SEQ(PRI)S2}$
$K_{SEQ(PRI)S1}$	Sequestration capital of the 'mining and utilities' sector (US$ trillion)	0.018	Calculated from Eq. (86) using the initial value of $K_{G(PRI)S1}$
$K_{SEQ(PRI)S2}$	Sequestration capital of the 'manufacturing and construction' sector (US$ trillion)	0.005	Calculated from Eq. (86) using the initial value of $K_{G(PRI)S2}$
L	Total loans of firms (US$ trillion)	82.7	Calculated from the identity $L=(credit-B/Y)*Y$; *credit* is the credit to the non-financial corporations in percent of GDP taken from BIS (Bank for International Settlements); it is assumed that *credit* includes both loans and bonds
L_{C}	Conventional loans (US$ trillion)	80.1	Calculated from Eq. (76) using the initial values of L and L_{G}
L_{CS1}	Conventional loans of the 'mining and utilities' sector (US$ trillion)	4.4	Calculated from the identity $L_{CS1}=sh_{(GVA)S1}*L_{C}$; we use the initial value of L_{C}
L_{CS2}	Conventional loans of the 'manufacturing and construction' sector (US$ trillion)	17.9	Calculated from the identity $L_{CS2}=sh_{(GVA)S2}*L_{C}$; we use the initial value of L_{C}

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Symbol	Description	Value	Remarks/sources
L_{CS3}	Conventional loans of the 'transport' sector (US$ trillion)	7.4	Calculated from the identity $L_{CS3}=sh_{(GVA)S3}*L_C$; we use the initial value of L_C
L_{CS4}	Conventional loans of the 'other sectors' (US$ trillion)	50.5	Calculated from the identity $L_{CS4}=sh_{(GVA)S4}*L_C$; we use the initial value of L_C
L_G	Green loans (US$ trillion)	2.5	Calculated by assuming that $L_G/L=K_{G(PRI)}/K_{(PRI)}=x$; we use the initial values of x and L
L_{GS1}	Green loans of the 'mining and utilities' sector (US$ trillion)	0.1	Calculated from the identity $L_{GS1}=sh_{(GVA)S1}*L_G$; we use the initial value of L_G
L_{GS2}	Green loans of the 'manufacturing and construction' sector (US$ trillion)	0.6	Calculated from the identity $L_{GS2}=sh_{(GVA)S2}*L_G$; we use the initial value of L_G
L_{GS3}	Green loans of the 'transport' sector (US$ trillion)	0.2	Calculated from the identity $L_{GS3}=sh_{(GVA)S3}*L_G$; we use the initial value of L_G
L_{GS4}	Green loans of the 'other sectors' (US$ trillion)	1.6	Calculated from the identity $L_{GS4}=sh_{(GVA)S4}*L_G$; we use the initial value of L_G
lev_B	Banks' leverage ratio	10.8	Based on World Bank
LF	Labour force (billion people)	3.45	Taken from World Bank
lf_1	Autonomous labour force-to-population ratio	0.45	Calculated from Eq. (138) using the initial values of LF, POP, $hazratio$ and D_{TF}
M	Extraction of new matter from the ground, excluding the matter included in fossil energy sources (Gt)	47.1	Calculated from Eq. (2) using the initial values of M and REC
MY	Matter necessary for the production of output (Gt)	52.6	Taken from Wiedenhofer et al. (2019); the figure refers to primary plus secondary stock-building inputs
N	Number of employees (billion people)	3.2	Calculated from the definition of the rate of employment ($re=N/LF$) using the initial values of re and LF
$NL_{CS1}{}^D$	Desired new amount of conventional loans of the 'mining and utilities' sector (US$ trillion)	0.58	Calculated from Eq. (68) using the initial values of $I_{CS1}{}^D$, θ_{S1}, RP, L_{CS1}, δ, K_{CS1} and b_C
$NL_{CS2}{}^D$	Desired new amount of conventional loans of the 'manufacturing and construction' sector (US$ trillion)	3.45	Calculated from Eq. (68) using the initial values of $I_{CS2}{}^D$, θ_{S2}, RP, L_{CS2}, δ, K_{CS2} and b_C
$NL_{CS3}{}^D$	Desired new amount of conventional loans of the 'transport' sector (US$ trillion)	1.29	Calculated from Eq. (68) using the initial values of $I_{CS3}{}^D$, θ_{S3}, RP, L_{CS3}, δ, K_{CS3} and b_C
$NL_{CS4}{}^D$	Desired new amount of conventional loans of the 'other sectors' (US$ trillion)	9.77	Calculated from Eq. (68) using the initial values of $I_{CS4}{}^D$, θ_{S4}, RP, L_{CS4}, δ, K_{CS4} and b_C
$NL_{GS1}{}^D$	Desired new amount of green loans of the 'mining and utilities' sector (US$ trillion)	0.13	Calculated from Eq. (67) using the initial values of $I_{GS1}{}^D$, θ_{S1}, RP, L_{GS1}, δ, K_{GS1} and b_G
$NL_{GS2}{}^D$	Desired new amount of green loans of the 'manufacturing and construction' sector (US$ trillion)	0.08	Calculated from Eq. (67) using the initial values of $I_{GS2}{}^D$, θ_{S2}, RP, L_{GS2}, δ, K_{GS2} and b_G
$NL_{GS3}{}^D$	Desired new amount of green loans of the 'transport' sector (US$ trillion)	0.09	Calculated from Eq. (67) using the initial values of $I_{GS3}{}^D$, θ_{S3}, RP, L_{GS3}, δ, K_{GS3} and b_G
$NL_{GS4}{}^D$	Desired new amount of green loans of the 'other sectors' (US$ trillion)	0.19	Calculated from Eq. (67) using the initial values of $I_{GS4}{}^D$, θ_{S4}, RP, L_{GS4}, δ, K_{GS4} and b_G
$O2$	Oxygen used for the combustion of fossil fuels (Gt)	26.5	Calculated from Eq. (8) using the initial values of $EMIS_{IN}$ and CEN
p_C	Market price of conventional corporate bonds (US$)	100	The price has been normalised such that it is equal to US$100 (the par value of bonds) in 2021
p_G	Market price of green corporate bonds (US$)	100	The price has been normalised such that it is equal to US$100 (the par value of bonds) in 2021
POP	Population (billions)	7.70	Taken from the SSP3 6.0 W/m² scenario (see Riahi et al., 2017)
r	Rate of total profits	0.080	Calculated from Eq. (53) using the initial values of TP and $K_{(PRI)}$
re	Rate of employment	0.94	Calculated from Eq. (100) using the initial value of ur
REC	Recycled socio-economic stock (Gt)	5.5	Taken from Wiedenhofer et al. (2019); the figure refers to end-of-life waste from stocks minus final waste, after recycling
RES_E	Fossil energy resources (EJ)	504805	Taken from BGR (2020, p. 41)
RES_M	Material resources (Gt)	115677	Calculated by assuming $RES_M/REV_M=63.8$ (based on UNEP, 2011)
REV_E	Fossil energy reserves (EJ)	40769	Taken from BGR (2020, p. 41)
REV_M	Material reserves (Gt)	1813	Calculated from Eq. (14) using the initial values of M and dep_M
RP	Retained profits of firms (US$ trillion)	2.3	Calculated from Eq. (51) using the initial value of TP
SEC	Total outstanding amount of government securities (US$ trillion)	93.2	Calculated from the identity *general government debt-to-GDP* $=SEC/Y$ using the initial value of Y and the value of the *general government debt-to-GDP* ratio (taken from IMF)
SEC_B	Government securities held by banks (US$ trillion)	14.9	Calculated by assuming that $SEC_B/SEC=0.15$ based on Arslanalp and Tsuda (2014), updated in 2022
SEC_{CB}	Government securities held by central banks (US$ trillion)	2.7	Calculated from the identity $SEC_{CB}=HPM+V_{CB}-\bar{p}_C b_{CCB}-\bar{p}_G b_{GCB}-A$ using the initial values of V_{CB}, b_{CCB}, b_{GCB}, A and HPM
SEC_H	Government securities held by households (US$ trillion)	75.6	Calculated from Eq. (187) using the initial values of SEC, SEC_{CB} and SEC_B

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Symbol	Description	Value	Remarks/sources
seq	Proportion of carbon that is sequestrated	0.004	Based on GCCS (2021, p. 14)
SES	Socio-economic stock (Gt)	1178.1	Calculated from the identity $SES = \mu(K+DC)$ using the initial values of μ, K and DC
$sh_{(NLG)}$	Share of desired green loans in total desired loans	0.03	Calculated from the formula $sh_{(NLG)} = \Sigma NL_{GI}^{D} / (\Sigma NL_{GI}^{D} + \Sigma NL_{CI}^{D})$ using the initial values of NL_{GI}^{D} and NL_{CI}^{D}
$sh_{(NLC)S1}$	Share of desired conventional loans in total desired loans, 'mining and utilities' sector	0.05	Calculated from the formula $sh_{(NLC)S1} = NL_{CS1}^{D} / (\Sigma NL_{GI}^{D} + \Sigma NL_{CI}^{D})$ using the initial values of NL_{GI}^{D} and NL_{CI}^{D}
$sh_{(NLC)S2}$	Share of desired conventional loans in total desired loans, 'manufacturing and construction' sector	0.22	Calculated from the formula $sh_{(NLC)S2} = NL_{CS2}^{D} / (\Sigma NL_{GI}^{D} + \Sigma NL_{CI}^{D})$ using the initial values of NL_{GI}^{D} and NL_{CI}^{D}
$sh_{(NLC)S3}$	Share of desired conventional loans in total desired loans, 'transport' sector	0.09	Calculated from the formula $sh_{(NLC)S3} = NL_{CS3}^{D} / (\Sigma NL_{GI}^{D} + \Sigma NL_{CI}^{D})$ using the initial values of NL_{GI}^{D} and NL_{CI}^{D}
$sh_{(NLC)S4}$	Share of desired conventional loans in total desired loans, 'other sectors'	0.61	Calculated from the formula $sh_{(NLC)S4} = 1 - sh_{(NLG)} - sh_{(NLC)S1} - sh_{(NLC)S2} - sh_{(NLC)S3}$
$sh_{(L)}$	Share of loans in total firm liabilities	0.85	Calculated from the formula $sh_{(L)} = L/(L+B)$ using the initial values of L and B
$sh_{(LC)S1}$	Share of conventional loans in total loans, 'mining and utilities' sector	0.05	Calculated from the formula $sh_{(LC)S1} = L_{CS1}/L$ using the initial values of L and L_{CS1}
$sh_{(LC)S2}$	Share of conventional loans in total loans, 'manufacturing and construction' sector	0.22	Calculated from the formula $sh_{(LC)S2} = L_{CS2}/L$ using the initial values of L and L_{CS2}
$sh_{(LC)S3}$	Share of conventional loans in total loans, 'transport' sector	0.09	Calculated from the formula $sh_{(LC)S3} = L_{CS3}/L$ using the initial values of L and L_{CS3}
$sh_{(LC)S4}$	Share of conventional loans in total loans, 'other sectors'	0.61	Calculated from the formula $sh_{(LC)S4} = L_{CS4}/L$ using the initial values of L and L_{CS4}
$sh_{(LG)}$	Share of green loans in total loans	0.03	Calculated from the formula $sh_{(LG)} = L_{G}/L$ using the initial values of L and L_{G}
spr	Spread on total loans	0.03	Based on World Bank
spr_{G}	Spread on green loans	0.03	Calculated from Eq. (161) using the initial values of w_{G}, w_{LT} and spr
spr_{CS1}	Spread on conventional loans of the 'mining and utilities' sector	0.034	Calculated from Eq. (162) using the initial values of w_{CS1}, w_{LT} and spr
spr_{CS2}	Spread on conventional loans of the 'manufacturing and construction' sector	0.034	Calculated from Eq. (162) using the initial values of w_{CS2}, w_{LT} and spr
spr_{CS3}	Spread on conventional loans of the 'transport' sector	0.034	Calculated from Eq. (162) using the initial values of w_{CS3}, w_{LT} and spr
spr_{CS4}	Spread on conventional loans of the 'other sectors'	0.034	Calculated from Eq. (163) using the initial values of sh_{LG}, spr, spr_{G} and spr_{CS1}, spr_{CS2} and spr_{CS3}
s_{W}	Wage income share	0.55	Based on Penn World Table 10.0 (see Feenstra et al., 2015)
SUB	Green government subsidies	0.084	Calculated from Eq. (176) using the initial value of T_{C}
T	Total taxes (US$ trillion)	20.2	Calculated from Eq. (181) using the initial values of T_{H}, T_{F} and T_{C}
T_{C}	Revenues from carbon taxes (US$ trillion)	0.084	Taken from World Bank Group (2022)
$TEMP$	Surface temperature change from the pre-industrial period (°C)	1.21	Taken from European Environment Agency/NOAA
T_{F}	Taxes on firms' profits (US$ trillion)	3.4	Calculated from Eq. (179) using the initial value of TP_{G}
T_{H}	Taxes on households' disposable income	16.7	Calculated from Eq. (178) using the initial value of Y_{HG}
TP	Total profits of firms (US$ trillion)	20.0	Calculated from Eq. (50) using the initial values of TP_{G}, T_{F}, T_{C} and SUB
TP_{G}	Total gross profits of firms (US$ trillion)	23.4	Calculated from Eq. (49) using the initial values of Y, w, N, L_{CI}, L_{GI}, int_{CI}, int_{G}, δ, $K_{(PRI)}$, $coupon_{C}$, b_{C}, $coupon_{G}$ and b_{G}
$tucn$	Total unit cost of producing renewable energy	0.02	Calculated from Eq. (61) using the initial values of ucn, τ_{C}, ω and seq
$tucr$	Total unit cost of generating non-renewable energy	0.02	Calculated from Eq. (60) using the initial values of ucr and gov_{SUB}
u	Rate of capacity utilisation	0.73	Based on World Bank, Enterprise Surveys
ucn	Pre-taxes levelised cost of generating non-renewable energy (US$ trillion/EJ)	0.021	Based on IRENA (2021)
ucr	Pre-subsidies levelised cost of producing renewable energy (US$ trillion/EJ)	0.025	Based on IRENA (2021)
ue	Rate of energy utilisation	0.01	Calculated from Eq. (43) using the initial values of Y and Y_{E}^{*}
um	Rate of matter utilisation	0.03	Calculated from Eq. (42) using the initial values of Y, $C_{(GOV)}$ and Y_{M}^{*}
ur	Unemployment rate	0.06	Based on World Bank
v	Capital productivity	0.53	Calculated from Eqs. (38) and (44) using the initial values of Y, u and $K_{(PRI)}$
V_{CB}	Wealth of central banks (US$ trillion)	0	It is assumed that there are no accumulated capital gains for the central banks
V_{H}	Wealth of households (US$ trillion)	1642.0	Calculated from the identity $V_{H} = DC + D + \bar{p}_{C} b_{CH} + \bar{p}_{G} b_{GH} + SEC_{H}$ using the initial values of SEC_{H}, b_{CH}, b_{GH}, DC and D
V_{HF}	Financial wealth of households (US$ trillion)	179.5	Calculated from the identity $V_{HF} = D + p_{C} b_{CH} + p_{G} b_{GH} + SEC_{H}$ using the initial values of SEC_{H}, p_{C}, b_{CH}, p_{G}, b_{GH} and D
w	Annual wage rate (US$ trillion/billions of employees)	16.33	Calculated from Eq. (97) using the initial value of λ

(continued from the previous page)

Symbol	Description	Value	Remarks/sources
W	Waste (Gt)	14.09	Calculated from the identity $W = DEM - REC$ using the initial values of DEM and REC
w_{CS1}	Risk weight on conventional loans provided to the 'mining and utilities' sector	1	Based on BCBS (2006)
w_{CS2}	Risk weight on conventional loans provided to the 'manufacturing and construction' sector	1	Based on BCBS (2006)
w_{CS3}	Risk weight on conventional loans provided to the 'transport' sector	1	Based on BCBS (2006)
w_{CS4}	Risk weight on conventional loans provided to the 'other sectors'	1	Based on BCBS (2006)
w_G	Risk weight on green loans	1	Based on BCBS (2006)
w_{LT}	Risk weight on total loans	1	Calculated from Eq. (157) using the initial values of w_G, w_{CI}, $sh_{(LG)}$, $sh_{(LC)S1}$, $sh_{(LC)S2}$ and $sh_{(LC)S3}$
x_1	Proportion of desired conventional investment funded via bonds	0.02	Calibrated such that the model generates the baseline scenario
x_2	Proportion of desired green investment funded via bonds	0.02	Calibrated such that the model generates the baseline scenario
x_{20}	Autonomous proportion of desired green investment funded via bonds	0.03	Calculated from Eq. (106) using the initial values of $yield_G$ and x_2
Y	Output (US$ trillion)	96.1	Taken from World Bank (2021 prices)
Y^*	Potential output (US$ trillion)	102.5	Calculated from Eq. (40) using the initial values of Y_M^*, Y_E^*, Y_K^* and Y_N^*
Y_E^*	Energy-determined potential output (US$ trillion)	7707.9	Calculated from Eq. (37) using the initial values of REV_E, θ and ε
Y_H	Disposable income of households (US$ trillion)	60.1	Calculated from Eq. (123) using the initial values of Y_{HG} and T_H
Y_{HD}	Household disposable income net of depreciation (US$ trillion)	46.0	Calculated from the identity $Y_{HD} = Y_H - \xi DC$ using the initial values of Y_H and DC
Y_{HG}	Gross disposable income of households (US$ trillion)	76.8	Calculated from Eq. (122) using the initial values of w, N, DP, BP_D, D, SEC_H, $coupon_C$, b_{CH}, $coupon_G$ and b_{GH}
$yield_C$	Yield on conventional corporate bonds	0.05	Based on S&P Global
$yield_G$	Yield on green corporate bonds	0.05	Based on S&P Global
Y_K^*	Capital-determined potential output (US$ trillion)	131.6	Calculated from Eq. (38) using the initial values of v and $K_{(PRI)}$
Y_M^*	Matter-determined potential output (US$ trillion)	2772.5	Calculated from Eq. (36) using the initial values of REV_M, REC and μ
Y_N^*	Labour-determined potential output (US$ trillion)	102.5	Calculated from Eq. (39) using the initial values of λ and LF
β_{S1}	Share of desired green investment of the 'mining and utilities' sector in total investment	0.26	Calculated from Eq. (56) using the initial values of $I^D_{(PRI)S1}$ and $I^D_{G(PRI)S1}$
β_{S2}	Share of desired green investment of the 'manufacturing and construction' sector in total investment	0.01	Calculated from Eq. (56) using the initial values of $I^D_{(PRI)S2}$ and $I^D_{G(PRI)S2}$
β_{S3}	Share of desired green investment of the 'transport' sector in total investment	0.09	Calculated from Eq. (56) using the initial values of $I^D_{(PRI)S3}$ and $I^D_{G(PRI)S3}$
β_{S4}	Share of desired green investment of the 'other sectors' in total investment	0.01	Calculated from Eq. (56) using the initial values of $I^D_{(PRI)S4}$ and $I^D_{G(PRI)S4}$
β_{0S1}	Autonomous share of desired green investment of the 'mining and utilities' sector in total investment	0.29	Calculated from Eq. (57) using the initial values of β_{S1}, $tucn$, $tucr$, sh_L, int_G, int_{LCS1}, $yield_G$ and $yield_C$
β_{0S2}	Autonomous share of desired green investment of the 'manufacturing and construction' sector in total investment	0.02	Calculated from Eq. (57) using the initial values of β_{S2}, $tucn$, $tucr$, sh_L, int_G, int_{LCS2}, $yield_G$ and $yield_C$
β_{0S3}	Autonomous share of desired green investment of the 'transport' sector in total investment	0.10	Calculated from Eq. (57) using the initial values of β_{S3}, $tucn$, $tucr$, sh_L, int_G, int_{LCS3}, $yield_G$ and $yield_C$
β_{0S4}	Autonomous share of desired green investment of the 'other sectors' in total investment	0.01	Calculated from Eq. (57) using the initial values of β_{S4}, $tucn$, $tucr$, sh_L, int_G, int_{LCS4}, $yield_G$ and $yield_C$
δ	Depreciation rate of capital stock	0.05	Calculated from Eq. (92) using the initial value D_{TF}
ε	Energy intensity (EJ/US$ trillion)	6.22	Calculated from Eq. (15) using the initial values of E and Y
θ	Share of non-fossil energy in total energy	0.15	Taken from the SSP3 6.0 W/m² scenario (see Riahi et al., 2017)
$\varkappa$	Ratio of green capital to total capital	0.03	Calculated from Eq. (75) using the initial values of $I_{G(PRI)}$ and $I_{(PRI)}$
λ	Hourly labour productivity (US$ trillion/(billions of employees*annual hours worked per employee))	0.02	Calculated from Eq. (99) using the initial values of Y and N
λ_{30}	Households' portfolio choice parameter related to the autonomous demand for green bonds	0.01	Calculated from Eq. (129) using the initial values of B_{GH}, V_{HF}, D_T, $yield_C$, $yield_G$ and Y_H
μ	Material intensity (kg/$)	0.66	Calculated from Eq. (1) using the initial values of MY, $C_{(GOV)}$ and Y
ρ	Recycling rate	0.28	Calculated from Eq. (3) using the initial values of REC and DEM
σ_0	Autonomous growth rate of labour productivity	-0.02	Calibrated such that the model generates the baseline scenario
τ_C	Carbon tax	0.002	Calculated from Eq. (180) using the initial values of $EMIS_{IN}$ and T_C
ω	CO_2 intensity of fossil energy ($GtCO_2$/EJ)	0.07	Calculated from Eq. (23) using the initial values of $EMIS_{IN}$, E_F and seq

Table 6: Symbols and values for parameters and exogenous variables (baseline scenario)

Symbol	Description	Value	Remarks/sources
ad_K	Fraction of gross damages to capital stock avoided through adaptation	0.80	Selected from a reasonable range of values
ad_{LF}	Fraction of gross damages to labour force avoided through adaptation	0.95	Selected from a reasonable range of values
ad_P	Fraction of gross damages to productivity avoided through adaptation	0.95	Selected from a reasonable range of values
c_1	Propensity to consume out of disposable income	0.80	Calibrated such that the model generates the baseline scenario
c_2	Propensity to consume out of financial wealth	0.05	Based on econometric estimations for a panel of countries over the period 1995-2019 (available upon request)
CAR^{min}	Minimum capital adequacy ratio	0.08	Based on the Basel III regulatory framework
con_E	Conversion rate of fossil energy resources into reserves	0.003	Selected from a reasonable range of values
con_M	Conversion rate of material resources into reserves	0.0015	Selected from a reasonable range of values
CR^{max}	Maximum degree of credit rationing	0.5	Selected from a reasonable range of values
dd_{S1}	Degree of dirtiness of the 'mining and utilities' sector	8.60	Calculated from the formula $dd_{S1} = (carbon_{S1}/GVA_{S1})/(carbon/GVA)$ where $carbon_{S1}$ denotes the carbon emissions of sector S1, *carbon* denotes the total carbon emissions (taken from IEA), GVA_{S1} is the gross value added of sector S1 and *GVA* is the total gross value added (taken from UN)
dd_{S2}	Degree of dirtiness of the 'manufacturing and construction' sector	0.82	Calculated from the formula $dd_{S2} = (carbon_{S2}/GVA_{S2})/(carbon/GVA)$ where $carbon_{S2}$ denotes the carbon emissions of sector S2, *carbon* denotes the total carbon emissions (taken from IEA), GVA_{S2} is the gross value added of sector S2 and *GVA* is the total gross value added (taken from UN)
dd_{S3}	Degree of dirtiness of the 'transport' sector	2.66	Calculated from the formula $dd_{S3} = (carbon_{S3}/GVA_{S3})/(carbon/GVA)$ where $carbon_{S3}$ denotes the carbon emissions of sector S3, *carbon* denotes the total carbon emissions (taken from IEA), GVA_{S3} is the gross value added of sector S3 and *GVA* is the total gross value added (taken from UN)
dd_{S4}	Degree of dirtiness of the 'other sectors'	0.16	Calculated from the formula $dd_{S4} = (carbon_{S4}/GVA_{S4})/(carbon/GVA)$ where $carbon_{S4}$ denotes the carbon emissions of sector S4, *carbon* denotes the total carbon emissions (taken from IEA), GVA_{S4} is the gross value added of sector S4 and *GVA* is the total gross value added (taken from UN)
def^{max}	Maximum default rate of loans	0.2	Selected from a reasonable range of values
def_0	Parameter of the default rate function	6.69	Calculated from Eq. (119) using the initial value of *illiq*
def_1	Parameter of the default rate function	8.53	Calibrated such that the model generates the baseline scenario
def_2	Parameter of the default rate function (related to the sensitivity of the default rate to the illiquidity ratio of firms)	11.05	Selected from a reasonable range of values
f_{nc}	Non-CO_2 fraction of total anthropogenic forcing	0.1	Taken from Matthews et al. (2021)
gov_C	Share of government expenditures in output	0.17	Based on World Bank; the figure includes only the consumption government expenditures
gov_{IC}	Share of conventional public spending in output	0.06	Calculated from Eq. (167) using the initial values of *Y* and $I_{C(GOV)}$
gov_{IG}	Share of green public spending in output	0.0020	Calculated from Eq. (166) using the initial values of *Y* and $I_{G(GOV)}$
h_1	Banks' reserve ratio	0.21	Based on World Bank
h_2	Banks' government securities-to-deposits ratio	0.17	Calculated from Eq. (145) using the initial values of SEC_B and *D*
haz	Proportion of hazardous waste in total waste	0.04	EEA (2012, p. 22) reports a figure equal to 3.7% for EU-27
int_A	Interest rate on advances	0.056	Based on Global Interest Rate Monitor
int_D	Interest rate on deposits	0.04	Based on World Bank
int_S	Interest rate on government securities	0.0175	Based on FTSE Russell (2022)
l_1	Parameter in the function of the credit rationing on green/conventional loans (related to the sensitivity of credit rationing to the difference between the weight on green/conventional loans and total loans)	1.00	Selected from a reasonable range of values
lev_B^{max}	Maximum leverage ratio	33.33	Based on the Basel III regulatory framework (the Basel III bank leverage can be proxied by the capital-to-assets ratio and its minimum value is 3%; since in our model the bank leverage is defined as the assets-to-capital ratio, the maximum value used is equal to 1/0.03)
lf_2	Sensitivity of the labour force-to-population ratio to hazardous waste	0.001	Selected from a reasonable range of values
p	Share of productivity damage in total damage caused by climate change	0.1	Selected from a reasonable range of values
$\bar{p}_C$	Par value of conventional corporate bonds (US$)	100	The par value of bonds is assumed to be always equal to US$100
$\bar{p}_G$	Par value of green corporate bonds (US$)	100	The par value of bonds is assumed to be always equal to US$100
pr	Ratio of demand-determined output to supply-determined output under the existence of supply-side constraints	0.99	Selected such that it is reasonably close to 1

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Symbol	Description	Value	Remarks/sources
r_0	Parameter in the function of the credit rationing on total loans	1.50	Calibrated such that the initial value of credit rationing is 20%. This figure is slightly higher than the one implied by the results in ECB (2017) that rely on the Survey on Access to Finance of Enterprises (SAFE) that covers EU countries. This is because credit rationing is expected to be higher in emerging and developing countries
r_1	Parameter in the function of the credit rationing on total loans	4.29	Calibrated such that the initial value of credit rationing is 20%. This figure is slightly higher than the one implied by the results in ECB (2017) that rely on the Survey on Access to Finance of Enterprises (SAFE) that covers EU countries. This is because credit rationing is expected to be higher in emerging and developing countries
r_2	Parameter in the function of the credit rationing on total loans (related to the sensitivity of credit rationing to the debt service ratio)	8.54	Based on econometric estimations for a panel of countries over the period 1995-2019 (available upon request)
r_3	Parameter in the function of the credit rationing on total loans (related to the sensitivity of credit rationing to the capital adequacy ratio of banks)	11.61	Based on econometric estimations for a panel of countries over the period 1995-2019 (available upon request)
rep	Loan repayment ratio	0.1	Selected from a reasonable range of values
s_B	Banks' retention rate	0.79	Calibrated such that the model generates the baseline scenario
s_C	Share of conventional corporate bonds held by central banks (US$ trillion)	0.03	Calculated from Eq. (184) using the initial values of B_{CCB} and B_C
s_F	Firms' retention rate	0.12	Calibrated such that the model generates the baseline scenario
s_G	Share of green corporate bonds held by central banks (US$ trillion)	0.09	Calculated from Eq. (183) using the initial values of B_{GCB} and B_G
s_{W0}	Parameter in the wage share function	0.56	Calculated from Eq. (98) using the initial values of s_W and ur
s_{W1}	Parameter in the wage share function (related to the sensitivity of the wage share to the unemployment rate)	0.18	Based on econometric estimations for a panel of countries over the period 1995-2019 (available upon request)
$sh_{(EMISF)S1}$	Share of industrial emissions of the sector 'mining and utilities' to total industrial emissions	0.47	Calculated from the equation $carbon_{S1}/\Sigma carbon_{Si}$ where $carbon_{Si}$ denotes the industrial emissions of the i sector taken by IEA
$sh_{(EMISF)S2}$	Share of industrial emissions of the sector 'manufacturing and construction' to total industrial emissions	0.18	Calculated from the equation $carbon_{S2}/\Sigma carbon_{Si}$ where $carbon_{Si}$ denotes the industrial emissions of the i sector taken from IEA
$sh_{(EMISF)S3}$	Share of industrial emissions of the sector 'transport' to total industrial emissions	0.24	Calculated from the equation $carbon_{S3}/\Sigma carbon_{Si}$ where $carbon_{Si}$ denotes the industrial emissions of the i sector taken from IEA
$sh_{(EMISF)S4}$	Share of industrial emissions of the 'other sectors' to total industrial emissions	0.10	Calculated from the equation $carbon_{S4}/\Sigma carbon_{Si}$ where $carbon_{Si}$ denotes the industrial emissions of the i sector taken from IEA
$sh_{(GREEN)S1}$	Share in green investment, 'mining and utilities' sector	0.47	Based on CPI (2021)
$sh_{(GREEN)S2}$	Share in green investment, 'manufacturing and construction' sector	0.10	Based on CPI (2021)
$sh_{(GREEN)S3}$	Share in green investment, 'transport' sector	0.26	Based on CPI (2021)
$sh_{(GREEN)S4}$	Share in green investment, 'other sectors'	0.18	Based on CPI (2021)
$sh_{(GVA)S1}$	Share in total gross value added, 'mining and utilities' sector	0.05	Calculated from the equation $GVA_{S1}/\Sigma GVA_{Si}$ where GVA_{Si} denotes the gross value added of the i sector taken from UNCTAD
$sh_{(GVA)S2}$	Share in total gross value added, 'manufacturing and construction' sector	0.22	Calculated from the equation $GVA_{S2}/\Sigma GVA_{Si}$ where GVA_{Si} denotes the gross value added of the i sector taken from UNCTAD
$sh_{(GVA)S3}$	Share in total gross value added, 'transport' sector	0.09	Calculated from the equation $GVA_{S3}/\Sigma GVA_{Si}$ where GVA_{Si} denotes the gross value added of the i sector taken from UNCTAD
$sh_{(GVA)S4}$	Share in total gross value added, 'other sectors'	0.63	Calculated from the equation $GVA_{S4}/\Sigma GVA_{Si}$ where GVA_{Si} denotes the gross value added of the i sector taken from UNCTAD
spr_0	Parameter in the function of the spread on total loans	0.02	Calculated from Eq. (157) using the initial values of CAR and dsr
spr_1	Parameter in the function of the spread on total loans (related to the sensitivity of spread to the capital adequacy ratio of banks)	0.03	Based on econometric estimations for a panel of countries over the period 1995-2019 (the econometric estimations are available upon request)
spr_2	Parameter in the function of the spread on total loans (related to the sensitivity of spread to the debt service ratio of firms)	0.02	Based on econometric estimations for a panel of countries over the period 1995-2019 (the econometric estimations are available upon request)
spr_3	Parameter in the function of the spread on green/conventional loans (related to the sensitivity of spread on green/conventional loans to the difference between the weight on green/conventional loans and total loans)	1.00	Selected from a reasonable range of values
TCRE	Transient Climate Response to cumulative carbon Emissions (TCRE) ($^{o}C/GtCO_2$)	0.0004	Taken from Matthews et al. (2021)
ur^T	Target unemployment rate when working hours are allowed to change	0.06	Close to the current unemployment rate
w_H	Risk weight on high-powered money	0	Based on BCBS (2006)
w_S	Risk weight on government securities	0	Based on BCBS (2006)
x_{10}	Autonomous proportion of desired conventional investment funded via bonds	0.03	Calculated from Eq. (105) using the initial values of $yield_C$ and x_1

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Symbol	Description	Value	Remarks/sources
x_{11}	Sensitivity of the proportion of desired conventional investment funded via bonds to the conventional bond yield	0.25	Selected from a reasonable range of values
x_{21}	Sensitivity of the proportion of desired green investment funded via bonds to the green bond yield	0.25	Selected from a reasonable range of values
α_{00}	Parameter in the desired investment function	0.18	Calibrated such that the model generates the baseline scenario
α_{01}	Parameter in the desired investment function	0.37	Calibrated such that the model generates the baseline scenario
α_1	Parameter in the desired investment function (related to the sensitivity of investment to the capacity utilisation)	0.98	Based on econometric estimations for a panel of countries over the period 1995-2019 (available upon request)
α_2	Parameter in the desired investment function (related to the sensitivity of investment to the rate of profit)	1.09	Based on econometric estimations for a panel of countries over the period 1995-2019 (available upon request)
α_{31}	Parameter in the desired investment function (related to the sensitivity of investment to the unemployment rate)	0.06	Based on econometric estimations for a panel of countries over the period 1995-2019 (available upon request)
α_{32}	Parameter in the desired investment function (related to the sensitivity of investment to the unemployment rate)	0.5	Selected from a reasonable range of values
α_{41}	Parameter in the desired investment function (related to the sensitivity of investment to the energy utilisation rate)	0.1	Selected from a reasonable range of values
α_{42}	Parameter in the desired investment function (related to the sensitivity of investment to the energy utilisation rate)	0.99	Selected from a reasonable range of values
α_{51}	Parameter in the desired investment function (related to the sensitivity of investment to the matter utilisation rate)	0.1	Selected from a reasonable range of values
α_{52}	Parameter in the desired investment function (related to the sensitivity of investment to the matter utilisation rate)	0.99	Selected from a reasonable range of values
β_1	Autonomous share of desired green investment in total investment	17	Calibrated such that the model generates the baseline scenario
β_2	Sensitivity of the desired green investment share to the interest rate differential between green loans/bonds and conventional loans/bonds	1	Selected from a reasonable range of values
γ_E	Proportion of energy government capital in total government capital	0.737	Based on CPI (2021)
γ_{E1}	Proportion of energy capital in the total capital of the sector S1	0.969	Based on CPI (2021)
γ_{E2}	Proportion of energy capital in the total capital of the sector S2	0.387	Based on CPI (2021)
γ_{E3}	Proportion of energy capital in the total capital of the sector S3	0.906	Based on CPI (2021)
γ_{E4}	Proportion of energy capital in the total capital of the sector S4	0.075	Based on CPI (2021)
γ_{SEQ1}	Proportion of sequestration capital in the green energy capital of the sector	0.005	Based on Bloomberg
γ_{SEQ2}	Proportion of sequestration capital in the green energy capital of the sector	0.017	Based on Bloomberg
δ_0	Depreciation rate of capital stock when there are no climate damages	0.048	Based on Penn World Table 10.0 (see Feenstra et al., 2015)
ε^{max}	Maximum potential value of energy intensity (EJ/US$ trillion)	12	Selected such that it is reasonably higher than initial ε
ε^{min}	Minimum potential value of energy intensity (EJ/US$ trillion)	2	Selected such that it is reasonably higher than 0
ζ_1	Rate of decline of the (absolute) growth rate of ω	0.0015	Calibrated such that the model generates the baseline scenario
ζ_2	Rate of decline of the growth rate of β_0	0.500	Calibrated such that the model generates the baseline scenario
ζ_3	Rate of decline of the autonomous (absolute) growth rate of λ	0.01	Calibrated such that the model generates the baseline scenario
ζ_4	Rate of decline of the growth rates of x_{20}	0.40	Calibrated such that the model generates the baseline scenario
ζ_5	Rate of decline of the growth rate of population	0.0145	Calibrated such that the model generates the baseline scenario
ζ_6	Rate of decline of the autonomous labour force-to-population ratio	0.0003	Calibrated such that the model generates the baseline scenario
ζ_7	Rate of decline of the growth rate of ucr	0.7000	Calibrated such that the model generates the baseline scenario
ζ_8	Rate of decline of the growth rate of ucn	0.0300	Calibrated such that the model generates the baseline scenario
ζ_9	Rate of decline of the growth rate of $EMIS_L$	0.0070	Calibrated such that the model generates the baseline scenario
ζ_{10}	Parameter linking the demand for green bonds with their supply	0.18	Calibrated such that the model generates the baseline scenario
η_1	Parameter of the damage function	0	Based on Dietz and Stern (2015); D_T=50% when T_{AT}=4°C
η_2	Parameter of the damage function	0.00284	Based on Dietz and Stern (2015); D_T=50% when T_{AT}=4°C
η_3	Parameter of the damage function	0.00008	Based on Dietz and Stern (2015); D_T=50% when T_{AT}=4°C
λ_{10}	Parameter of households' portfolio choice	0.44	Calculated from Eq. (127) using the initial values of SEC_H, V_{HF}, D_T, $yield_C$, $yield_G$ and Y_H
λ_{10}'	Parameter of households' portfolio choice	0.10	Selected from a reasonable range of values
λ_{11}	Parameter of households' portfolio choice	0.03	Calculated from the constraint $\lambda_{11}=-\lambda_{21}-\lambda_{31}-\lambda_{41}$
λ_{12}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{13}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{14}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{15}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{20}	Parameter of households' portfolio choice	0.08	Calculated from Eq. (128) using the initial values of B_{CH}, V_{HF}, D_T, $yield_C$, $yield_G$ and Y_H
λ_{20}'	Parameter of households' portfolio choice	-0.20	Selected from a reasonable range of values
λ_{21}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{21}=\lambda_{12}$

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Symbol	Description	Value	Remarks/sources
λ_{22}	Parameter of households' portfolio choice	0.03	Calculated from the constraint $\lambda_{22}=-\lambda_{12}-\lambda_{32}-\lambda_{42}$
λ_{23}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{24}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{25}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{30}'	Parameter of households' portfolio choice	0.00	Climate damages are assumed to have no impact on the holdings of green bonds
λ_{31}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{31}=\lambda_{13}$
λ_{32}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{32}=\lambda_{23}$
λ_{33}	Parameter of households' portfolio choice	0.03	Calculated from the constraint $\lambda_{33}=-\lambda_{13}-\lambda_{23}-\lambda_{43}$
λ_{34}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{35}	Parameter of households' portfolio choice	-0.01	Selected from a reasonable range of values
λ_{40}	Parameter of households' portfolio choice	0.48	Calculated from the constraint $\lambda_{40}=1-\lambda_{10}-\lambda_{20}-\lambda_{30}$
λ_{40}'	Parameter of households' portfolio choice	0.10	Calculated from the constraint $\lambda_{40}'=-\lambda_{10}'-\lambda_{20}'-\lambda_{30}'$
λ_{41}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{41}=\lambda_{14}$
λ_{42}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{42}=\lambda_{24}$
λ_{43}	Parameter of households' portfolio choice	-0.01	Calculated from the constraint $\lambda_{43}=\lambda_{34}$
λ_{44}	Parameter of households' portfolio choice	0.03	Calculated from the constraint $\lambda_{44}=-\lambda_{14}-\lambda_{24}-\lambda_{34}$
λ_{45}	Parameter of households' portfolio choice	0.03	Calculated from the constraint $\lambda_{45}=-\lambda_{15}-\lambda_{25}-\lambda_{35}$
μ^{max}	Maximum potential value of material intensity (kg/US$)	1.5	Selected such that it is reasonably higher than initial μ
μ^{min}	Minimum potential value of material intensity (kg/US$)	0.3	Selected such that it is reasonably higher than 0
ξ	Proportion of durable consumption goods discarded every year	0.010	Selected such that the initial growth of *DC* is equal to the growth rate of output
π_1	Parameter linking the green to conventional non-energy capital ratio with material intensity	0.52	Calibrated such that the model generates the baseline scenario
π_2	Parameter linking the green to conventional non-energy capital ratio with material intensity	15.00	Calibrated such that the model generates the baseline scenario
π_3	Parameter linking the green to conventional non-energy capital ratio with recycling rate	2.79	Calibrated such that the model generates the baseline scenario
π_4	Parameter linking the green to conventional non-energy capital ratio with recycling rate	30.42	Calibrated such that the model generates the baseline scenario
π_5	Parameter linking the green to conventional energy capital ratio with energy intensity	4.38	Calibrated such that the model generates the baseline scenario
π_6	Parameter linking the green to conventional energy capital ratio with energy intensity	30.03	Calibrated such that the model generates the baseline scenario
π_7	Parameter linking the green to conventional energy capital ratio with the share of non-fossil energy	17.64	Calibrated such that the model generates the baseline scenario
π_8	Parameter linking the green to conventional energy capital ratio with the share of non-fossil energy	19.06	Calibrated such that the model generates the baseline scenario
π_9	Parameter linking the sequestration to conventional energy capital ratio with the sequestration rate	559.09	Calibrated such that the model generates the baseline scenario
π_{10}	Parameter linking the sequestration to conventional energy capital ratio with the sequestration rate	1249.86	Calibrated such that the model generates the baseline scenario
ρ^{max}	Maximum potential value of recycling rate	0.8	Selected such that it is reasonably lower than 1
σ_1	Autonomous growth rate of labour productivity	0.01	Calibrated such that the model generates the baseline scenario
σ_2	Sensitivity of labour productivity growth to the growth rate of output	0.85	Based on econometric estimations for a panel of countries over the period 1991-2019 (available upon request)
τ_F	Firms' tax rate	0.15	Selected from a reasonable range of values
τ_H	Households' tax rate	0.22	Calibrated such that the model generates the baseline scenario
φ	Responsiveness of working hours to changes in the unemployment rate	0	In the baseline scenario the working hours are assumed to be constant

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