Dynamic Ecosystem-FINance-Economy (DEFINE) model: Technical description and data

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 stock-flow-fund ecological macroeconomic model that analyses the interactions between the ecosystem, the financial system and the macroeconomy. It incorporates explicitly the laws of thermodynamics, the carbon cycle, the climate change 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 stock-flow consistent (SFC) approach developed by Godley and Lavoie (2007) with the flow-fund model of Georgescu-Roegen (1971, ch. 9; 1979; 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; 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. non-renewable energy 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 standard specifications from the integrated assessment modelling literature (see Nordhaus and Sztorc, 2013). 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.

Version 1.1. of DEFINE differs from version 1.0 mainly in the following ways. *First*, an explicit distinction is made between conventional investments with a different 'degree of brownness'. This brownness is defined based on data about the carbon emissions of different sectors of the economy. By making such a distinction we are able (a) to capture more accurately the impact of brown capital on the evolution of ecological efficiency indicators and (b) to assess financial policies that might impose higher capital requirements on bank loans provided for brown 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 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

[1] The stock-flow resources (non-renewable 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.

brownness 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.

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 parameters and variables.

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 non-renewable sources (e.g. oil, gas and coal) or renewable 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.

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[2] For brevity, the energy produced from (non-)renewable sources is henceforth referred to as (non-)renewable energy. For simplicity, the model does not incorporate energy and matter from biomass. However, the figure used for the share of renewable 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., 2015). 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.

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 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 the analysis that we pursue here. 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.

As mentioned above, there are two types of capital: green capital and conventional capital. Conventional capital is characterised by a degree of brownness. This degree of brownness differs between the capital of different sectors of the economy. 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 degree of

[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. A more detailed disaggregation would complicate our model without changing the substance of the analysis. However, such a disaggregation could be used in future applications of the model to specific countries or regions.

brownness of each sector is proxied by the carbon emissions per gross value added (GVA). The sectors in which carbon-GVA intensity is higher, the degree of brownness of their conventional capital is assumed to be higher.

An increase in green capital leads, ceteris paribus, to lower energy intensity, lower material intensity and higher recycling rate. Moreover, green capital is conducive to the production of energy using renewable sources. On the contrary, conventional brown capital is conducive to a higher energy intensity, a higher material intensity and a lower recycling rate.[5] The higher the degree of brownness the more significant the adverse environmental effects.

Firms invest in conventional and green capital by using retained profits, loans and bonds. Commercial 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 base interest rate, provide liquidity to the commercial 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 use US dollar ($) as a reference currency.

[5] A more realistic formulation would be to assume different 'shades of green' and 'shades of brown' depending on the number of 'green' and 'brown' properties that each capital has. In that case the 'greenest' ('brownest') capital would be that capital that can generate renewable (non-renewable) energy and is endowed by the lowest (highest) energy intensity, lowest (highest) material intensity and highest (lowest) recycling rate. On the other hand, the least 'green' ('brown') capital would be the capital that has only one of these properties. However, such a formulation would complicate the model significantly since it would require the distinction between many types of green investment and would make the calibration of the model a much more challenging exercise.

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).[6] According to this balance, the total inputs of matter into the socio-economic system over a year (extracted matter, the carbon mass of non-renewable energy and the oxygen included in CO_2 emissions) should be equal to the total outputs of matter over the same year (industrial 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	$+M$	
Renewable energy		$+ER$
Non-renewable energy	$+CEN$	$+EN$
Oxygen used for fossil fuel combustion	$+O2$	
Outputs		
Industrial CO_2 emissions	$-EMIS_{IN}$	
Waste	$-W$	
Dissipated energy		$-ED$
Change in socio-economic stock	$-\Delta SES$	
Total	0	0

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

[6] For the use of the material balance in material flow accounting, see Fischer-Kowalski et al. (2011).

Table 2 displays the physical stock-flow matrix of our model.[7] This matrix presents the dynamic change in those physical stocks that are considered more important for human activities. These are the material and non-renewable energy reserves, the atmospheric CO_2 concentration, the socio-economic stock and the stock of 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.

Table 2: Physical stock-flow matrix

	Material reserves	Non-renewable energy reserves	Atmospheric CO_2 concentration	Socio-economic stock	Hazardous waste
Opening stock	REV_{M-1}	REV_{E-1}	$CO2_{AT-1}$	SES_{-1}	HWS_{-1}
Additions to stock					
Resources converted into reserves	$+CON_M$	$+CON_E$			
CO_2 emissions			$+EMIS$		
Production of material goods				$+MY$	
Non-recycled hazardous waste					$+hazW$
Reductions of stock					
Extraction/use of matter or energy	$-M$	$-EN$			
Net transfer of CO_2 to oceans/biosphere			$+(\phi_{11}-1)CO2_{AT-1}+\phi_{21}CO2_{UP-1}$		
Demolished/disposed socio-economic stock				$-DEM$	
Closing stock	REV_M	REV_E	$CO2_{AT}$	SES	HWS

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

The reserves of matter and non-renewable energy are those volumes expected to be produced economically using the existing technology. The reserves stem from the resources which 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 energy and matter transformation (CO_2 emissions and hazardous material waste). As will be explained below, these by-products cause the degradation of ecosystem services 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

[7] For a similar presentation of the physical stock-flow interactions see United Nations (2014).

processes transform the low-entropy energy embodied in these resources into high-entropy energy, sustainability requires the reliance of economic processes on renewable 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, embody a specific amount of matter, MY (Eq. 1).[8] Material intensity (μ) is defined as the matter included in each output produced. The socio-economic stock (SES) is the material content of the total capital goods (K) and durable consumption goods (DC) that remain in the socio-economic system. Thus, $SES = \mu(K + DC)$. As shown in Eq. (2), the matter embodied in goods comes from extraction (M 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). The latter is defined in Eq. (3); ρ denotes the recycling rate, which is defined as the ratio of recycled matter to the total amount of demolished/discarded socio-economic stock (DEM). 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 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) 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) generated during the production process is used as a residual. Regarding non-renewable energy, only its carbon mass, CEN, has been included as input in the material balance. As shown in Eq. (7), this mass is estimated from the industrial emissions ($EMIS_{IN}$) 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 ($O2$) is introduced as an input in the material balance because it is

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

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 $W = DEM - REC$; in other words, waste is equal to the 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.[9] This hazardous waste is added to the accumulated stock of hazardous waste, HWS (Eq. 9). Eq. (10) defines the per capital accumulated hazardous waste ($hazratio$) which is equal to the accumulated stock of hazardous waste in Gt divided by the population (POP).

$$MY = \mu\left(Y - C_{(GOV)}\right) \quad (1)$$

$$M = MY - REC \quad (2)$$

$$REC = \rho DEM \quad (3)$$

$$DEM = \mu\left(\delta K_{-1} + \xi DC_{-1}\right) \quad (4)$$

$$SES = SES_{-1} + MY - DEM \quad (5)$$

$$W = M + CEN + O2 - EMIS_{IN} - \Delta SES \quad (6)$$

$$CEN = \frac{EMIS_{IN}}{car} \quad (7)$$

$$O2 = EMIS_{IN} - CEN \quad (8)$$

$$HWS = HWS_{-1} + hazW \quad (9)$$

$$hazratio = \frac{HWS}{POP} \quad (10)$$

The material stock-flow dynamics are presented in Eqs. (11)-(14). Eq. (11) shows that the material reserves (REV_M) 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_M) 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_M). To capture the scarcity of matter we define the matter depletion ratio (dep_M), 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.

[9] 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).

$$REV_M = REV_{M-1} + CON_M - M \quad (11)$$

$$CON_M = con_M RES_{M-1} \quad (12)$$

$$RES_M = RES_{M-1} - CON_M \quad (13)$$

$$dep_M = \frac{M}{REV_{M-1}} \quad (14)$$

2.1.2 Energy

The energy required for production (E) is a function of output (Eq. 15). When energy intensity (ε) declines, the energy required per unit of output becomes lower. As shown in Eqs. (16) and (17), energy is generated either from renewable (ER) or non-renewable sources (EN). The share of renewable energy in total energy is denoted by θ. The dissipated energy (ED) is determined based on the energy balance (Eq. 18).

$$E = \varepsilon Y \quad (15)$$

$$ER = \theta E \quad (16)$$

$$EN = E - ER \quad (17)$$

$$ED = EN + ER \quad (18)$$

Eqs. (19)-(22) represent the stock-flow dynamics of the energy produced from non-renewables. Eq. (19) shows the change in the non-renewable energy reserves (REV_E). CON_E 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 non-renewable energy (RES_E) change every year according to Eq. (21). The energy depletion ratio (dep_E), which captures scarcity problems, shows the non-renewable energy that is extracted and is used every year, relative to the remaining reserves (Eq. 22).

$$REV_E = REV_{E-1} + CON_E - EN \quad (19)$$

$$CON_E = con_E RES_{E-1} \quad (20)$$

$$RES_E = RES_{E-1} - CON_E \quad (21)$$

$$dep_E = \frac{EN}{REV_{E-1}} \quad (22)$$

2.1.3 Emissions and climate change

Our formalisation of emissions and climate change follows closely the traditional integrated assessment models (see Nordhaus and Sztorc, 2013). Every year industrial CO_2 emissions ($EMIS_{IN}$) are generated due to the use of the non-renewable energy sources (Eq. 23). CO_2 intensity (ω) is defined as the industrial emissions produced per unit of non-renewable energy. Every year land-use CO_2 emissions ($EMIS_L$) are also generated because of changes in the use of land (Eq. 24). These emissions are assumed to decline exogenously at a rate lr. Eq. (25) gives the total emissions ($EMIS$).

The atmospheric CO_2 concentration ($CO2_{AT}$) is driven by these emissions and the carbon cycle. The carbon cycle, represented by Eqs. (26)-(28), shows that every year there is exchange of carbon between the atmosphere and the upper ocean/biosphere and between the upper ocean/biosphere and the lower ocean; $CO2_{UP}$ is the upper ocean/biosphere CO_2 concentration and $CO2_{LO}$ is the lower ocean CO_2 concentration. The higher the net transfers of carbon from the atmosphere into the other two reservoirs the lower the atmospheric CO_2 concentration. The accumulation of atmospheric CO_2 and other greenhouse gases increases radiative forcing, F (Eq. 29), placing upward pressures on the atmospheric temperature, T_{AT} (Eq. 31). $F_{2\times CO_2}$ is the increase in radiative forcing (since the pre-industrial period) due to doubling of CO_2 concentration from pre-industrial levels ($CO2_{AT-PRE}$) and S is the equilibrium climate sensitivity. For simplicity, the radiative forcing due to non-CO_2 greenhouse gas emissions (F_{EX}) is determined exogenously (Eq. 30).[10] Eq. (32) shows the change in the temperature of the lower ocean (T_{LO}).

$$EMIS_{IN} = \omega EN \tag{23}$$

$$EMIS_L = EMIS_{L-1}(1 - lr) \tag{24}$$

$$EMIS = EMIS_{IN} + EMIS_L \tag{25}$$

$$CO2_{AT} = EMIS + \phi_{11} CO2_{AT-1} + \phi_{21} CO2_{UP-1} \tag{26}$$

$$CO2_{UP} = \phi_{12} CO2_{AT-1} + \phi_{22} CO2_{UP-1} + \phi_{32} CO2_{LO-1} \tag{27}$$

$$CO2_{LO} = \phi_{23} CO2_{UP-1} + \phi_{33} CO2_{LO-1} \tag{28}$$

$$F = F_{2\times CO2} \, log_2 \frac{CO2_{AT}}{CO2_{AT-PRE}} + F_{EX} \tag{29}$$

$$F_{EX} = F_{EX-1} + fex \tag{30}$$

[10] For the modelling of radiative forcing as an endogenous function of some key non-CO_2 greenhouse gas emissions, see e.g. Anthoff and Tol (2014).

$$T_{AT} = T_{AT-1} + t_1\left(F - \frac{F_{2\times CO2}}{S} T_{AT-1} - t_2\left(T_{AT-1} - T_{LO-1}\right)\right) \quad (31)$$

$$T_{LO} = T_{LO-1} + t_3\left(T_{AT-1} - T_{LO-1}\right) \quad (32)$$

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 renewable energy in total energy goes up. CO_2 intensity changes in an exogenous way. As shown in Eqs. (33) and (34), CO_2 intensity is reduced with a declining rate ($g_\omega < 0$ and $\zeta_1 > 0$).[11] This reduction is, for example, related to use of technologies, like carbon capture and storage, and the replacement of coal with other fossil fuels that generate less carbon emissions.

As mentioned above, green capital is conducive to lower material and energy intensity and to higher recycling and use of renewables. Hence, we postulate that the efficiency related to these indicators increases when the ratio of green capital (K_G) to the brown-weighted conventional capital (K_B) rises. The latter is defined based on the degree of brownness of the conventional capital of different sectors (the exact equation is described in the next sub-section).

The ecological efficiency indicators are shown in Eqs. (35)-(38). μ, ρ, ε and θ denote, respectively, the material intensity, recycling rate, energy intensity and the share of renewable energy in total energy. ε^{min} and $\mu^{\min}$ are the minimum potential values of energy intensity and material intensity respectively. These minimum values are approached when green capital becomes sufficiently high compared to the brown-weighted conventional capital. $\rho^{\max}$ is the maximum potential value of recycling rate which is also approached when K_G/K_B becomes sufficiently high. ε^{max}, $\mu^{\max}$ are, respectively, the maximum potential values of energy intensity and material intensity which are approached when green capital is equal to zero.

The use of logistic functions in Eqs. (35)-(38) allows us to take into account learning processes which play a key role in the diffusion and efficiency of new technologies.[12] It also allows us to

[11] See Nordhaus and Sztorc (2013) for a similar assumption.
[12] For the importance of these processes in energy systems and renewable energy technologies, see e.g. Kahouli-Brahmi (2009) and Tang and Popp (2016).

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).

$$\omega = \omega_{-1}(1 + g_{\omega}) \tag{33}$$

$$g_{\omega} = g_{\omega-1}(1 - \zeta_1) \tag{34}$$

$$\mu = \mu^{max} - \frac{\mu^{max} - \mu^{min}}{1 + \pi_1 e^{-\pi_2 (K_{G-1}/K_{B-1})}} \tag{35}$$

$$\rho = \frac{\rho^{max}}{1 + \pi_3 e^{-\pi_4 (K_{G-1}/K_{B-1})}} \tag{36}$$

$$\varepsilon = \varepsilon^{max} - \frac{\varepsilon^{max} - \varepsilon^{min}}{1 + \pi_5 e^{-\pi_6 (K_{G-1}/K_{B-1})}} \tag{37}$$

$$\theta = \frac{1}{1 + \pi_7 e^{-\pi_8 (K_{G-1}/K_{B-1})}} \tag{38}$$

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 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		Commercial banks		Government sector		Central banks		Total
	Current	Capital	Current	Capital	Current	Capital	Current	Capital	Current	Capital	
Private consumption expenditures		$-C_{(PRI)}$	$+C_{(PRI)}$								0
Government consumption expenditures			$+C_{(GOV)}$				$-C_{(GOV)}$				0
Conventional investment			$+\Sigma I_{C(PRI)i}+I_{C(GOV)}$	$-\Sigma I_{C(PRI)i}$				$-I_{C(GOV)}$			0
Green investment			$+\Sigma I_{G(PRI)i}+I_{G(GOV)}$	$-\Sigma I_{G(PRI)i}$				$-I_{G(GOV)}$			0
Green subsidies			$+SUB$				$-SUB$				0
Household disposable income net of depreciation	$-Y_{HD}$	$+Y_{HD}$									0
Wages	$+wN$		$-wN$								0
Government balance							$-GB$	$+GB$			0
Taxes	$-T_H$		$-T_F-T_C$				$+T$				0
Firms' profits	$+DP$		$-TP$	$+RP$							0
Commercial banks' profits	$+BP_D$				$-BP$	$+BP_U$					0
Interest on deposits	$+int_D D_{-1}$				$-int_D D_{-1}$						0
Depreciation of green capital			$-\delta \Sigma K_{G(PRI)i-1}$	$+\delta \Sigma K_{G(PRI)i-1}$			$-\delta K_{G(GOV)-1}$	$+\delta K_{G(GOV)-1}$			0
Depreciation of conventional capital			$-\delta \Sigma K_{C(PRI)i-1}$	$+\delta \Sigma K_{C(PRI)i-1}$			$-\delta K_{C(GOV)-1}$	$+\delta K_{C(GOV)-1}$			0
Interest on conventional loans			$-\Sigma int_{Ci} L_{Ci-1}$		$+\Sigma int_{Ci} L_{Ci-1}$						0
Interest on green loans			$-\Sigma int_G L_{Gi-1}$		$+\Sigma int_G L_{Gi-1}$						0
Interest on conventional bonds	$+coupon_C b_{CH-1}$		$-coupon_C b_{C-1}$						$+coupon_C b_{CCB-1}$		0
Interest on green bonds	$+coupon_G b_{GH-1}$		$-coupon_G b_{G-1}$						$+coupon_G b_{GCB-1}$		0
Interest on government securities	$+int_S SEC_{H-1}$				$+int_S SEC_{B-1}$		$-int_S SEC_{-1}$		$+int_S SEC_{CB-1}$		0
Interest on advances					$-int_A A_{-1}$				$+int_A A_{-1}$		0
Depreciation of durable consumption goods	$-\xi DC_{-1}$	$+\xi DC_{-1}$									0
Central bank's profits							$+CBP$		$-CBP$		0
Bailout of banks						$+BAILOUT$	$-BAILOUT$				0
Δdeposits		$-\Delta D$				$+\Delta D$					0
Δconventional loans				$+\Sigma \Delta L_{Ci}$		$-\Sigma \Delta L_{Ci}$					0
Δgreen loans				$+\Sigma \Delta L_{Gi}$		$-\Sigma \Delta L_{Gi}$					0
Δconventional bonds		$-\bar{p}_C \Delta b_{CH}$		$+\bar{p}_C \Delta b_C$						$-\bar{p}_C \Delta b_{CCB}$	0
Δgreen bonds		$-\bar{p}_G \Delta b_{GH}$		$+\bar{p}_G \Delta b_G$						$-\bar{p}_G \Delta b_{GCB}$	0
Δgovernment securities		$-\Delta SEC_H$				$-\Delta SEC_B$		$+\Delta SEC$		$-\Delta SEC_{CB}$	0
Δadvances						$+\Delta A$				$-\Delta A$	0
Δhigh-powered money						$-\Delta HPM$				$+\Delta HPM$	0
Defaulted loans				$+DL$		$-DL$					0
Total	0	0	0	0	0	0	0	0	0	0	0

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

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 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	Commercial banks	Government sector	Central banks	Total
Conventional capital		$+\Sigma K_{C(PRI)i}$		$+K_{C(GOV)}$		$+K_C$
Green capital		$+\Sigma K_{G(PRI)i}$		$+K_{G(GOV)}$		$+K_G$
Durable consumption goods	$+DC$					$+DC$
Deposits	$+D$		$-D$			0
Conventional loans		$-\Sigma L_{Ci}$	$+\Sigma L_{Ci}$			0
Green loans		$-\Sigma L_{Gi}$	$+\Sigma L_{Gi}$			0
Conventional bonds	$+\bar{p}_C b_{CH}$	$-\bar{p}_C b_C$			$+\bar{p}_C b_{CCB}$	0
Green bonds	$+\bar{p}_G b_{GH}$	$-\bar{p}_G b_G$			$+\bar{p}_G b_{GCB}$	0
Government securities	$+SEC_H$		$+SEC_B$	$-SEC$	$+SEC_{CB}$	0
High-powered money			$+HPM$		$-HPM$	0
Advances			$-A$		$+A$	0
Total (net worth)	$+V_H$	$+V_F$	$+CAP$	$-SEC+K_{C(GOV)}+K_{G(GOV)}$	$+V_{CB}$	$+K_C+K_G+DC$

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 non-renewable energy. The fund-service resources are labour and capital.[13] We define four different types of potential output. The matter-determined potential output (Y_M^*) is defined in Eq. (39) 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_E^*) is defined in Eq. (40) and is higher the higher are the non-renewable energy reserves, the lower is the energy intensity and the higher is the share of renewable energy in total energy. The capital-determined potential output (Y_K^*) is defined in Eq. (41) and is higher the higher is

[13] We assume away Ricardian land.

the private capital stock ($K_{(PRI)}$) and the productivity of capital (v). Lastly, the labour-determined potential output (Y_N^*) is defined in Eq. (42) and is higher the higher is the labour force (LF), the hourly labour productivity (λ) and the annual working hours per employee (h). The overall potential output (Y^*) is the minimum of all these potential outputs (Eq. 43).

In line with the post-Keynesian tradition, actual output (Y) is demand-determined (Eq. 44): it is equal to the sum of private consumption ($C_{(PRI)}$), private investment ($I_{(PRI)}$), government investment ($I_{(GOV)}$) and government consumption ($C_{(GOV)}$). 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. 45-48). The first two ratios are the matter utilisation rate (um) and the energy utilisation rate (ue), which refer to the use of stock-flow resources.[14] When these ratios increase, the output produced approaches the potential output determined by the material and energy reserves. The last two ratios are the utilisation rate (u) and the rate of employment (re), which refer to the use of fund-service resources. A rise in these ratios reflects a higher scarcity of capital and labour.

$$Y_M^* = \frac{REV_{M-1} + REC}{\mu} \tag{39}$$

$$Y_E^* = \frac{REV_{E-1}}{(1-\theta)\varepsilon} \tag{40}$$

$$Y_K^* = vK_{(PRI)} \tag{41}$$

$$Y_N^* = \lambda h LF \tag{42}$$

$$Y^* = min\left(Y_M^*, Y_E^*, Y_K^*, Y_N^*\right) \tag{43}$$

$$Y = C_{(PRI)} + I_{(PRI)} + I_{(GOV)} + C_{(GOV)} \tag{44}$$

$$um = \frac{Y - C_{(GOV)}}{Y_M^*} \tag{45}$$

$$ue = \frac{Y}{Y_E^*} \tag{46}$$

$$u = \frac{Y}{Y_K^*} \tag{47}$$

$$re = \frac{Y}{Y_N^*} \tag{48}$$

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

Global warming 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.[15] Moreover, experiencing or observing the natural disasters and the health problems, households might be induced to save more for precautionary reasons.[16] 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_K^* and Y_N^*, they place upward pressures on u and re. 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. (2009), we thereby make a distinction between gross damages and net damages.

15 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.

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

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.[17]

Eq. (49) is the damage function, which shows how atmospheric temperature and damages are linked. D_T is the proportional gross damage which lies between 0 (no damage) and 1 (complete catastrophe). The form of Eq. (49) 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 $\eta_3 T_{AT}^{6.754}$ where η_3 and the corresponding exponent have been selected such that $D_T = 0.5$ when $T_{AT} = 6$°C.

In most integrated assessments models D_T affects directly the supply-determined output. On the contrary, as mentioned above, in our model D_T affects the potential output and the aggregate demand. Hence, the variable D_T enters into both (i) the determination of funds and their productivities (see Eqs. 82, 83, 86 and 125) and (ii) the consumption and investment demand (see Eqs. 58 and 112). It is also necessary to partition the gross damage between the fund (D_{TF}) and its productivity (D_{TP}), so as to warrant that when $D_T = x\%$ 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. (50) and (51).[18]

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 $(1-ad_P)D_{TP}$. We assume that adaptation does not affect private investment and consumption demand: firms and households make decisions based on gross damages.

$$D_T = 1 - \frac{1}{1 + \eta_1 T_{AT} + \eta_2 T_{AT}^2 + \eta_3 T_{AT}^{6.754}} \quad (49)$$

$$D_{TP} = pD_T \quad (50)$$

[17] We do not include the financial cost of the adaptation measures in net damages.
[18] See also Moyer et al. (2015).

$$D_{TF} = 1 - \frac{1 - D_T}{1 - D_{TP}} \tag{51}$$

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*). Recall that each sector has a conventional capital with a different degree of brownness. In addition, 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_G) are given by Eq. (52); w is the wage rate, N is the number of employed workers, int_{Ci} is the interest rate on conventional loans for sector *i* (where *i*=*S1*, *S2*, *S3* and *S4*), int_G is the interest rate on green loans (which is the same for all sectors of the economy), $coupon_C$ denotes the coupon payments on conventional bonds, $coupon_G$ denotes the coupon payments on green bonds, L_{Ci} is the amount of conventional loans for sector *i*, L_{Gi} is the amount of green loans for sector *i*, b_C is the number of conventional bonds, b_G is the number of green bonds, SUB is the value of green subsidies provided by the government, $K_{(PRI)}$ is the private capital stock and δ 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) are equal to gross profits minus the taxes on firms' profits (T_F) and the taxes on carbon (T_C) (Eq. 53). Firms' retained profits (RP) are a proportion (s_F) of their total profits (Eq. 54). The distributed profits of firms (DP) are determined as a residual (Eq. 55). Eq. (56) gives the total profit rate (r).

$$TP_G = Y - wN - \sum int_{Ci} L_{Ci-1} - \sum int_G L_{Gi-1} - \delta K_{(PRI)-1} - coupon_C b_{C-1} - coupon_G b_{G-1} + SUB \tag{52}$$

$$TP = TP_G - T_F - T_C \tag{53}$$

$$RP = s_F TP_{-1} \tag{54}$$

$$DP = TP - RP \tag{55}$$

$$r = TP/K_{(PRI)} \tag{56}$$

Total desired net investment is affected by a number of factors (Eq. 57). First, following the Kaleckian approach (see e.g. Blecker, 2002), it depends positively on the rate of profit (r) and the rate of capacity utilisation (u). 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) 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.[19]

Third, the scarcity of energy and material resources can dampen investment, for example because of a rise in resource prices; ue and um 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.

[19] 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.

Fourth, in order to capture exogenous random factors that might affect desired investment, we have assumed that $I^D_{(PRI)}$ also depends on a random component, ε_I, that follows a stochastic AR(1) process. 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.

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. (58), where the desired investment of each sector ($I^D_{(PRI)i}$) 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 ($I^D_{G(PRI)i}$), which is a proportion, β_i, of the total desired investment of each sector (Eq. 59).[20] Desired conventional investment ($I^D_{C(PRI)i}$) is determined as a residual (Eq. 60).

The proportion of green investment depends on three factors (Eq. 61). The first factor is captured by the term β_{0i} which reflects exogenous developments, such as environmental preferences or institutional changes linked with environmental regulation. It is assumed that β_{0i} increases every year but with a declining rate (Eqs. 62 and 63). The second factor reflects the cost of green capital compared to conventional capital. As shown in Eqs. (64) and (65), this relative cost (RC), is assumed to decline exogenously as a result of green technical progress. This 'realised' relative cost for firms is, however, different. This is because of the potential existence of green subsidies and carbon taxes which increase the relative advantage of green investment compared to conventional investment. Therefore, in Eq. (61) the relative cost is adjusted based on the subsidy rate (gov_{SUB}) and the carbon taxes that firms have to pay due to the carbon emissions generated as a result of their conventional investment; the carbon tax, τ_C, denotes how many US$ firms pay per kg of CO_2. Note that the carbon taxes paid by each sector are different since each one of them generates a different amount of emissions; $sh_{(EMIS_{IN})i}$ shows the share of total emissions per sector. As the adjusted relative cost declines, firms are more willing to invest in green capital.

[20] Our formulation implicitly assumes that green investment crowds out conventional investment. This is in line with the recent empirical literature (see Weche, 2018). However, such crowding out is not assumed in the case of public green investment: government can conduct green investment on top of conventional investment.

The third factor is captured by the term $\beta_2\left[sh_{L-1}\left(int_{G-1}-int_{Ci-1}\right)+\left(1-sh_{L-1}\right)\left(yield_{G-1}-yield_{C-1}\right)\right]$, reflects the borrowing cost of investing in green capital relative to conventional capital; $yield_C$ is the yield on conventional bonds, $yield_G$ is the yield on green bonds and sh_L is the share of loans in the total liabilities of firms (loans plus bonds). As the cost of borrowing of green capital (via bank lending or bonds) declines compared to conventional capital, firms tend to increase green investment.

$$I_{(PRI)}^{D}=\left(\frac{\alpha_{00}}{1+exp\left(\alpha_{01}-\alpha_1 u_{-1}-\alpha_2 r_{-1}+\alpha_{31}ur_{-1}^{-\alpha_{32}}+\alpha_{41}\left(1-ue_{-1}\right)^{-\alpha_{42}}+\alpha_{51}\left(1-um_{-1}\right)^{-\alpha_{52}}\right)}K_{(PRI)-1}+\varepsilon_I K_{(PRI)-1}+\delta K_{(PRI)-1}\right)\left(1-D_{T-1}\right) \quad (57)$$

$$I_{(PRI)i}^{D}=sh_{(GVA)i}I_{(PRI)}^{D} \quad (58)$$

$$I_{G(PRI)i}^{D}=\beta_i I_{(PRI)i}^{D} \quad (59)$$

$$I_{C(PRI)i}^{D}=I_{(PRI)i}^{D}-I_{G(PRI)i}^{D} \quad (60)$$

$$\beta_i=\beta_{0i}-\beta_1 RC\left(1-gov_{SUB}\right)\Bigg/\left(1+sh_{(EMIS_{IN})i}\tau_C\frac{EMIS_{IN-1}}{I_{C(PRI)i-1}}\right)-\beta_2\left[sh_{L-1}\left(int_{G-1}-int_{Ci-1}\right)+\left(1-sh_{L-1}\right)\left(yield_{G-1}-yield_{C-1}\right)\right] \quad (61)$$

$$\beta_{0i}=\beta_{0i-1}\left(1+g_{\beta 0}\right) \quad (62)$$

$$g_{\beta 0}=g_{\beta 0-1}\left(1-\zeta_2\right) \quad (63)$$

$$RC=RC_{-1}\left(1-g_{RC}\right) \quad (64)$$

$$g_{RC}=g_{RC-1}\left(1-\zeta_3\right) \quad (65)$$

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.[21]

Eq. (66) gives the desired new green loans for sector *i* (NL_{Gi}^{D}) and Eq. (67) gives the desired new conventional loans (NL_{Ci}^{D}). The green, conventional investment goods for each sector after credit rationing are shown in Eqs. (68), (69) and (70);[22] $I_{G(PRI)i}$ is green private

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[21] See also Dafermos (2012), Nikolaidi (2014) and Jakab and Kumhof, 2018).
[22] Note that in Eq. (69) $i=1,2,3$.

investment for sector *i*, $I_{C(PRI)i}$ is conventional investment, $\bar{p}_C$ is the par value of conventional bonds, $\bar{p}_G$ is the par value of green bonds, DL is the amount of defaulted loans and def is the rate of default. Eqs. (71), (72) and (73) show the green, conventional and total investment of the private sector. The total loans of firms (L) are equal to conventional loans plus green loans (Eq. 74). The change in green and conventional private capital stock of each sector is equal to gross investment minus the depreciation of capital (Eqs. 75 and 76). Total green and conventional private capital is the sum of green capital of each sector (Eqs. 77 and 78). Eq. (79) shows that total private capital is equal to conventional private capital ($K_{C(PRI)}$) plus green private capital ($K_{G(PRI)}$). The ratio of green capital to total capital (κ) is given by Eq. (80).

The brown-weighted conventional capital is estimated by taking into account the degree of brownness (db_i) of the conventional capital of each sector (see Eq. 81). We calibrate the degree of brownness of conventional investment by utilising global data for the level of carbon emissions per gross value added (GVA) in different sectors of the economy. An investment is considered to be 'browner' when it is undertaken by a sector that has a higher carbon-GVA intensity. We estimate carbon-GVA intensities for different sectors using data from UNCTAD (for gross value added) and IEA (for carbon emissions). The higher the carbon-GVA intensity of a specific sector compared to the carbon-GVA intensity of the total economy, the higher the degree of brownness. If a sector has a carbon-GVA intensity equal to the carbon-GVA intensity of the total economy, its degree of brownness is equal to 1. The degree of brownness (db_i) is thereby given by:[23]

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

[23] For simplicity, we assume that the degree of brownness of the government sector is equal to one, which means that its carbon-GVA intensity is equal to the average carbon-GVA intensity of the economy.

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.[24]

$$NL_{Gi}^{D} = I_{G(PRI)i}^{D} - sh_{(GVA)i}\beta_i RP + repL_{Gi-1} - \delta K_{G(PRI)i-1} - sh_{(GVA)i}\bar{p}_G \Delta b_G \quad (66)$$

$$NL_{Ci}^{D} = I_{C(PRI)i}^{D} - sh_{(GVA)i}(1-\beta_i)RP + repL_{Ci-1} - \delta K_{C(PRI)i-1} - sh_{(GVA)i}\bar{p}_C \Delta b_C \quad (67)$$

$$I_{G(PRI)i} = sh_{(GVA)i}\beta_i RP + \Delta L_{Gi} + \delta K_{G(PRI)i-1} + sh_{(GVA)i}\bar{p}_G \Delta b_G + defL_{Gi-1} \quad (68)$$

$$I_{C(PRI)i} = sh_{(GVA)i}(1-\beta_i)RP + \Delta L_{Ci} + \delta K_{C(PRI)i-1} + defL_{Ci-1} + sh_{(GVA)i}\bar{p}_C \Delta b_C \quad (69)$$

$$I_{C(PRI)S4} = RP + \Delta L_{Ci} + \Delta L_{Gi} + \delta K_{(PRI)-1} - I_{G(PRI)i} - I_{C(PRI)S1} - I_{C(PRI)S2} - I_{C(PRI)S3} + \bar{p}_G \Delta b_G + \bar{p}_C \Delta b_C + DL \quad (70)$$

$$I_{G(PRI)} = \sum I_{G(PRI)i} \quad (71)$$

$$I_{C(PRI)} = \sum I_{C(PRI)i} \quad (72)$$

$$I_{(PRI)} = I_{C(PRI)} + I_{G(PRI)} \quad (73)$$

$$L = L_C + L_G \quad (74)$$

$$K_{G(PRI)i} = K_{G(PRI)i-1} + I_{G(PRI)i} - \delta K_{G(PRI)i-1} \quad (75)$$

$$K_{C(PRI)i} = K_{C(PRI)i-1} + I_{C(PRI)i} - \delta K_{C(PRI)i-1} \quad (76)$$

$$K_{G(PRI)} = \sum K_{G(PRI)i} \quad (77)$$

$$K_{C(PRI)} = \sum K_{C(PRI)i} \quad (78)$$

$$K_{(PRI)} = K_{C(PRI)} + K_{G(PRI)} \quad (79)$$

$$\kappa = I_{G(PRI)} / I_{(PRI)} \quad (80)$$

$$K_B = \sum db_i K_{C(PRI)i} + db_{(GOV)} K_{C(GOV)} \quad (81)$$

Eq. (82) 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. 41); 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. 57).

24 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.

Eqs. (83) and (86) 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 $\sigma_0 + \sigma_1$ (see Eq. 84). These factors increase productivity growth (g_λ) 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_Y). 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. 42).

Eq. (87) gives the wage rate. The wage share (s_W) is assumed to be exogenous. The number of employees is determined by Eq. (88). The unemployment rate is defined in Eq. (89).

$$\delta = \delta_0 + (1-\delta_0)(1-ad_K)D_{TF-1} \quad (82)$$

$$v = v_{-1}[1-(1-ad_P)D_{TP-1}] \quad (83)$$

$$g_\lambda = \sigma_0 + \sigma_1 + \sigma_2 g_{Y-1} \quad (84)$$

$$\sigma_0 = \sigma_{0-1}(1-\zeta_4) \quad (85)$$

$$\lambda = \lambda_{-1}(1+g_\lambda)[1-(1-ad_P)D_{TP-1}] \quad (86)$$

$$w = s_W \lambda h \quad (87)$$

$$N = \frac{Y}{h\lambda} \quad (88)$$

$$ur = 1 - re \quad (89)$$

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. (90) and (91) show the proportion of firms' desired investment which is funded via conventional and green bonds respectively; x_1 is the proportion of firms' conventional desired investment financed via bonds, x_2 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

[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.

bonds. Eqs. (92)-(93) 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. (94) and (95) show that the growth rate of the proportion of firms' green desired investment funded via bonds (g_{x20}) increases with a declining rate ($g_{x20} > 0$ and $\zeta_5 > 0$). 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.

Eqs. (96) and (97) 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. (98) and (99). 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. (100) and (101) define the value of conventional bonds (B_C) and green bonds (B_G) respectively; B_{CH} is the value of conventional bonds held by households, B_{CCB} is the value of conventional bonds held by central banks, B_{GH} is the value of green bonds held by households and B_{GCB} is the value of green bonds held by central banks. We postulate a price-clearing mechanism in the bond market (see Eqs. 102 and 103). p_C is the market price of conventional bonds and p_G is the market price of green bonds. Eq. (104) shows the value of total bonds (B) that is equal to the value of conventional plus the value of green bonds.

$$b_C = b_{C-1} + \frac{x_1 \sum I^D_{C(PRI)i}}{\bar{p}_C} \tag{90}$$

$$b_G = b_{G-1} + \frac{x_2 \sum I^D_{G(PRI)i}}{\bar{p}_G} \tag{91}$$

$$x_1 = x_{10} - x_{11} yield_{C-1} \tag{92}$$

$$x_2 = x_{20} - x_{21} yield_{G-1} \tag{93}$$

$$x_{20} = x_{20-1}(1 + g_{x20}) \tag{94}$$

$$g_{x20} = g_{x20-1}(1 - \zeta_5) \tag{95}$$

$$yield_C = \frac{coupon_C}{p_C} \tag{96}$$

$$yield_G = \frac{coupon_G}{p_G} \tag{97}$$

$$coupon_C = yield_{C-1} \bar{p}_C \tag{98}$$

$$coupon_G = yield_{G-1}\bar{p}_G \quad (99)$$

$$B_C = B_{CH} + B_{CCB} \quad (100)$$

$$B_G = B_{GH} + B_{GCB} \quad (101)$$

$$p_C = \frac{B_C}{b_C} \quad (102)$$

$$p_G = \frac{B_G}{b_G} \quad (103)$$

$$B = B_C + B_G \quad (104)$$

Firms might default on their loans. When this happens, a part of their accumulated loans is not repaid, deteriorating the financial position of banks. The amount of defaulted loans (DL) is a proportion (def) of total loans of firms (see Eq. 105). The rate of default (def) is assumed to increase when firms become less liquid (see Eq. 106); def^{max} is the maximum default rate.[26] 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, $illiq$, which expresses the cash outflows of firms relative to their cash inflows (see Eq. 107). Cash outflows include wages, interest, taxes, 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 and the issuance of bonds. CR_{Ci} is the degree of credit rationing on the conventional loans of each sector and CR_G is the degree of credit rationing on green loans. Eq. (108) defines the debt service ratio (dsr), 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.

$$DL = defL_{-1} \quad (105)$$

$$def = \frac{def^{max}}{1 + def_0\, exp(def_1 - def_2 illiq_{-1})} \quad (106)$$

$$illiq = \frac{\sum(int_{Ci} + rep)L_{Ci-1} + \sum(int_G + rep)L_{Gi-1} + coupon_C b_{C-1} + coupon_G b_{G-1} + wN + T_F + T_C + \delta K_{(PRI)-1}}{Y + \sum(1 - CR_{Ci})NL^D_{Ci} + \sum(1 - CR_G)NL^D_{Gi} + \bar{p}_C \Delta b_C + \bar{p}_G \Delta b_G} \quad (107)$$

$$dsr = \frac{\sum(int_{Ci} + rep)L_{Ci-1} + \sum(int_G + rep)L_{Gi-1} + coupon_C b_{C-1} + coupon_G b_{G-1}}{TP + \sum int_{Ci} L_{Ci-1} + \sum int_G L_{Gi-1} + coupon_C b_{C-1} + coupon_G b_{G-1}} \quad (108)$$

[26] We use a logistic function, in similar lines with Caiani et al. (2016).

2.2.3 Households

Eq. (109) gives the gross disposable income of households (Y_{HG}); BP_D denotes the distributed profits of banks, int_D is the interest rate on deposits, D is the amount of deposits, int_S is the interest rate on government securities, SEC_H is the amount of government securities held by households, b_{CH} is the number of conventional corporate bonds held by households, b_{GH} is the number of green bonds held by households. Eq. (110) defines the net disposable income of households (Y_H), which is equal to the gross disposable income minus the taxes on households' gross disposable income (T_H). Households' consumption ($C_{(PRI)N}$), adjusted for climate damages, depends on lagged income (which is a proxy for the expected one) and lagged financial wealth (Eq. 111). However, Eq. (111) holds only when there are no supply-side constraints; in that case, $C_{(PRI)} = C_{(PRI)N}$). If the overall demand in the economy is higher than the supply-determined output, Y^*, consumption adjusts such that the overall demand in the economy is below Y^*; note that pr is slightly lower than 1. This is shown in Eq. (112).

$$Y_{HG} = wN + DP + BP_D + int_D\, D_{-1} + int_S\, SEC_{H-1} + coupon_C b_{CH-1} + coupon_G b_{GH-1} \quad (109)$$

$$Y_H = Y_{HG} - T_H \quad (110)$$

$$C_{(PRI)N} = \left(c_1 Y_{H-1} + c_2 V_{HF-1}\right)\left(1 - D_{T-1}\right) \quad (111)$$

$$C_{(PRI)} = C_{(PRI)N} \text{ if } C_{(PRI)N} + I_{(PRI)} + I_{(GOV)} + C_{(GOV)} < Y^*\text{; otherwise}$$

$$C_{(PRI)} = pr\left(Y^* - I_{(GOV)} - I_{(PRI)} - C_{(GOV)}\right) \quad (112)$$

Eq. (113) defines the financial wealth of households (V_{HF}). Households invest their expected financial wealth in four different assets: government securities (SEC_H), conventional corporate bonds (B_{CH}), green corporate bonds (B_{GH}) and deposits (D). In the portfolio choice, captured by Eqs. (114)-(117n), Godley's (1999) imperfect asset substitutability framework is adopted.[27]

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 and less risky assets (see also Batten et al., 2016). Since damages destroy capital and the profitability opportunities of firms, we assume that as D_T increases, households

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

reduce their holding of corporate conventional bonds and increase the proportion of their wealth held in deposits and government securities which are considered safer.[28] 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.[29]

Eqs. (118) and (119) show that the growth rate of households' portfolio choice parameter (λ_{30}) related to the autonomous demand for green bonds ($g_{\lambda 30}$) increases with a declining rate ($g_{\lambda 30} > 0$ and $\zeta_5 > 0$). This captures the fact that the preference for green bonds is expected to increase in the next years. Eq. (120) and (121) 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. 122).

$$V_{HF} = V_{HF-1} + Y_H - C_{(PRI)} + b_{CH-1}\Delta p_C + b_{GH-1}\Delta p_G \tag{113}$$

$$\frac{SEC_H}{V_{HF-1}} = \lambda_{10} + \lambda'_{10} D_{T-1} + \lambda_{11} int_S + \lambda_{12} yield_{C-1} + \lambda_{13} yield_{G-1} + \lambda_{14} int_D + \lambda_{15} \frac{Y_{H-1}}{V_{HF-1}} \tag{114}$$

$$\frac{B_{CH}}{V_{HF-1}} = \lambda_{20} + \lambda'_{20} D_{T-1} + \lambda_{21} int_S + \lambda_{22} yield_{C-1} + \lambda_{23} yield_{G-1} + \lambda_{24} int_D + \lambda_{25} \frac{Y_{H-1}}{V_{HF-1}} \tag{115}$$

$$\frac{B_{GH}}{V_{HF-1}} = \lambda_{30} + \lambda'_{30} D_{T-1} + \lambda_{31} int_S + \lambda_{32} yield_{C-1} + \lambda_{33} yield_{G-1} + \lambda_{34} int_D + \lambda_{35} \frac{Y_{H-1}}{V_{HF-1}} \tag{116}$$

$$\frac{D}{V_{HF-1}} = \lambda_{40} + \lambda'_{40} D_{T-1} + \lambda_{41} int_S + \lambda_{42} yield_{C-1} + \lambda_{43} yield_{G-1} + \lambda_{44} int_D + \lambda_{45} \frac{Y_{H-1}}{V_{HF-1}} \tag{117n}$$

$$D = D_{-1} + Y_H - C_{(PRI)} - \Delta SEC_H - \bar{p}_C \Delta b_{CH} - \bar{p}_G \Delta b_{GH} \tag{117}$$

$$\lambda_{30} = \lambda_{30-1}(1 + g_{\lambda 30}) \tag{118}$$

$$g_{\lambda 30} = g_{\lambda 30-1}(1 - \zeta_5) \tag{119}$$

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[28] 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 $\lambda'_{30} = 0$ in our simulations.

[29] Note that balance sheet restrictions require that Eq. (117n) must be replaced by Eq. (117) in the computer simulations.

$$b_{CH} = \frac{B_{CH}}{p_C} \tag{120}$$

$$b_{GH} = \frac{B_{GH}}{p_G} \tag{121}$$

$$DC = DC_{-1} + C - \xi DC_{-1} \tag{122}$$

Eqs. (123) and (124) show that the growth rate of population (g_{POP}) increases with a declining rate ($g_{POP} > 0$ and $\zeta_6 > 0$), reflecting the projections of United Nations (2017). As mentioned above, climate change reduces the ratio labour force to population ratio (Eq. 125). However, there are two additional factors that drive the change in labour force. First, in line with the population projections of United Nations (2017), there are some fundamental dynamics that influence fertility and mortality and tend to reduce the labour force to population ratio. This is reflected in the term lf_1 (see Eq. 126). 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 ($\zeta_7 > 0$).

$$g_{POP} = g_{POP-1}(1 - \zeta_6) \tag{123}$$

$$POP = POP_{-1}(1 + g_{POP}) \tag{124}$$

$$LF = (lf_1 - lf_2 hazratio_{-1})(1 - (1 - ad_{LF})D_{TF-1})POP \tag{125}$$

$$lf_1 = lf_{1-1}(1 - \zeta_7) \tag{126}$$

2.2.4 Commercial banks

The profits of banks (BP) 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. 127); SEC_B stands for the government securities that banks hold, int_A is the interest rate on advances and A is the advances. As shown in Eq. (128), the change in the capital of banks (CAP) is equal to their undistributed profits (BP_U) minus the amount of defaulted loans plus the amount of bailout of the government ($BAILOUT$). The undistributed profits of banks are a proportion (s_B) of total profits of banks (see Eq. 129). The distributed profits of banks are determined as the residual (see Eq. 130). According to Eqs. (131) and (132), high-powered money (HPM) 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. 133).[30]

$$BP = \sum int_{Ci} L_{Ci-1} + \sum int_G L_{Gi-1} + int_S SEC_{B-1} - int_D D_{-1} - int_A A_{-1} \quad (127)$$

$$CAP = CAP_{-1} + BP_U - DL + BAILOUT \quad (128)$$

$$BP_U = s_B BP_{-1} \quad (129)$$

$$BP_D = BP - BP_U \quad (130)$$

$$HPM = h_1 D \quad (131)$$

$$SEC_B = h_2 D \quad (132)$$

$$A = A_{-1} + \Delta HPM + \Delta L_G + \Delta L_C + \Delta SEC_B + DL - \Delta D - BP_U - BAILOUT \quad (133)$$

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) shows this proportion of demanded loans that are provided by banks (Eq. 134). 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., 2018).

Eq. (134) refers to total credit rationing on firm loans. 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. (135), (136), and (137); CR_{Ci} is the degree of credit rationing on conventional loans for each sector, CR_G is the degree of credit rationing on green loans, $sh_{(NLG)}$ is the share of desired green loans in total desired loans and $sh_{(NLC)i}$ is the share of desired conventional loans in total desired loans. When $w_{Ci} = w_{LT}$ and $w_G = w_{LT}$, the credit

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

rationing on green loans and conventional loans is the same with the total credit rationing. When $w_G < w_{LT}$, the credit rationing on green loans becomes lower than the total credit rationing and when $w_{Ci} > w_{LT}$, 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.

As in the case of investment, we assume that credit rationing is also dependent on a random component, ε_{CR}, that follows a stochastic AR(1) process; CR^{max} is the maximum degree of credit rationing.

The conventional loans and the green loans for each sector are defined in Eqs. (138) and (139). Eqs. (140) and (141) show the total conventional and green loans. Eq. (142) and (143) show the bank leverage ratio (lev_B) and the capital adequacy ratio of banks; w_S, w_G and w_{Ci} are the risk weights on 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 bailouts 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.

$$CR = \frac{CR^{max}}{1 + r_0 \, exp\left(r_1 - r_2 dsr_{-1} + r_3\left(CAR_{-1} - CAR^{min}\right)\right)} + \varepsilon_{CR} \quad (134)$$

$$CR_G = \left[1 + l_1\left(w_G - w_{LT}\right)\right]CR \quad (135)$$

$$CR_{Ci} = \left[1 + l_1\left(w_{Ci} - w_{LT}\right)\right]CR \quad (136)$$

$$CR_{CS4} = \frac{CR - sh_{(NLG)-1}CR_G - sh_{(NLC)S1-1}CR_{CS1} - sh_{(NLC)S2-1}CR_{CS2} - sh_{(NLC)S3-1}CR_{CS3}}{sh_{(NLC)S4-1}} \quad (137)$$

$$L_{Ci} = L_{Ci-1} + \left(1 - CR_{Ci}\right)NL_{Ci}^{D} - repL_{Ci-1} - defL_{Ci-1} \quad (138)$$

$$L_{Gi} = L_{Gi-1} + \left(1 - CR_G\right)NL_{Gi}^{D} - repL_{Gi-1} - defL_{Gi-1} \quad (139)$$

$$L_C = \sum L_{Ci} \quad (140)$$

$$L_G = \sum L_{Gi} \quad (141)$$

$$lev_B = \left(L_C + L_G + SEC_B + HPM\right)/CAP \quad (142)$$

$$CAR = CAP \Big/ \left[w_G L_G + \sum w_{Ci} L_{Ci} + w_S SEC_B \right] \tag{143}$$

The weight on total loans is shown in Eq. (144); $sh_{(LG)}$ is the share of green loans in total loans and $sh_{(LC)i}$ 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 base interest rate which is determined by central banks; spr_G is the lending spread on green loans and spr_{Ci} is the lending spread on conventional loans for each sector. The total lending spread (spr) depends on the capital adequacy ratio (see Eq. 147).[31] 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). 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. (148), (149) and (150).

$$w_{LT} = sh_{(LG)-1} w_G + \sum sh_{(LC)i-1} w_{Ci} \tag{144}$$

$$int_G = spr_G + int_A \tag{145}$$

$$int_{Ci} = spr_{Ci} + int_A \tag{146}$$

$$spr = spr_0 - spr_1 \left(CAR_{-1} - CAR^{min} \right) \tag{147}$$

$$spr_G = \left[1 + spr_2 \left(w_G - w_{LT} \right) \right] spr \tag{148}$$

$$spr_{Ci} = \left[1 + spr_2 \left(w_{Ci} - w_{LT} \right) \right] spr \tag{149}$$

$$spr_{CS4} = \frac{spr - sh_{(LG)-1} spr_G - sh_{(LC)S1-1} spr_{CS1} - sh_{(LC)S2-1} spr_{CS2} - sh_{(LC)S3-1} spr_{CS3}}{sh_{(LC)S4-1}} \tag{150}$$

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 receives from the central bank. Current government expenditures comprise government consumption, green subsidies and the interest paid on accumulated government securities. The current government balance (GB) is equal to revenues minus current expenditures (Eq. 151).

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[31] In our econometric estimations we found that the financial position of firms does not have a statistically significant impact on the lending spread.

The government sector issues securities (SEC) in order to finance its deficit. Government debt is therefore equal to the accumulated amount of securities. The change in securities equals investment spending ($I_{(GOV)}$) (adjusted for depreciation) minus the current balance (Eq. 152). Government investment includes both green investment ($I_{G(GOV)}$) and conventional investment ($I_{C(GOV)}$), which are determined as an exogenous proportion of GDP, gov_{IG} and gov_{IC}, respectively (see Eqs. 153 and 154). Total government investment is the sum of green and conventional investment (see Eq. 155). Eqs. (156) and (157) are the law of motion of green capital and conventional capital. The capital of the government sector is given by Eq. (158). Total capital stock is the sum of the private and government capital stock (see Eq. 159). Eqs. (160) and (161) show the total conventional and green capital; $K_{G(GOV)}$ is green government capital, $K_{C(GOV)}$ is conventional government capital, $K_{(GOV)}$ is total capital of the government, K_G is green total capital, K_C is conventional total capital, SUB are the green subsidies of the government and CBP are the profits of the central bank.

Government consumption expenditures are also set exogenously as a fraction, gov_C, of GDP (Eq. 162). Subsidies are a proportion (gov_{SUB}) of green private investment (see Eq. 163). The taxes on households' disposable income are a proportion (τ_H) of the gross disposable income (Eq. 164), the taxes on firms' profits are a proportion (τ_F) of total gross profits (see Eq. 165) and the carbon taxes are a proportion (τ_C) of industrial carbon emissions (Eq. 166). This proportion increases with an exogenous growth rate ($g_{\tau C}$) (Eq. 167). The total taxes are equal to the sum of taxes on households, the taxes on firms and the carbon taxes (Eq. 168).

$$GB = -C_{(GOV)} - SUB + T - int_S\, SEC_{-1} + CBP - BAILOUT - \delta K_{(GOV)-1} \quad (151)$$

$$SEC = SEC_{-1} + I_{(GOV)} - GB - \delta K_{(GOV)-1} \quad (152)$$

$$I_{G(GOV)} = gov_{IG} Y_{-1} \quad (153)$$

$$I_{C(GOV)} = gov_{IC} Y_{-1} \quad (154)$$

$$I_{(GOV)} = I_{G(GOV)} + I_{C(GOV)} \quad (155)$$

$$K_{G(GOV)} = K_{G(GOV)-1} + I_{G(GOV)} - \delta K_{G(GOV)-1} \quad (156)$$

$$K_{C(GOV)} = K_{C(GOV)-1} + I_{C(GOV)} - \delta K_{C(GOV)-1} \quad (157)$$

$$K_{(GOV)} = K_{C(GOV)} + K_{G(GOV)} \quad (158)$$

$$K = K_{(PRI)} + K_{(GOV)} \tag{159}$$

$$K_C = K_{C(PRI)} + K_{C(GOV)} \tag{160}$$

$$K_G = K_{G(PRI)} + K_{G(GOV)} \tag{161}$$

$$C_{(GOV)} = gov_C Y_{-1} \tag{162}$$

$$SUB = gov_{SUB} I_{G(PRI)-1} \tag{163}$$

$$T_H = \tau_H Y_{HG-1} \tag{164}$$

$$T_F = \tau_F TP_{G-1} \tag{165}$$

$$T_C = \tau_C EMIS_{IN-1} \tag{166}$$

$$\tau_C = \tau_{C-1}(1 + g_{\tau C}) \tag{167}$$

$$T = T_H + T_F + T_C \tag{168}$$

2.2.6 Central banks

Central banks determine the base interest rate, provide liquidity to commercial 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.[32] Currently, central banks do not 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 purchases.

Nonetheless, the implementation of a green QE programme should not be viewed as a simple extension of the current corporate sector purchase programme of central banks. The current corporate QE programmes have as an aim to improve credit conditions in order to help central banks achieve their inflation targets and they are meant to be of temporary nature. On the contrary, a green QE would be a kind of industrial policy with a much longer-term commitment. Hence, the decision of central banks to conduct such a programme would

[32] 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 commercial 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 commercial 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 base interest rate, for example because there is a floor system in place (for the role of these systems in central bank interest rate setting, see Lavoie, 2014, ch. 4).

require a re-consideration of their mandate or a different interpretation of their role in ensuring financial stability in economies that might face increasing climate-related financial risks. This is especially the case for the central banks of high-income countries, which have a narrower focus on price stability in comparison with the central banks of low-income countries (see Campiglio et al., 2018).

The profits of the central bank are defined in Eq. (169); b_{CCB} is the number of conventional corporate bonds held by central banks, b_{GCB} is the number of green bonds held by central banks and SEC_{CB} are the government securities held by central banks.

The value of green corporate bonds held by central banks (B_{GCB}) is a share (s_G) of total outstanding green bonds (see Eq. 170). We assume that this share is currently equal to zero since central banks do not implement green QE programmes. The value of conventional corporate bonds held by central banks (B_{CCB}) is a share (s_C) of total outstanding conventional bonds (see Eq. 171). Currently, this share is very low since the corporate bond purchases of central banks represent a very small proportion of the total bond market.

Eqs. (172) and (173) define the number of conventional corporate bonds held by central banks and the number of green bonds held by central banks respectively. Eq. (174) shows the government securities held by central banks. Eq. (175-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.

$$CBP = coupon_C b_{CCB-1} + coupon_G b_{GCB-1} + int_A A_{-1} + int_S SEC_{CB-1} \quad (169)$$

$$B_{GCB} = s_G B_{G-1} \quad (170)$$

$$B_{CCB} = s_C B_{C-1} \quad (171)$$

$$b_{CCB} = \frac{B_{CCB}}{p_C} \quad (172)$$

$$b_{GCB} = \frac{B_{GCB}}{p_G} \quad (173)$$

$$SEC_{CB} = SEC - SEC_H - SEC_B \quad (174)$$

$$SEC_{CB} = SEC_{CB-1} + \Delta HPM - \Delta A - \bar{p}_C \Delta b_{CCB} - \bar{p}_G \Delta b_{GGB} \quad (175\text{-red})$$

3. Baseline scenario

In our baseline scenario the global economy continues to expand in broad line with recent trends and ecological efficiency improves slowly, due to green technical progress and some moderate mitigation action. This action is not enough to avoid a significant rise in atmospheric temperature by the end of this century.

The key features of the baseline scenario are shown in Table 5. The economy grows on average at a rate close to 2.5% till 2050; in other words, we postulate an economic expansion a little bit slower than the one observed over the last two decades or so.[33] Crucially, economic growth has a declining trend, partially because of demographic changes. The unemployment rate remains, on average, slightly lower than 6% till 2050. Drawing on the United Nations (2017) population projections (medium fertility variant), the population is assumed to grow at a declining rate, becoming equal to around 9.77bn people in 2050. Moreover, the default rate on corporate loans is assumed to remain, on average, close to its current level, which is slightly higher than 4%.

Table 5: Key features of the baseline scenario

Variable	Value/trend
Economic growth till 2050	approximately 2.5% (on average)
Unemployment rate till 2050	slightly lower than 6% (on average)
Population in 2050	9.77 billion
Labour force-to-population ratio in 2050	0.45
Default rate on corporate loans till 2050	slightly higher than 4% (on average)
Carbon tax	Increases by 3% per year
Green public investment	Remains stable as a proportion of GDP
Green subsidies	Remain stable as a proportion of green investment
CO_2 intensity in 2050 as a ratio of CO_2 intensity in 2017	around 0.9
Share of renewable energy in total energy in 2050	around 25%
Energy intensity in 2050 as a ratio of energy intensity in 2017	around 0.7
Annual green investment in the period 2017-2050	around US$ 1.5 trillion
Yield of conventional bonds	quite stable till around 2050
Yield of green bonds	declines slightly in the next decade or so

In terms of environmental policies, the carbon tax is assumed to increase by 3% per year. The subsidy rate on green investment remains the same. Green public investment increases, but remains constant as a proportion of GDP. It is implicitly assumed that environmental regulation becomes gradually stricter, contributing to the moderate rise in green investment as

33 Based on data from World Bank.

a proportion of conventional investment. Overall, annual green investment during the period 2017-2050 is equal to around US$ 1.5 trillion.[34]

The accumulation of green capital leads to an improvement in ecological efficiency indicators. The share of renewable energy increases to about 25% till 2050 (from about 14% which is the current level), while energy intensity is assumed to become approximately 30% lower in 2050 compared to its 2017 level. Material intensity and recycling rate also improve. CO_2 intensity (which captures the industrial emissions per unit of fossil-fuel energy) declines by 10% till 2050, for example due to the continuation in the replacement of coal with gas and the use of carbon capture and storage technologies.[35]

We also assume that the yield on conventional bonds remains relatively stable till 2050, while the yield of green bonds improves in the next decade or so. The latter is a result of an increasing demand for green bonds that outstrips their supply, in line with recent trends (see, Climate Bonds Initiative, 2017b, 2018a, 2018b).

[34] Note that in the reference scenario of IRENA (2018, p. 41) the annual investment in renewables and energy efficiency over the period 2015-2050 is close to US$ 1.3 trillion. Recall that green investment in our model does not only include investment in renewables and energy efficiency: it also includes investment that improves material intensity and the recycling rate.

[35] For the importance of these factors in the determination of CO_2 intensity, see e.g. Peters et al. (2017).

4. Symbols and values

Table 6: Symbols and initial values for endogenous variables (baseline scenario)

Symbol	Description	Value	Remarks/sources
A	Advances (trillion US$)	9.0	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 (trillion US$)	12.0	Based on McKinsey (2018, p. 7)
$BAILOUT$	Bailout funds provided to the banking system from the government sector	0	No bailout is assumed in 2017 since $lev_B<lev_B^{max}$ and $CAR>CAR^{min}$
B_C	Value of conventional corporate bonds (trillion US$)	11.8	Calculated from Eq. (104) using the initial values of B and B_G
b_C	Number of conventional corporate bonds (trillions)	0.118	Calculated from Eq. (102) using the initial values of p_C and B_C
B_{CCB}	Value of conventional corporate bonds held by central banks (trillion US$)	0.1	Based on the recent holdings of central banks as part of their corporate sector purchase
b_{CCB}	Number of conventional corporate bonds held by central banks (trillions)	0.001	Calculated from Eq. (172) using the initial values of p_C and B_{CCB}
B_{CH}	Value of conventional corporate bonds held by households (trillion US$)	11.7	Calculated from Eq. (100) using the initial values of B_{CCB} and B_C
b_{CH}	Number of conventional corporate bonds held by households (trillions)	0.1	Calculated from Eq. (120) using the initial values of p_C and B_{CH}
B_G	Value of green corporate bonds (trillion US$)	0.25	Based on Climate Bonds Initiative (2017a); we use the value of the climate-alligned bonds that has been issued by the financial and the non-financial corporate sector
b_G	Number of green corporate bonds (trillions)	0.003	Calculated from Eq. (103) using the initial values of p_G and B_G
B_{GCB}	Value of green corporate bonds held by central banks (trillion US$)	0	There was no green QE programme in 2017
b_{GCB}	Number of green corporate bonds held by central banks (trillions)	0	Calculated from Eq. (173) using the initial values of p_G and B_{GCB}
B_{GH}	Value of green corporate bonds held by households (trillion US$)	0.25	Calculated from Eq. (101) using the initial values of B_G and B_{GCB}
b_{GH}	Number of green corporate bonds held by households (trillions)	0.0025	Calculated from Eq. (121) using the initial values of p_G and B_{GH}
BP	Profits of banks (trillion US$)	3.30	Calculated from Eq. (127) using the initial values of int_G, int_G, L_G, L_{Gi}, SEC_B, D and A
BP_D	Distributed profits of banks (trillion US$)	0.54	Calculated from Eq. (130) using the initial values of BP and BP_U
BP_U	Retained profits of banks (trillion US$)	2.76	Calculated from Eq. (129) using the initial value of BP
$C_{(GOV)}$	Government expenditures (trillion US$)	13.4	Calculated from Eq. (162) using the initial value of Y
$C_{(PRI)}$	Consumption (trillion US$)	48.8	No supply-side constraints are assumed in 2017 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 (trillion US$)	48.8	Calculated from Eq. (44) using the initial values of Y, $C_{(GOV)}$, $I_{(PRI)}$ and $I_{(GOV)}$ (since
CAP	Capital of banks (trillion US$)	9.5	Calculated from Eq. (142) using the initial values of lev_B, L_C, L_G, SEC_B and HPM
CAR	Capital adequacy ratio	0.1	Calculated from Eq. (143) using the initial values of CAP, L_C, L_G and SEC_B
CBP	Central banks' profits (trillion US$)	0.4	Calculated from Eq. (169) using the initial values of $coupon_C$, b_{CCB}, $coupon_G$, b_{GCB}, A and
CEN	Carbon mass of the non-renewable energy sources (Gt)	9.9	Calculated from Eq. (7) using the initial value of $EMIS_{IN}$
$CO2_{AT}$	Atmospheric CO_2 concentration ($GtCO_2$)	3164	Taken from NOAA/ESRL (National Oceanic & Atmospheric Administration/Earth System Research Laboratory)
$CO2_{LO}$	Lower ocean CO_2 concentration ($GtCO_2$)	6380.6	Based on the DICE-2016R2 model (Nordhaus, 2018); GtC have been transformed into
$CO2_{UP}$	Upper ocean/biosphere CO_2 concentration ($GtCO_2$)	1694.2	Based on the DICE-2016R2 model (Nordhaus, 2018); GtC have been transformed into
CON_E	Amount of non-renewable energy resources converted into non-renewable	1652.1	Calculated from Eq. (20) using the initial value of RES_E
CON_M	Amount of material resources converted into material reserves (Gt)	253	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. (98) using the initial values of p_C and $yield_C$
$coupon_G$	Fixed coupon paid per green corporate bond (US$)	5	Calculated from Eq. (99) using the initial values of p_G and $yield_G$
CR	Degree of total credit rationing on loans	0.2	Calculated from Eq. (134) using the initial values of dsr and CAR
CR_{CS1}	Degree of credit rationing on conventional loans of the 'mining and utilities'	0.2	Calculated from Eq. (136) using the initial values of w_{LT} and CR
CR_{CS2}	Degree of credit rationing on conventional loans of the 'manufacturing and	0.2	Calculated from Eq. (136) using the initial values of w_{LT} and CR
CR_{CS3}	Degree of credit rationing on conventional loans of the 'transport' sector	0.2	Calculated from Eq. (136) using the initial values of w_{LT} and CR
CR_{CS4}	Degree of credit rationing on conventional loans of the 'other sectors'	0.2	Calculated from Eq. (137) using the initial values of sh_{NLG}, sh_{NLG}, CR, CR_G, CR_{CS1}, CR_{CS2} and CR_{CS3}
CR_G	Degree of credit rationing on green loans	0.2	Calculated from Eq. (135) using the initial values of w_{LT} and CR
D	Deposits (trillion US$)	70.0	Based on Allianz (2017)
DC	Stock of durable consumption goods (trillion US$)	1545	Calculated from Eq. (4) using the initial values of K, DEM, δ and μ
def	Rate of default	0.040	Based on World Bank
DEM	Demolished/discarded socio-economic stock (Gt)	17.0	Taken from Wiedenhofer et al (2019); the figure refers to EoL waste from stocks
dep_E	Energy depletion ratio	0.013	Calculated from Eq. (22) using the initial values of EN and REV_E
dep_M	Matter depletion ratio	0.020	Based on World Bank (2017)
DL	Amount of defaulted loans (trillion US$)	2.5	Calculated from Eq. (105) using the initial values of L and def
DP	Distributed profits of firms (trillion US$)	19.3	Calculated from Eq. (55) using the initial values of TP and RP
dsr	Debt service ratio of firms	0.47	Calculated from Eq. (108) using the initial values of int_G, int_G, L_G, L_{Gi}, $coupon_C$, b_C, $coupon_G$, b_G and TP
D_T	Total proportional damage caused by climate change	0.0035	Calculated from Eq. (49) using the initial value of T_{AT}
D_{TF}	Part of damage that affects directly the fund-service resources	0.0031	Calculated from Eq. (51) using the initial values of D_T and D_{TP}
D_{TP}	Part of damage that reduces the productivities of fund-service resources	0.0003	Calculated from Eq. (50) using the initial value of D_T
E	Energy used for the production of output (EJ)	580.0	Based on IEA (International Energy Agency); total primary energy supply is used
ED	Dissipated energy (EJ)	580.0	Calculated from Eq. (18) using the initial values of EN and ER
$EMIS$	Total CO_2 emissions ($GtCO_2$)	38.7	Calculated from Eq. (25) using the initial values of $EMIS_{IN}$ and $EMIS_L$
$EMIS_{IN}$	Industrial CO_2 emissions ($GtCO_2$)	36.2	Taken from CDIAC (Carbon Dioxide Information Analysis Center)
$EMIS_L$	Land-use CO_2 emissions ($GtCO_2$)	2.5	Taken from the DICE-2016R2 model (Nordhaus, 2018)
EN	Energy produced from non-renewable sources (EJ)	498.8	Calculated from Eq. (17) using the initial values of E and ER
ER	Energy produced from renewable sources (EJ)	81.2	Calculated from Eq. (16) using the initial values of θ and E

(continued from the previous page)

Symbol	Description	Value	Remarks/sources
F	Radiative forcing over pre-industrial levels (W/m^2)	2.55	Calculated from Eq. (29) using the initial values of $CO2_{AT}$ and F_{EX}
F_{EX}	Radiative forcing, over pre-industrial levels, due to non-CO_2 greenhouse gases	0.51	Based on the DICE-2016R2 model (Nordhaus, 2018)
GB	Government balance (trillion US$)	3.4	Calculated from Eq. (151) using the initial values of $C_{(GOV)}$, SUB, T, SEC, CBP, $BAILOUT$, δ and $K_{(GOV)}$
g_{POP}	Growth rate of population	0.012	Taken from United Nations (medium fertility variant)
g_{RC}	Growth rate of the cost of green capital compared to conventional capital	0.010	Calibrated such that the model generates the baseline scenario
g_{x20}	Growth rate of the autonomous proportion of desired green investment	0.040	Calibrated such that the model generates the baseline scenario
g_Y	Growth rate of output	0.031	Based on World Bank
$g_{\beta 0}$	Growth rate of the autonomous share of green investment in total investment	0.0003	Calibrated such that the model generates the baseline scenario
g_λ	Growth rate of labour productivity	0.019	Calculated from Eq. (84) using the initial values of g_Y and σ_0
$g_{\lambda 30}$	Growth rate of the households' portfolio choice parameter related to the	0.040	Calibrated such that the model generates the baseline scenario
g_ω	Growth rate of CO_2 intensity	-0.003	Calibrated such that the model generates the baseline scenario
hazratio	Hazardous waste accumulation ratio (tonnes per person)	1.87	Calculated from Eq. (10) using the initial values of HWS and POP
HPM	High-powered money (trillion US$)	14.00	Calculated from Eq. (131) using the initial value of D
HWS	Stock of hazardous waste (Gt)	14.1	Calculated assuming a constant ratio of hazardous waste to GDP since 1960
$I_{(GOV)}$	Investment of the government sector (trillion US$)	5.20	Calculated from the identity $I_{(GOV)}$=(1-*prop*)*(I/Y)*Y where *prop* is the proportion of private investment in total investment (based on data from IMF), and I/Y is the proportion of total investment in GDP (taken from World Bank)
$I_{(PRI)}$	Investment of the private sector (trillion US$)	13.36	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) and I/Y is the proportion of total investment in GDP (taken from World Bank)
$I_{C(GOV)}$	Conventional investment of the government sector (trillion US$)	5.00	Calculated from Eq. (155) using the initial values of $I_{(GOV)}$ and $I_{G(GOV)}$
$I_{C(PRI)}$	Conventional investment of the private sector (trillion US$)	12.86	Calculated from Eq. (73) using the initial values of $I_{(PRI)}$ and $I_{G(PRI)}$
$I_{C(PRI)S1}$	Conventional investment of the 'mining and utilities' sector (trillion US$)	1.20	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 (trillion	2.46	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 (trillion US$)	1.14	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 (trillion US$)	8.07	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 $I_{G(PRI)S4}$
$I_{G(GOV)}$	Green investment of the government sector (trillion US$)	0.196	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 (2018); we use a higher value than the one reported in CPI (2018) 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 (trillion US$)	0.5	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 (2018); we use a higher value than the one reported in CPI (2018) 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 (trillion US$)	0.2	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 (trillion US$)	0.04	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 (trillion US$)	0.09	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' (trillion US$)	0.13	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 (trillion US$)	16.1	Calibrated such that the model generates the baseline scenario
$I^D_{(PRI)S1}$	Desired total investment of the 'mining and utilities' sector (trillion US$)	1.7	Calculated from the identity $I^D_{(PRI)S1}=sh_{(GVA)S1}*I^D_{(PRI)}$; we use the initial value of $I^D_{(PRI)}$
$I^D_{(PRI)S2}$	Desired total investment of the 'manufacturing and construction' sector (trillion US$)	3.02	Calculated from the identity $I^D_{(PRI)S2}=sh_{(GVA)S2}*I^D_{(PRI)}$; we use the initial value of $I^D_{(PRI)}$
$I^D_{(PRI)S3}$	Desired total investment of the 'transport' sector (trillion US$)	1.49	Calculated from the identity $I^D_{(PRI)S3}=sh_{(GVA)S3}*I^D_{(PRI)}$; we use the initial value of $I^D_{(PRI)}$
$I^D_{(PRI)S4}$	Desired total investment of the 'other sectors' (trillion US$)	9.91	Calculated from the identity $I^D_{(PRI)S4}=sh_{(GVA)S4}*I^D_{(PRI)}$; we use the initial value of $I^D_{(PRI)}$
$I^D_{C(PRI)S1}$	Desired conventional investment of the 'mining and utilities' sector (trillion US$)	1.45	Calculated from the identity $I^D_{C(PRI)S1}=I^D_{(PRI)S1}-I^D_{G(PRI)S1}$; we use 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 (trillion US$)	3.0	Calculated from the identity $I^D_{C(PRI)S2}=I^D_{(PRI)S2}-I^D_{G(PRI)S2}$; we use 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 (trillion US$)	1.38	Calculated from the identity $I^D_{C(PRI)S3}=I^D_{(PRI)S3}-I^D_{G(PRI)S3}$; we use 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' (trillion US$)	9.75	Calculated from the identity $I^D_{C(PRI)S4}=I^D_{(PRI)S4}-I^D_{G(PRI)S4}$; we use 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 (trillion US$)	0.29	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	0.05	Calculated such that it is reasonably higher than $I_{G(PRI)S2}$
$I^D_{G(PRI)S3}$	Desired green investment of the 'transport' sector (trillion US$)	0.11	Calculated such that it is reasonably higher than $I_{G(PRI)S3}$
$I^D_{G(PRI)S4}$	Desired green investment of the 'other sectors' (trillion US$)	0.16	Calculated such that it is reasonably higher than $I_{G(PRI)S4}$
illiq	Illiquidity ratio	0.74	Calculated from Eq. (107) using the initial values of int_G, int_G, L_{Ci}, L_{Gi}, $coupon_C$, b_C, $coupon_G$, b_G, w, N, T_F, T_C, δ, $K_{(PRI)}$, Y, CR_G, NL_G^D, CR_G and NL_{Gi}^D
int_{CS1}	Interest rate on conventional loans of the 'mining and utilities' sector	0.08	Calculated from Eq. (146) using the initial value of spr_{CS1}
int_{CS2}	Interest rate on conventional loans of the 'manufacturing and construction' secto	0.08	Calculated from Eq. (146) using the initial value of spr_{CS2}
int_{CS3}	Interest rate on conventional loans of the 'transport' sector	0.08	Calculated from Eq. (146) using the initial value of spr_{CS3}
int_{CS4}	Interest rate on conventional loans of the 'other sectors'	0.08	Calculated from Eq. (146) using the initial value of spr_{CS4}
int_G	Interest rate on green loans	0.08	Calculated from Eq. (145) using the initial value of spr_G
K	Total capital stock	254.2	Calculated by using the initial value of Y and a capital-to-output equal to 3.15; the latter has been selected such that the model generates the baseline scenario

(continued from the previous page)

Symbol	Description	Value	Remarks/sources
K_B	Brown-weighted conventional capital	245.2	Calculated from Eq. (81) using the initial values of $K_{C(PRI)i}$ and $K_{C(GOV)}$
$K_{(GOV)}$	Capital stock of the government	71.2	Calculated from the identity $K_{(GOV)}=(1\text{-}prop)*K$ where *prop* is the proportion of private investment in total investment (based on data from IMF)
$K_{(PRI)}$	Capital stock of firms (trillion US$)	183.0	Calculated from the identity $K_{(PRI)}=prop*K$ where *prop* is the proportion of private investment in total investment (based on data from IMF)
K_C	Conventional capital stock (trillion US$)	244.6	Calculated from Eq. (160) using the initial values of $K_{C(PRI)}$ and $K_{C(GOV)}$
$K_{C(GOV)}$	Conventional capital stock of the government sector (trillion US$)	68.5	Calculated from Eq. (158) using the initial values of $K_{(GOV)}$ and $K_{G(GOV)}$
$K_{C(PRI)}$	Conventional capital stock of firms (trillion US$)	176.1	Calculated from Eq. (79) using the initial values of $K_{(PRI)}$ and $K_{G(PRI)}$
$K_{C(PRI)S1}$	Conventional capital stock of the 'mining and utilities' sector (trillion US$)	18.9	Calculated from the identity $K_{C(PRI)S1}=sh_{(GVA)S1}*K_{C(PRI)}$; we use the initial value of $K_{C(PRI)}$
$K_{C(PRI)S2}$	Conventional capital stock of the 'manufacturing and construction' sector	32.9	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 (trillion US$)	16.2	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' (trillion US$)	108.1	Calculated from the identity $K_{C(PRI)S4}=sh_{(GVA)S4}*K_{C(PRI)}$; we use the initial value of $K_{C(PRI)}$
K_G	Green capital stock (trillion US$)	9.6	Calculated from Eq. (161) using the initial values of $K_{G(PRI)}$ and $K_{G(GOV)}$
$K_{G(GOV)}$	Green capital stock of the government sector (trillion US$)	2.7	Calibrated such that the model generates the baseline scenario
$K_{G(PRI)}$	Green capital stock of firms (trillion US$)	6.9	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 (trillion US$)	3.3	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 (trillion US$)	0.6	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 (trillion US$)	1.3	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' (trillion US$)	1.8	Calculated from the identity $K_{G(PRI)S4}=sh_{(GREEN)S4}*K_{G(PRI)}$; we use the initial value of $K_{G(PRI)}$
L	Total loans of firms (trillion US$)	64.4	Calculated from the identity $L=(credit\text{-}B/Y)*Y$; *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 (trillion US$)	62.0	Calculated from Eq. (74) using the initial values of L and L_G
L_{CS1}	Conventional loans of the 'mining and utilities' sector (trillion US$)	6.7	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 (trillion US$)	11.6	Calculated from the identity $L_{CS2}=sh_{(GVA)S2}*L_C$; we use the initial value of L_C
L_{CS3}	Conventional loans of the 'transport' sector (trillion US$)	5.7	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' (trillion US$)	38.0	Calculated from the identity $L_{CS4}=sh_{(GVA)S4}*L_C$; we use the initial value of L_C
L_G	Green loans (trillion US$)	2.4	Calculated by assuming that $L_G/L=K_{G(PRI)}/K_{(PRI)}=\varkappa$; we use the initial values of $\varkappa$ and L
L_{GS1}	Green loans of the 'mining and utilities' sector (trillion US$)	0.3	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 (trillion US$)	0.5	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 (trillion US$)	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' (trillion US$)	1.5	Calculated from the identity $L_{GS4}=sh_{(GVA)S4}*L_G$; we use the initial value of L_G
lev_B	Banks' leverage ratio	9.3	Taken from World Bank
LF	Labour force (billion people)	3.45	Taken from World Bank
lf_1	Autonomous labour force-to-population ratio	0.46	Calculated from Eq. (125) using the initial values of LF, POP, *hazratio* and D_{TF}
M	Extraction of new matter from the ground, excluding the matter included in non-renewable energy sources (Gt)	52.1	Taken from Wiedenhofer et al. (2019); the figure refers to primary plus secondary stock-building inputs
MY	Output in material terms (Gt)	56.7	Calculated from Eq. (2) using the initial values of M and REC
N	Number of employees (billion people)	3.3	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 (trillion US$)	1.14	Calculated from Eq. (67) using the initial values of $I_{CS1}{}^D$, β_{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 (trillion US$)	2.42	Calculated from Eq. (67) using the initial values of $I_{CS2}{}^D$, β_{S2}, RP, L_{CS2}, δ, K_{CS2} and b_C
$NL_{CS3}{}^D$	Desired new amount of conventional loans of the 'transport' sector (trillion	1.11	Calculated from Eq. (67) using the initial values of $I_{CS3}{}^D$, β_{S3}, RP, L_{CS3}, δ, K_{CS3} and b_C
$NL_{CS4}{}^D$	Desired new amount of conventional loans of the 'other sectors' (trillion US$)	7.94	Calculated from Eq. (67) using the initial values of $I_{CS4}{}^D$, β_{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 (trillion	0.15	Calculated from Eq. (66) using the initial values of $I_{GS1}{}^D$, β_{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 (trillion US$)	0.06	Calculated from Eq. (66) using the initial values of $I_{GS2}{}^D$, β_{S2}, RP, L_{GS2}, δ, K_{GS2} and b_G
$NL_{GS3}{}^D$	Desired new amount of green loans of the 'transport' sector (trillion US$)	0.07	Calculated from Eq. (66) using the initial values of $I_{GS3}{}^D$, β_{S3}, RP, L_{GS3}, δ, K_{GS3} and b_G
$NL_{GS4}{}^D$	Desired new amount of green loans of the 'other sectors' (trillion US$)	0.21	Calculated from Eq. (66) using the initial values of $I_{GS4}{}^D$, β_{S4}, RP, L_{GS4}, δ, K_{GS4} and b_G
$O2$	Oxygen used for the combustion of fossil fuels (Gt)	26.3	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$100 (the par value of bonds) in
p_G	Market price of green corporate bonds (US$)	100	The price has been normalised such that it is equal to US$100 (the par value of bonds) in
POP	Population (billions)	7.55	Taken from United Nations (2017) (medium fertility variant)
r	Rate of total profits	0.107	Calculated from Eq. (56) using the initial values of TP and $K_{(PRI)}$
RC	Relative cost	1.050	Selected from a reasonable range of values
re	Rate of employment	0.95	Calculated from Eq. (89) using the initial value of ur
REC	Recycled socio-economic stock (Gt)	4.6	Taken from Wiedenhofer et al (2019); the figure refers to end-of-life waste from stocks minus final waste, after recycling
RES_E	Non-renewable energy resources (EJ)	550690	Taken from BGR (2017, p. 41)
RES_M	Material resources (Gt)	168875	Calculated by assuming RES_M/REV_M=64.8 (based on UNEP, 2011)
REV_E	Non-renewable energy reserves (EJ)	39530	Taken from BGR (2017, p. 41)
REV_M	Material reserves (Gt)	2606	Calculated from Eq. (14) using the initial values of M and dep_M
RP	Retained profits of firms (trillion US$)	0.3	Calculated from Eq. (54) using the initial value of TP
SEC	Total amount of government securities	67.1	Calculated from the identity *general government debt-to-GDP*$=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 (trillion US$)	10.1	Calculated by assuming that SEC_B/SEC=0.15 based on Alli Abbas et al. (2014)
SEC_{CB}	Government securities held by central banks (trillion US$)	4.9	Calculated from the identity $SEC_{CB}=HPM+V_{CB}\text{-}\bar{p}_C b_{CCB}\text{-}\bar{p}_G b_{GCB}\text{-}A$ using the initial values of V_{CB}, b_{CCB}, b_{GCB}, A and HPM

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Symbol	Description	Value	Remarks/sources
SEC_H	Government securities held by households (trillion US$)	52.1	Calculated from Eq. (174) using the initial values of SEC, SEC_{CB} and SEC_B
SES	Socio-economic stock (Gt)	1514.0	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	0.08	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	0.18	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	0.08	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	0.84	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	0.10	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'	0.18	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'	0.59	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	0.04	Calculated from the formula $sh_{(LG)}=L_G/L$ using the initial values of L and L_G
spr	Spread on total loans	0.05	Based on World Bank
spr_G	Spread on green loans	0.05	Calculated from Eq. (148) using the initial values of w_{LT} and spr
spr_{CS1}	Spread on conventional loans of the 'mining and utilities' sector	0.05	Calculated from Eq. (149) using the initial values of w_{LT} and spr
spr_{CS2}	Spread on conventional loans of the 'manufacturing and construction' sector	0.05	Calculated from Eq. (149) using the initial values of w_{LT} and spr
spr_{CS3}	Spread on conventional loans of the 'transport' sector	0.05	Calculated from Eq. (149) using the initial values of w_{LT} and spr
spr_{CS4}	Spread on conventional loans of the 'other sectors'	0.05	Calculated from Eq. (150) using the initial values of sh_{LG}, spr, spr_G and spr_{CS1}, spr_{CS2} and spr_{CS3}
SUB	Green government subsidies	0.14	Based on IEA
T	Total taxes (trillion US$)	18.2	Calculated from Eq. (168) using the initial values of T_H, T_F and T_C
T_{AT}	Atmospheric temperature over pre-industrial levels (^oC)	1.10	Based on Met Office
T_C	Carbon tax	0.033	Based on World Bank (2018)
T_F	Taxes on firms' profits (trillion US$)	3.4	Calculated from Eq. (165) using the initial value of TP_G
T_H	Taxes on households' disposable income	14.8	Calculated from Eq. (164) using the initial value Y_{HG}
T_{LO}	Lower ocean temperature over pre-industrial levels (^oC)	0.0112	Based on the DICE-2016R2 model (Nordhaus, 2018)
TP	Total profits of firms (trillion US$)	19.6	Calculated from Eq. (53) using the initial values of TP_G, T_F and T_C
TP_G	Total gross profits of firms (trillion US$)	23.0	Calculated from Eq. (52) using the initial values of Y, w, N, L_G, L_{Gi}, int_C, int_G, δ, $K_{(PRI)}$, $coupon_C$, b_C, $coupon_G$ and b_G
u	Rate of capacity utilisation	0.72	Based on World Bank, Enterprise Surveys
ue	Rate of energy utilisation	0.01	Calculated from Eq. (46) using the initial values of Y and Y_E^*
um	Rate of matter utilisation	0.02	Calculated from Eq. (45) using the initial values of Y, $C_{(GOV)}$ and Y_M^*
ur	Unemployment rate	0.06	Based on World Bank
v	Capital productivity	0.61	Calculated from Eqs. (41) and (47) using the initial values of Y, u and $K_{(PRI)}$
V_{CB}	Wealth of central banks (trillion US$)	0	It is assumed that there are no accumulated capital gains for the central banks
V_H	Wealth of households (trillion US$)	1678.6	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 (trillion US$)	134.0	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 (trillion US$/billions of employees)	13.37	Calculated from Eq. (87) using the initial value of λ
W	Waste (Gt)	12.43	Calculated from the identity $W=DEM-REC$ using the initial values of DEM and REC
w_{LT}	Risk weight on total loans	1.0	Calculated from Eq. (144) using the initial values of $sh_{(LG)}$, $sh_{(LC)S1}$, $sh_{(LC)S2}$ 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	0.01	Calibrated such that the model generates the baseline scenario
x_{20}	Autonomous proportion of desired green investment funded via bonds	0.02	Calculated from Eq. (93) using the initial values of $yield_G$ and x_2
Y	Output (trillion US$)	80.7	Taken from World Bank (current prices)
Y^*	Potential output (trillion US$)	85.4	Calculated from Eq. (43) using the initial values of Y_M^*, Y_E^*, Y_K^* and Y_N^*
Y_E^*	Energy-determined potential output (trillion US$)	6395.5	Calculated from Eq. (40) using the initial values of REV_E, θ and ε
Y_H	Disposable income of households (trillion US$)	52.1	Calculated from Eq. (110) using the initial values of Y_{HG} and T_H
Y_{HD}	Household disposable income net of depreciation (trillion US$)	73.5	Calculated from the identity $Y_{HD}=Y_H-\xi DC_{-1}$ using the initial values of Y_H and DC
Y_{HG}	Gross disposable income of households (trillion US$)	66.9	Calculated from Eq. (109) 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 FTSE Russell (2018)
$yield_G$	Yield on green corporate bonds	0.05	Based on FTSE Russell (2018)
Y_K^*	Capital-determined potential output (trillion US$)	112.1	Calculated from Eq. (41) using the initial values of v and $K_{(PRI)}$
Y_M^*	Matter-determined potential output (trillion US$)	3101.0	Calculated from Eq. (39) using the initial values of REV_M, REC and μ
Y_N^*	Labour-determined potential output (trillion US$)	85.4	Calculated from Eq. (42) using the initial values of λ and LF
β_{S1}	Share of desired green investment of the 'mining and utilities' sector in total	0.17	Calculated from Eq. (59) 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'	0.02	Calculated from Eq. (59) 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	0.07	Calculated from Eq. (59) 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	0.02	Calculated from Eq. (59) 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	0.31	Calculated from Eq. (61) using the initial values of β_{S1}, RC, τ_C, $EMIS_{IN}$, $I_{C(PRI)S1}$, sh_L, int_G, int_{LCS1}, $yield_G$ and $yield_C$

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Symbol	Description	Value	Remarks/sources
β_{0S2}	Autonomous share of desired green investment of the 'manufacturing and construction' sector in total investment	0.17	Calculated from Eq. (61) using the initial values of β_{S2}, RC, τ_C, $EMIS_{IN}$, $I_{C(PRI)S2}$, 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	0.22	Calculated from Eq. (61) using the initial values of β_{S3}, RC, τ_C, $EMIS_{IN}$, $I_{C(PRI)S3}$, 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	0.17	Calculated from Eq. (61) using the initial values of β_{S4}, RC, τ_C, $EMIS_{IN}$, $I_{C(PRI)S4}$, sh_L, int_G, int_{LCS4}, $yield_G$ and $yield_C$
δ	Depreciation rate of capital stock	0.05	Calculated from Eq. (82) using the initial value D_{TF}
ε	Energy intensity (EJ/trillion US$)	7.19	Calculated from Eq. (15) using the initial values of E and Y
θ	Share of renewable energy in total energy	0.14	Based on IEA (International Energy Agency); total primary energy supply is used
$\varkappa$	Ratio of green capital to total capital	0.04	Calculated from Eq. (80) using the initial values of $I_{G(PRI)}$ and $I_{(PRI)}$
λ	Hourly labour productivity (trillion US$/(billions of employees*annual hours worked per employee))	0.01	Calculated from Eq. (88) 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. (116) using the initial values of B_{GH}, V_{HF}, D_T, $yield_C$, $yield_G$ and Y_H
μ	Material intensity (kg/$)	0.84	Calculated from Eq. (1) using the initial values of MY, $C_{(GOV)}$ and Y
ϱ	Recycling rate	0.27	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	0.001	Calculated from Eq. (166) using the initial values of $EMIS_{IN}$ and T_C
ω	CO_2 intensity of non-renewable energy ($GtCO_2$/EJ)	0.07	Calculated from Eq. (23) using the initial values of $EMIS_{IN}$ and EN

Table 7: 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	0.80	Selected from a reasonable range of values
ad_P	Fraction of gross damages to productivity avoided through adaptation	0.80	Selected from a reasonable range of values
c_1	Propensity to consume out of disposable income	0.84	Calibrated such that the model generates the baseline scenario
c_2	Propensity to consume out of financial wealth	0.05	Empirically estimated using data for a panel of countries over the period 1995-2017 (the econometric estimations are available upon request)
car	Coefficient for the conversion of GtC into $GtCO_2$	3.67	Taken from CDIAC (Carbon Dioxide Information Analysis Center)
CAR^{min}	Minimum capital adequacy ratio	0.08	Based on the Basel III regulatory framework
$CO2_{AT\text{-}PRE}$	Pre-industrial CO_2 concentration in atmosphere ($GtCO_2$)	2156.2	Taken from DICE-2016R2 model (Nordhaus, 2018); GtC have been transformed into $GtCO_2$
$CO2_{LO\text{-}PRE}$	Pre-industrial CO_2 concentration in upper ocean/biosphere ($GtCO_2$)	6307.2	Taken from DICE-2016R2 model (Nordhaus, 2018); GtC have been transformed into $GtCO_2$
$CO2_{UP\text{-}PRE}$	Pre-industrial CO_2 concentration in lower ocean ($GtCO_2$)	1320.1	Taken from DICE-2016R2 model (Nordhaus, 2018); GtC have been transformed into $GtCO_2$
con_E	Conversion rate of non-renewable 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
db_{S1}	Degree of browness of the 'mining and utilities' sector	4.43	Calculated from the formula $db_{S1} = (carbon_{S1}/GVA_{S1})/(carbon/GVA)$ 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 UNCTAD)
db_{S2}	Degree of browness of the 'manufacturing and construction' sector	0.99	Calculated from the formula $db_{S2} = (carbon_{S2}/GVA_{S2})/(carbon/GVA)$ 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 UNCTAD)
db_{S3}	Degree of browness of the 'transport' sector	2.61	Calculated from the formula $db_{S3} = (carbon_{S3}/GVA_{S3})/(carbon/GVA)$ 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 UNCTAD)
db_{S4}	Degree of browness of the 'other sectors'	0.17	Calculated from the formula $db_{S4} = (carbon_{S4}/GVA_{S4})/(carbon/GVA)$ 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 UNCTAD)
db_{GOV}	Degree of browness of the government capital stock	1.00	Calculated as the average value of all sectors
def^{max}	Maximum default rate of loans	0.2	Selected from a reasonable range of values
def_0	Parameter of the default rate function	4.00	Calculated from Eq. (106) using the initial value of *illiq*
def_1	Parameter of the default rate function	5.76	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	7.81	Selected from a reasonable range of values
F_{2xCO2}	Increase in radiative forcing (since the pre-industrial period) due to doubling of CO_2	3.7	Taken from the DICE-2016R2 model (Nordhaus, 2018)
fex	Annual increase in radiative forcing (since the pre-industrial period) due to non-CO_2	0.006	Based on the DICE-2016R2 model (Nordhaus, 2018)
$g_{\tau C}$	Growth rate of the carbon tax	0.03	Selected from a reasonable range of values
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. (154) using the initial values of Y and $I_{C(GOV)}$
gov_{IG}	Share of green public spending in output	0.0025	Calculated from Eq. (153) using the initial values of Y and $I_{G(GOV)}$
gov_{SUB}	Share of green subsidies in output	0.29	Calculated from Eq. (163) using the initial values of SUB and $I_{G(PRI)}$
h	Annual working hours per employee	1900	Based on Penn World Table 9.1 (see Feenstra et al., 2015)
h_1	Banks' reserve ratio	0.2	Based on World Bank
h_2	Banks' government securities-to-deposits ratio	0.14	Calculated from Eq. (132) 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	0.03	Based on Global Interest Rate Monitor
int_D	Interest rate on deposits	0.025	Based on World Bank
int_S	Interest rate on government securities	0.025	Based on FTSE Russell (2018)
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
lr	Rate of decline of land-use CO_2 emissions	0.024	Taken from the DICE-2016R2 model (Nordhaus, 2018); has been adjusted to reflect a 1-year time step
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
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 European Commission (2017) that rely on the Survey on Access to Finance of Enterprises (SAFE) that covers EU countries. This is because credit rationing is expected not be higher in emerging and developing countries
r_1	Parameter in the function of the credit rationing on total loans	4.83	Calibrated such that the initial value of credit rationing is 20%. This figure is slightly higher than the one implied by the results in European Commission (2017) that rely on the Survey on Access to Finance of Enterprises (SAFE) that covers EU countries. This is because credit rationing is expected not be higher in emerging and developing countries

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Symbol	Description	Value	Remarks/sources
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)	12.13	Based on econometric estimations for a panel of countries over the period 1995-2017
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)	13.08	Based on econometric estimations for a panel of countries over the period 1995-2017
rep	Loan repayment ratio	0.1	Selected from a reasonable range of values
S	Equilibrium climate sensitivity, i.e. increase in equilibrium temperature due to doubling of CO_2 concentration from pre-industrial levels (^oC)	3.1	Taken from then DICE-2016R2 model (Nordhaus, 2018)
s_B	Banks' retention rate	0.86	Calibrated such that the model generates the baseline scenario
s_C	Share of conventional corporate bonds held by central banks (trillion US$)	0.01	Calculated from Eq. (171) using the initial values of B_{CCB} and B_C
s_F	Firms' retention rate	0.02	Calibrated such that the model generates the baseline scenario
s_G	Share of green corporate bonds held by central banks (trillion US$)	0.00	Calculated from Eq. (170) using the initial values of B_{GCB} and B_G
s_W	Wage income share	0.54	Based on Penn World Table 9.1 (see Feenstra et al., 2015)
$sh_{(GREEN)S1}$	Share in green investment, 'mining and utilities' sector	0.47	Based on CPI (2018)
$sh_{(GREEN)S2}$	Share in green investment, 'manufacturing and construction' sector	0.08	Based on CPI (2018)
$sh_{(GREEN)S3}$	Share in green investment, 'transport' sector	0.18	Based on CPI (2018)
$sh_{(GREEN)S4}$	Share in green investment, 'other sectors'	0.26	Based on CPI (2018)
$sh_{(GVA)S1}$	Share in total gross value added, 'mining and utilities' sector	0.11	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	0.19	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'	0.61	Calculated from the equation $GVA_{S4}/\Sigma GVA_{Si}$ where GVA_{Si} denotes the gross value added of the i sector taken from UNCTAD
$sh_{(EMISIN)S1}$	Share of industrial emissions to gross value added 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
$sh_{(EMISIN)S2}$	Share of industrial emissions to gross value added 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
$sh_{(EMISIN)S3}$	Share of industrial emissions to gross value added 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
$sh_{(EMISIN)S4}$	Share of industrial emissions to gross value added 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
spr_0	Parameter in the function of the spread on total loans	0.05	Calculated from Eq. (147) using the initial value of CAR
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)	0.05	Based on econometric estimations for a panel of countries over the period 1995-2017
spr_2	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
t_1	Speed of adjustment parameter in the atmospheric temperature equation	0.020	Taken from the DICE-2016R2 model (Nordhaus, 2018); has been adjusted to reflect a 1-year time step
t_2	Coefficient of heat loss from the atmosphere to the lower ocean (atmospheric temperature equation)	0.018	Taken from the DICE-2016R2 model (Nordhaus, 2018); has been adjusted to reflect a 1-year time step
t_3	Coefficient of heat loss from the atmosphere to the lower ocean (lower ocean temperature equation)	0.005	Taken from the DICE-2016R2 model (Nordhaus, 2018); has been adjusted to reflect a 1-year time step
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_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. (92) using the initial values of $yield_C$ and x_1
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	0.25	Selected from a reasonable range of values
a_{00}	Parameter in the desired investment function	0.18	Calibrated such that the model generates the baseline scenario
a_{01}	Parameter in the desired investment function	1.20	Calibrated such that the model generates the baseline scenario
a_1	Parameter in the desired investment function (related to the sensitivity of investment to the capacity utilisation)	1.71	Based on econometric estimations for a panel of countries over the period 1950-2017 (available upon request)
a_2	Parameter in the desired investment function (related to the sensitivity of investment to the rate of profit)	2.14	Based on econometric estimations for a panel of countries over the period 1950-2017 (available upon request)
a_{31}	Parameter in the desired investment function (related to the sensitivity of investment to the unemployment rate)	0.01	Based on econometric estimations for a panel of countries over the period 1950-2017 (available upon request)
a_{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
a_{41}	Parameter in the desired investment function (related to the sensitivity of investment	0.1	Selected from a reasonable range of values
a_{42}	Parameter in the desired investment function (related to the sensitivity of investment	0.99	Selected from a reasonable range of values
a_{51}	Parameter in the desired investment function (related to the sensitivity of investment	0.1	Selected from a reasonable range of values
a_{52}	Parameter in the desired investment function (related to the sensitivity of investment	0.99	Selected from a reasonable range of values
β_1	Autonomous share of desired green investment in total investment	0.2	Calibrated such that the model generates the baseline scenario
β_2	Sensitivity of the desired green investment share to the interest rate differential	1	Selected from a reasonable range of values
δ_0	Depreciation rate of capital stock when there are no climate damages	0.048	Based on Penn World Table 9.1 (see Feenstra et al., 2015)
ε^{max}	Maximum potential value of energy intensity (EJ/trillion US$)	12	Selected such that it is reasonably higher than initial ε
ε^{min}	Minimum potential value of energy intensity (EJ/trillion US$)	2	Selected such that it is reasonably higher than 0
ζ_1	Rate of decline of the (absolute) growth rate of CO_2 intensity	0.0004	Calibrated such that the model generates the baseline scenario
ζ_2	Rate of decline of the growth rate of β_0	0.020	Calibrated such that the model generates the baseline scenario
ζ_3	Rate of decline of the growth rate of RC	0.03	Calibrated such that the model generates the baseline scenario

(continued from the previous page)

Symbol	Description	Value	Remarks/sources
ζ_4	Rate of decline of the autonomous (absolute) growth rate of labour productivity	0.02	Calibrated such that the model generates the baseline scenario
ζ_5	Rate of decline of the growth rates of x_{20} and λ_{30}	0.20	Calibrated such that the model generates the baseline scenario
ζ_6	Rate of decline of the growth rate of population	0.0265	Calibrated such that the model generates the baseline scenario
ζ_7	Rate of decline of the autonomous labour force-to-population ratio	0.0003	Calibrated such that the model generates the baseline scenario
η_1	Parameter of damage function	0	Based on Weitzmann (2012) and Dietz and Stern (2015); D_T=50% when T_{AT}=5°C
η_2	Parameter of damage function	0.00284	Based on Weitzmann (2012) and Dietz and Stern (2015); D_T=50% when T_{AT}=5°C
η_3	Parameter of damage function	0.00002	Based on Weitzmann (2012) and Dietz and Stern (2015); D_T=50% when T_{AT}=5°C
λ_{10}	Parameter of households' portfolio choice	0.40	Calculated from Eq. (114) using the initial values of SEC_H, V_{HF}, D_T, $yield_C$, $yield_G$ and
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	0.09	Calculated from Eq. (115) 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 $\lambda_{21}=\lambda_{12}$
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	0.50	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	0.005	Selected such that the initial growth of DC is equal to the growth rate of output
π_1	Parameter linking the green capital-conventional capital ratio with material intensity	1.57	Calibrated such that initial μ corresponds to initial $\varkappa$ and $\mu(2050)=0.9\mu(2015)$ in line with the baseline scenario
π_2	Parameter linking the green capital-conventional capital ratio with material intensity	16.63	Calibrated such that initial μ corresponds to initial $\varkappa$ and $\mu(2050)=0.9\mu(2015)$ in line with the baseline scenario
π_3	Parameter linking the green capital-conventional capital ratio with recycling rate	6.98	Calibrated such that initial ϱ corresponds to initial $\varkappa$ and $\varrho(2050)=1.4\varrho(2015)$ in line with the baseline scenario
π_4	Parameter linking the green capital-conventional capital ratio with recycling rate	32.36	Calibrated such that initial ϱ corresponds to initial $\varkappa$ and $\varrho(2050)=1.4\varrho(2015)$ in line with the baseline scenario
π_5	Parameter linking the green capital-conventional capital ratio with energy intensity	8.26	Calibrated such that initial ε corresponds to initial $\varkappa$ and $\varepsilon(2050)=0.7\varepsilon(2015)$ in line with the baseline scenario
π_6	Parameter linking the green capital-conventional capital ratio with energy intensity	52.19	Calibrated such that initial ε corresponds to initial $\varkappa$ and $\varepsilon(2050)=0.7\varepsilon(2015)$ in line with the baseline scenario
π_7	Parameter linking the green capital-conventional capital ratio with the share of renewable energy	30.67	Calibrated such that initial θ corresponds to initial $\varkappa$ and $\theta(2050)=0.25$ in line with the baseline scenario
π_8	Parameter linking the green capital-conventional capital ratio with the share of renewable energy	41.22	Calibrated such that initial θ corresponds to initial $\varkappa$ and $\theta(2050)=0.25$ in line with 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	0.0095	Calibrated such that the model generates the baseline scenario
σ_2	Sensitivity of labour productivity growth to the growth rate of output	0.92	Empirically estimated using data for a panel of countries over the period 1991-2017 (the econometric estimations are available upon request)
τ_F	Firms' tax rate	0.15	Selected from a reasonable range of values
τ_H	Households' tax rate	0.23	Calibrated such that the model generates the baseline scenario
φ_{11}	Transfer coefficient for carbon from the atmosphere to the atmosphere	0.9760	Calculated from the formula $\varphi_{11}=1-\varphi_{12}$ (see the DICE-2016R2 model, Nordhaus, 2018)
φ_{12}	Transfer coefficient for carbon from the atmosphere to the upper ocean/biosphere	0.0240	Taken from the DICE-2016R2 model (Nordhaus, 2018); has been adjusted to reflect a 1-year time step
φ_{21}	Transfer coefficient for carbon from the upper ocean/biosphere to the atmosphere	0.0392	Calculated from the formula $\varphi_{21}=\varphi_{12}(CO2_{AT\text{-}PRE}/CO2_{UP\text{-}PRE})$ (see the DICE-2016R2 model, Nordhaus, 2018)
φ_{22}	Transfer coefficient for carbon from the upper ocean/biosphere to the upper ocean/biosphere	0.9595	Calculated from the formula $\varphi_{22}=1-\varphi_{21}-\varphi_{23}$ (see the DICE-2016R2 model, Nordhaus, 2018)
φ_{23}	Transfer coefficient for carbon from the upper ocean/biosphere to the lower ocean	0.0013	Taken from the DICE-2016R2 model (Nordhaus, 2018); has been adjusted to reflect a 1-year time step
φ_{32}	Transfer coefficient for carbon from the lower ocean to the upper ocean/biosphere	0.0003	Calculated from the formula $\varphi_{32}=\varphi_{23}(CO2_{UP\text{-}PRE}/CO2_{LO\text{-}PRE})$ (see the DICE-2016R2 model, Nordhaus, 2018)
φ_{33}	Transfer coefficient for carbon from the lower ocean to the lower ocean	0.9997	Calculated from the formula $\varphi_{33}=1-\varphi_{32}$ (see the DICE-2016R2 model, Nordhaus, 2018)

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