

Stock-flow consistent modelling and ecological macroeconomics

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The E-SFC modelling approach: an overview

- The ecological stock-flow consistent (E-SFC) modelling approach has emerged as an increasingly prominent tool in **ecological macroeconomics**.
- E-SFC models combine:
 - ① the **post-Keynesian SFC approach** of Godley and Lavoie, which provides a holistic perspective to the interaction between the real and financial spheres of our economies; and
 - ② the **ecological economics tradition** that goes back to Georgescu-Roegen and highlights the limits that physical laws and a finite planet pose to macroeconomic activity.
- This provides a solid modelling framework for analysing ecological macroeconomic dynamics from a **systems point of view**.

The E-SFC modelling approach: an overview

- E-SFC models are characterised by two types of principles:
 - ① **National accounting and physical accounting principles** for avoiding black holes in the modelling of environmental and macroeconomic variables.
 - ② **Post-Keynesian and ecological economics principles** for modelling macrofinancial and ecosystem processes (and their interactions).
- E-SFC models have been increasingly used to analyse **green macroeconomic policies** and the effects of climate change on **financial stability**, as well as the trade and exchange rate implications of the green transition (e.g. Dafermos et al., 2017; Bovari et al., 2018; Carnevali et al., 2019, 2021; Cieplinski et al., 2021; Dunz et al., 2021; D'Alessandro et al., 2025; Morlin et al., 2025; Yilmaz et al., 2025).
- E-SFC models have also been increasingly used by policymakers around the world.

Outline

- 1 Accounting principles for stock-flow consistency
- 2 Principles for modelling macrofinancial and ecosystem processes
- 3 DEFINE-SIMPLE: model development and calibration
- 4 DEFINE-GOV: model development
- 5 DEFINE-GLOBAL: land and water
- 6 Areas for future research

Outline

- 1 **Accounting principles for stock-flow consistency**
- 2 Principles for modelling macrofinancial and ecosystem processes
- 3 DEFINE-SIMPLE: model development and calibration
- 4 DEFINE-GOV: model development
- 5 DEFINE-GLOBAL: land and water
- 6 Areas for future research

The distinction between monetary and physical stocks and flows

- **Monetary stocks and flows** refer to economic assets and transactions measured in monetary units (such as dollars, pesos or rupees), while **physical stocks and flows** refer to stocks and flows of natural resources measured in physical units, such as tonnes, joules or cubic metres.
- A central feature of the E-SFC approach is that natural resources **do not need to have a price** to be taken into account in economic decisions.
- Instead, the components of the ecosystems are expressed in physical units – this makes it easy to identify how human activity might lead to the exceeding of **planetary boundaries** and what this implies for social and macrofinancial stability.
- **Monetary accounting matrices** capture monetary stocks and flows, while **physical accounting matrices** represent physical stocks and flows.

Accounting principles for modelling monetary stocks and flows

- To capture monetary stocks and flows, E-SFC models rely on the following standard national accounting principles: (i) **flow consistency**; (ii) **stock consistency**; (iii) **stock-flow consistency**; (iv) **quadruple entry principle**.
- These principles are applied by developing the **balance sheet matrix** and the **transactions flow matrix**.
- The balance sheet matrix captures the **assets and liabilities** of the economy. Assets are denoted by a plus sign, while liabilities are denoted by a minus sign.
- The transactions flow matrix records all the **transactions** that take place between the different sectors. For each sector, inflows are denoted by a plus sign, while outflows are denoted by a minus sign.

Accounting principles for modelling monetary stocks and flows

Balance sheet matrix

	Households	Firms	Commercial banks	Total
Deposits	$+D_t$		$-D_t$	0
Green loans		$-L_{Gt}$	$+L_{Gt}$	0
Conventional loans		$-L_{Ct}$	$+L_{Ct}$	0
Green capital		$+K_{Gt}$		$+K_{Gt}$
Conventional capital		$+K_{Ct}$		$+K_{Ct}$
Total (net worth)	$+D_t$	$+V_{Ft}$	0	$+K_t$

Source: Own illustration.

Accounting principles for modelling monetary stocks and flows

Transactions flow matrix

	Households	Firms		Commercial banks		Total
		Current	Capital	Current	Capital	
Consumption	$-CO_t$	$+CO_t$				0
Green investment		$+I_{Gt}$	$-I_{Gt}$			0
Conventional investment		$+I_{Ct}$	$-I_{Ct}$			0
Wages	$+W_t$	$-W_t$				0
Firms' profits	$+DP_t$	$-TP_t$	$+RP_t$			0
Banks' profits	$+BP_t$			$-BP_t$		0
Interest on deposits	$+int_D D_{t-1}$			$-int_D D_{t-1}$		0
Interest on green loans		$-int_G L_{Gt-1}$		$+int_G L_{Gt-1}$		0
Interest on conventional loans		$-int_C L_{Ct-1}$		$+int_C L_{Ct-1}$		0
Change in deposits	$-\Delta D_t$				$+\Delta D_t$	0
Change in green loans			$+\Delta L_{Gt}$		$-\Delta L_{Gt}$	0
Change in conventional loans			$+\Delta L_{Ct}$		$-\Delta L_{Ct}$	0
Total	0	0	0	0	0	0

Source: Own illustration.

Accounting principles for modelling physical stocks and flows

- The **First Law of Thermodynamics** suggests that energy cannot be created or destroyed when it is transformed during economic processes.
- The **Second Law of Thermodynamics** is captured by the fact that economic processes transform low-entropy energy (e.g. fossil fuels) into high-entropy dissipated energy (e.g. thermal energy).
- The **Law of Conservation of Mass** suggests that in mass transformation processes, mass cannot be created or destroyed: all the matter that enters the socio-economic system must either leave it or accumulate within it.
- Living on a **finite planet** implies that the total surface of the Earth is physically fixed and, therefore, land cannot be created – it can only be reallocated between uses.
- In E-SFC models, the physical accounting principles are captured by **physical stock-flow matrices**.

Accounting principles for modelling physical stocks and flows

Physical stock-flow matrix for matter

	Carbon content of fossil fuel resources	Carbon content of fossil fuel reserves	Cumulative carbon emissions	Material resources	Material reserves	Socio-economic material stock	Cumulative material waste	Total
Opening stock	$RES_{CF,t-1}$	$REV_{CF,t-1}$	$CARBON_{t-1}$	RES_{Mt-1}	REV_{Mt-1}	$SEMS_{t-1}$	$WASTE_{t-1}$	$MATTER_T$
Extracted (non-carbon) matter					$-M_t$	$+M_t$		0
Discarded matter						$-DISC_t$	$+DISC_t$	0
Recycled matter						$+REC_t$	$-REC_t$	0
Material resources converted into reserves				$-CON_{Mt}$	$+CON_{Mt}$			0
Fossil resources converted into reserves	$-CON_{Ft}$	$+CON_{Ft}$						0
Carbon released during fossil combustion		$-C_{COMBt}$	$+C_{COMBt}$					0
Carbon embodied in material goods		$-C_{MATt}$				$+C_{MATt}$		0
Closing stock	RES_{CFt}	REV_{CFt}	$CARBON_t$	RES_{Mt}	REV_{Mt}	$SEMS_t$	$WASTE_t$	$MATTER_T$

Source: Own illustration.

Note: Matter is measured in gigatonnes

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Modelling macrofinancial and ecosystem processes (I)

The accounting matrices provide the **skeleton** of E-SFC models. This skeleton needs to be accompanied by **equations** that capture macrofinancial and ecosystem processes and their interactions. These equations rely on the following principles:

- **Money is endogenous and macrofinancial feedback loops play a key role:** Money is endogenously created when banks decide to provide loans to borrowers; lending can have second-round effects that propagate through the financial system and the macroeconomy.
- **Economic activity is driven by demand, but is constrained by the supply side:** As long as the economy operates below potential output, an increase in demand can increase economic activity. When demand-determined output approaches potential output, inflation can arise, demand can be rationed or imports can increase.

Modelling macrofinancial and ecosystem processes (II)

- **Demand affects supply and hysteresis plays a key role:** Higher demand that increases investment can stimulate labour and capital productivity or improve material/energy efficiency and the use of renewables – when it is green. This makes long-run outcomes path-dependent.
- **Agents take decisions in a world of fundamental uncertainty:** Agents do not take decisions based on rational expectations. Instead, they rely on some form of adaptive expectations and might set targets (e.g. about their profitability, indebtedness or inventories) and take action to achieve such targets.
- **There is limited substitutability of natural resources in the production process:** Energy, matter, water, land and other natural resources can only be replaced by workers and human-made capital up to specific limits. The macroeconomy works as an open system within the closed ecosystem of the planet.

Modelling macrofinancial and ecosystem processes (III)

- **The economy affects the ecosystem through depletion and degradation channels:** Producing more goods requires more physical resources such as energy, materials, water and land. As a result, the quantity and the quality of these resources might be adversely affected.
- **Physical stocks affect the macrofinancial system through several non-linear channels:** For example, global warming increases the severity and frequency of hurricanes that can destroy capital stock; the accumulation of hazardous waste can adversely affect the health of people and their ability to work; a reduction in material reserves (e.g. lithium, which is needed for electric batteries) might increase inflation.
- **Environmental effects can be exacerbated through ecosystem interactions:** For example, global warming affects freshwater availability and deforestation; and deforestation can accelerate global warming and reduce groundwater stocks. E-SFC models are increasingly capturing these ecosystem interactions.

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The DEFINE modelling framework

Three categories of **DEFINE** (Dynamic Ecosystem-FINance-Economy) models:

- 1 The **DEFINE-GLOBAL** model, which is a large-scale model for the global economy and the global ecosystem (e.g. Dafermos et al., 2017, 2018; Dafermos and Nikolaidi, 2021, 2022).
- 2 **Country-specific DEFINE models**, which are large-scale models whose structure reflects the features of specific economies (DEFINE-UK, DEFINE-ALBANIA and DEFINE-PHILIPPINES) (e.g. George and Dafermos, 2026).
- 3 **Simplified DEFINE models**, which are small-scale or medium-scale models that focus on specific elements of the economy or the ecosystem, assuming away interactions with other elements (e.g. DEFINE-MATTER, DEFINE-CLIMATE, DEFINE-WATER, DEFINE-LAND, DEFINE-HOUSING) (e.g. Kökbudak and Nikolaidi, 2026).



www.define-model.org

DEFINE-SIMPLE: key features

- The steps for developing and calibrating a simple E-SFC model will be illustrated by using **DEFINE-SIMPLE**.
- DEFINE-SIMPLE is a simplified model that incorporates **green investment** and **emissions** in an SFC structure.
- The model assumes that a proportion of total private investment is green and that a part of **bank loans** is used to finance this type of investment. An increase in the proportion of green capital to conventional capital leads to a decline in **carbon intensity**.



DEFINE-SIMPLE

DEFINE-SIMPLE is a simplified DEFINE model that shows how consumption and investment decisions can affect the path of key economic variables and carbon emissions. The model consists of three sectors: firms, households and banks. Firms undertake investment by using retained profits and loans. A part of firms' profits is distributed to households. Households accumulate savings in the form of deposits. Banks provide firm loans by creating deposits. Banks' profits are distributed to households. The model assumes that a proportion of total private investment is green and that a part of bank loans is used to finance this type of investment. The higher the green investment relative to conventional capital the lower the carbon intensity.

For a publication that uses DEFINE-SIMPLE and the related R code, see [here](#).

Manual

Version	Date	Description
DEFINE-SIMPLE 1.1	May 2026	Revised version of DEFINE-SIMPLE 1.0
DEFINE-SIMPLE 1.0	May 2021	First version of DEFINE-SIMPLE

www.define-model.org/define-simple/

Steps in developing an SFC model

- **Step 1:** Identify the accounting structure of the model.
- **Step 2:** Specify the identities that stem from the accounting structure of the model.
- **Step 3:** Specify the rest of the equations (these include (i) *behavioural and process equations* that capture the economic behaviour of agents and institutional sectors as well as economic and ecological processes and (ii) *definitional equations* that reflect definitions, such as those that define disposable income, the wage share or the connection between water intensity, water use and economic activity).
- **Step 4:** Compile the complete model by collecting all the equations.

Step 1: Identify the accounting structure of the model

DEFINE-SIMPLE has the following **structure**:

- There are three **sectors**: firms, commercial banks and households.
- **Firms** undertake green and conventional investment by using retained profits and (green and conventional) loans. A part of firms' profits is distributed to households.
- **Commercial banks** provide firm loans by creating deposits. Banks distribute all their profits to households.
- **Households** accumulate savings in the form of deposits.
- Green investment affects **carbon intensity**. For a given carbon intensity, an increase in economic activity leads to an increase in emissions.

Step 1: Identify the accounting structure of the model

Balance sheet matrix

	Households	Firms	Commercial banks	Total
Deposits	$+D_t$		$-D_t$	0
Green loans		$-L_{Gt}$	$+L_{Gt}$	0
Conventional loans		$-L_{Ct}$	$+L_{Ct}$	0
Green capital		$+K_{Gt}$		$+K_{Gt}$
Conventional capital		$+K_{Ct}$		$+K_{Ct}$
Total (net worth)	$+D_t$	$+V_{Ft}$	0	$+K_t$

Source: Own illustration.

Step 1: Identify the accounting structure of the model

Transactions flow matrix

	Households	Firms		Commercial banks		Total
		Current	Capital	Current	Capital	
Consumption	$-CO_t$	$+CO_t$				0
Green investment		$+I_{Gt}$	$-I_{Gt}$			0
Conventional investment		$+I_{Ct}$	$-I_{Ct}$			0
Wages	$+W_t$	$-W_t$				0
Firms' profits	$+DP_t$	$-TP_t$	$+RP_t$			0
Banks' profits	$+BP_t$			$-BP_t$		0
Interest on deposits	$+int_D D_{t-1}$			$-int_D D_{t-1}$		0
Interest on green loans		$-int_G L_{Gt-1}$		$+int_G L_{Gt-1}$		0
Interest on conventional loans		$-int_C L_{Ct-1}$		$+int_C L_{Ct-1}$		0
Change in deposits	$-\Delta D_t$				$+\Delta D_t$	0
Change in green loans			$+\Delta L_{Gt}$		$-\Delta L_{Gt}$	0
Change in conventional loans			$+\Delta L_{Ct}$		$-\Delta L_{Ct}$	0
Total	0	0	0	0	0	0

Source: Own illustration.

Step 2: Specify the identities that stem from the accounting structure of the model

- Deposits: $D_t = D_{t-1} + Y_{Ht} - CO_t$
- Total profits of firms:
 $TP_t = Y_t - W_t - int_C L_{Ct-1} - int_G L_{Gt-1}$
- Conventional loans: $L_{Ct} = L_{Ct-1} + I_{Ct} + I_{Gt} - RP_t - (L_{Gt} - L_{Gt-1})$
- Profits of banks: $BP_t = int_G L_{Gt-1} + int_C L_{Ct-1} - int_D D_{t-1}$
- Deposits: $D_{redt} = L_t$
- Distributed profits: $DP_t = TP_t - RP_t$
- Output: $Y_t = CO_t + I_t$
- Conventional investment: $I_{Ct} = I_t - I_{Gt}$
- Disposable income of households:
 $Y_{Ht} = W_t + DP_t + BP_t + int_D D_{t-1}$
- Total loans: $L_t = L_{Ct} + L_{Gt}$

Transactions flow matrix

	Households	Firms		Commercial banks		Total
		Current	Capital	Current	Capital	
Consumption	$-CO_t$	$+CO_t$				0
Green investment		$+I_{Gt}$	$-I_{Gt}$			0
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Interest on conventional loans		$-int_C L_{Ct-1}$		$+int_C L_{Ct-1}$		0
Change in deposits	$-\Delta D_t$				$+\Delta D_t$	0
Change in green loans			$+\Delta L_{Gt}$		$-\Delta L_{Gt}$	0
Change in conventional loans			$+\Delta L_{Ct}$		$-\Delta L_{Ct}$	0
Total	0	0	0	0	0	0

Source: Own illustration.

Step 2: Specify the identities that stem from the accounting structure of the model

Balance sheet matrix

	Households	Firms	Commercial banks	Total
Deposits	$+D_t$		$-D_t$	0
Green loans		$-L_{Gt}$	$+L_{Gt}$	0
Conventional loans		$-L_{Ct}$	$+L_{Ct}$	0
Green capital		$+K_{Gt}$		$+K_{Gt}$
Conventional capital		$+K_{Ct}$		$+K_{Ct}$
Total (net worth)	$+D_t$	$+V_{Ft}$	0	$+K_t$

Source: Own illustration.

- Capital stock:
 $K_t = K_{Ct} + K_{Gt}$

Step 3: Specify the rest of the equations

- Consumption expenditures: CO_t
- Wage income: W_t
- Deposits (identity): D_t
- Total profits of firms (identity): TP_t
- Retained profits: RP_t
- Distributed profits (identity): DP_t
- Rate of profit: r_t
- Investment: I_t
- Green investment: I_{Gt}
- Share of green investment: β_t
- Conventional investment (identity): I_{Ct}
- Capital stock (identity): K_t
- Green capital stock: K_{Gt}
- Conventional capital stock: K_{Ct}
- Loans (identity): L_t
- Green loans: L_{Gt}
- Conventional loans (identity): L_{Ct}
- Profits of banks (identity): BP_t
- Fossil CO₂ emissions: $EMIS_{Ft}$
- Carbon intensity: CI_t
- Potential output: Y_{Pt}
- Capacity utilisation: u_t
- Growth rate of output: g_{Yt}
- Leverage ratio: lev_t

Step 3: Specify the rest of the equations

- Consumption expenditures: $CO_t = c_1 Y_{Ht-1} + c_2 D_{t-1}$
- Wage income: $W_t = s_W Y_t$
- Retained profits: $RP_t = s_F TP_t$
- Investment: $I_t = (\alpha_0 + \alpha_1 r_{t-1}) K_{t-1}$
- Rate of profit: $r_t = TP_t / K_t$

where Y_{Ht} : disposable income, D_t : deposits, Y_t : output, TP_t : total profits of firms, K_t : capital stock

Step 3: Specify the rest of the equations

- Green investment: $I_{Gt} = \beta_t I_t$
- Share of green investment in total investment: $\beta_t = \beta_0 - \beta_1 (int_G - int_C)$
- Green capital stock: $K_{Gt} = K_{Gt-1} + I_{Gt}$
- Conventional capital stock: $K_{Ct} = K_{Ct-1} + I_{Ct}$
- Green loans: $L_{Gt} = L_{Gt-1} + I_{Gt} - \beta_t RP_t$

where I_t : investment , int_G : interest rate on green loans, int_C : interest rate on conventional loans, I_{Ct} : conventional investment, RP_t retained profits of firms

Step 3: Specify the rest of the equations

Emissions:

- Fossil CO₂ emissions: $EMIS_{Ft} = CI_t Y_t$
- Carbon intensity: $CI_t = CI_{\min} + \frac{CI_{\max} - CI_{\min}}{1 + ((K_{Gt-1}/K_{Ct-1})/c_{CI})^{k_{CI}}}$

Auxiliary equations:

- Potential output: $Y_{Pt} = vK_t$
- Capacity utilisation: $u_t = Y_t/Y_{Pt}$
- Growth rate of output: $g_{Yt} = (Y_t - Y_{t-1})/Y_{t-1}$
- Leverage ratio: $lev_t = L_t/K_t$

where Y_t : output, K_{Gt} : green capital stock, K_{Ct} : conventional capital stock, K_t : capital stock, L_t : firms' loans

Step 4: Collect all equations

- The equations of DEFINE-SIMPLE are available on the DEFINE model's website (<https://define-model.org/define-simple/>).

Steps in calibrating an SFC model

- **Step 1:** Specify the initial-period equations
- **Step 2:** Determine model-constrained variables and parameters
- **Step 3:** Verify stock-flow consistency
- **Step 4:** Calibrate/estimate the rest of the parameters

Step 1: Specify the initial-period equations

- To derive the initial-period equations, we should address the fact that some variables are **lagged** in the model and, if we start running the model in period $t = 1$, we will not have values for these variables in period $t = 0$.
- To deal with that, we take into account that for each **variable** x_t we have $x_t = x_{t-1}(1 + g_{xt})$ where g_{xt} is the growth rate of this variable in period t . Therefore, $x_{t-1} = x_t / (1 + g_{xt})$.
- Writing this equation for $t = 1$, we get $x_{t=0} = x_{t=1} / (1 + g_{xt=1})$. The latter formula should therefore be used for all variables that have a **lag** in the equations of the model.

Step 1: Specify the initial-period equations

We should replace every lagged variable x_{t-1} with $x_{t=0} = \frac{x_{t=1}}{1 + g_{xt=1}}$. For example:

Consumption (Eq. 10):

$$CO_t = c_1 Y_{Ht-1} + c_2 D_{t-1} \implies CO_{t=1} = c_1 \frac{Y_{Ht=1}}{1 + g_{YHt=1}} + c_2 \frac{D_{t=1}}{1 + g_{Dt=1}}$$

Investment (Eq. 12):

$$I_t = (\alpha_0 + \alpha_1 r_t) K_{t-1} \implies I_{t=1} = (\alpha_0 + \alpha_1 r_{t=1}) \frac{K_{t=1}}{1 + g_{Kt=1}}$$

Leverage (Eq. 26): no lagged variables, so no adjustment is needed:

$$lev_t = L_t / K_t \implies lev_{t=1} = L_{t=1} / K_{t=1}$$

Question for discussion

Suppose that we have the following simple macro model:

$$Y_t = CO_t + I_t$$

$$CO_t = c Y_{t-1}$$

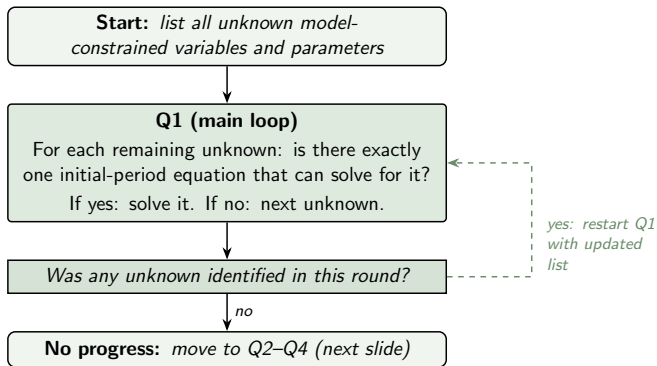
$$I_t = \alpha K_{t-1}$$

You are given the following:

Output ($Y_{t=1}$)	£100	Growth rate of output (g_Y)	2%
Consumption ($CO_{t=1}$)	£60	Propensity to consume (c)	0.75
Investment ($I_{t=1}$)	£20	Autonomous investment (α)	0.03
Capital stock ($K_{t=1}$)	£1000	Capital stock growth (g_K)	2%

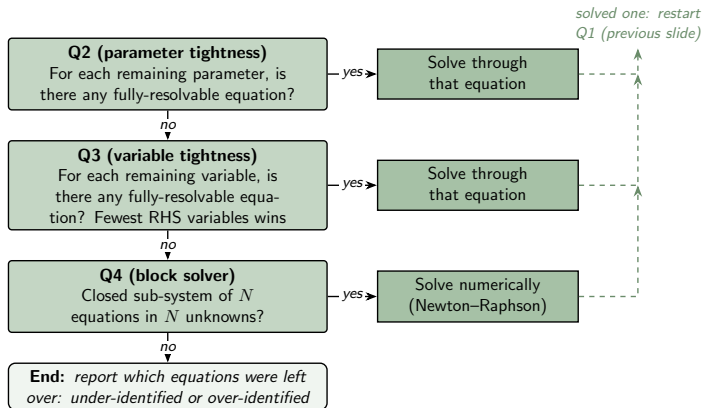
Question: (a) Derive the initial-period equations, (b) Can all these values be used for the initialisation of the model? If not, which values would you use?

Step 2: Determine model-constrained variables and parameters



Source: Own illustration.

Step 2: Determine model-constrained variables and parameters



Source: Own illustration.

Step 2: Determine model-constrained variables and parameters

Each initial-period equation is solved for one variable or parameter, which thereby becomes model-constrained. For example:

Consumption (Eq. 10): solved for the propensity to consume c_1 :

$$CO_{t=1} = c_1 \frac{Y_{Ht=1}}{1 + g_{YHt=1}} + c_2 \frac{D_{t=1}}{1 + g_{Dt=1}} \implies c_1 = \frac{CO_{t=1} - c_2 D_{t=1}/(1 + g_{Dt=1})}{Y_{Ht=1}/(1 + g_{YHt=1})}$$

Investment (Eq. 12): solved for the autonomous component α_0 :

$$I_{t=1} = (\alpha_0 + \alpha_1 r_{t=1}) \frac{K_{t=1}}{1 + g_{Kt=1}} \implies \alpha_0 = \frac{I_{t=1}}{K_{t=1}/(1 + g_{Kt=1})} - \alpha_1 r_{t=1}$$

Leverage (Eq. 26): determines $lev_{t=1}$ directly, so no rearrangement is needed:

$$lev_{t=1} = L_{t=1}/K_{t=1} \implies lev_{t=1} = L_{t=1}/K_{t=1}$$

Step 3: Verify stock-flow consistency

- In order for your model to be **consistent** you need to ensure that:
 - ① the **identities** from the transactions flow matrix and balance sheet matrix are correctly written;
 - ② in the **initial period** all the stocks in the model satisfy the restrictions of the balance sheet matrix;
 - ③ the **adding-up constraints** are satisfied (if your model includes portfolio allocation).
- In the numerical simulations, consistency is checked by verifying that the **redundant equation** is satisfied.

Step 4: Calibrate/estimate the rest of the parameters and initial values

The values of the rest of the parameters are specified using:

- estimates that rely on econometrics or other methods (e.g. simulated method of moments);
- use of values from real-world data;
- use of values from other studies;
- values that allow us to derive the baseline scenario;
- values from a reasonable range of values.

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DEFINE-GOV: key features

- DEFINE-GOV extends DEFINE-SIMPLE by introducing a **government sector** that collects taxes (including carbon taxes), provides green subsidies and undertakes consumption expenditures. This allows the analysis of specific green fiscal policies.
- DEFINE-GOV consists of four sectors: firms, households, banks and the government.
- Compared to DEFINE-SIMPLE, firms' **share of green investment** in total investment is not only affected by the difference between the interest rate on green loans and conventional loans. It is also a positive function of carbon taxes and green subsidies.

Step 1: Identify the accounting structure of the model

Government securities are held by households (SEC_{Ht}) and commercial banks (SEC_{Bt}).

Balance sheet matrix

	Households	Firms	Commercial banks	Government	Total
Deposits	$+D_t$		$-D_t$		0
Green loans		$-L_{Gt}$	$+L_{Gt}$		0
Conventional loans		$-L_{Ct}$	$+L_{Ct}$		0
Green capital		$+K_{Gt}$			$+K_{Gt}$
Conventional capital		$+K_{Ct}$			$+K_{Ct}$
Government securities	$+SEC_{Ht}$		$+SEC_{Bt}$	$-SEC_t$	0
Total (net worth)	$+V_{Ht}$	$+V_{Ft}$	0	$-SEC_t$	$+K_t$

Source: Own illustration.

Step 1: Identify the accounting structure of the model

The government pays interest on government securities, undertakes consumption spending and provides green subsidies. It also collects taxes from firms and households.

Transactions flow matrix

	Households	Firms		Commercial banks		Government	Total
		Current	Capital	Current	Capital		
Private consumption expenditures	$-CO_{PRIt}$	$+CO_{PRIt}$					0
Government consumption expenditures		$+CO_{GOVt}$				$-CO_{GOVt}$	0
Green investment		$+I_{Gt}$	$-I_{Gt}$				0
Conventional investment		$+I_{Ct}$	$-I_{Ct}$				0
Wages	$+W_t$	$-W_t$					0
Green subsidies		$+SUB_t$				$-SUB_t$	0
Taxes	$-TAX_{Ht}$	$-TAX_{Ft}-TAX_{Ct}$				$+TAX_t$	0
Firms' profits	$+DP_t$	$-TP_t$	$+RP_t$				0
Banks' profits	$+BP_t$			$-BP_t$			0
Interest on deposits	$+int_D D_{t-1}$			$-int_D D_{t-1}$			0
Interest on green loans		$-int_G L_{Gt-1}$		$+int_G L_{Gt-1}$			0
Interest on conventional loans		$-int_C L_{Ct-1}$		$+int_C L_{Ct-1}$			0
Interest on government securities	$+int_S SEC_{Ht-1}$			$+int_S SEC_{Bt-1}$		$-int_S SEC_{t-1}$	0
Change in deposits	$-\Delta D_t$				$+\Delta D_t$		0
Change in green loans			$+\Delta L_{Gt}$		$-\Delta L_{Gt}$		0
Change in conventional loans			$+\Delta L_{Ct}$		$-\Delta L_{Ct}$		0
Change in government securities	$-\Delta SEC_{Ht}$				$-\Delta SEC_{Bt}$	$+\Delta SEC_{Ct}$	0
Total	0	0	0	0	0	0	0

Source: Own illustration.

Step 2: Specify the identities that stem from the accounting structure of the model

Households

- Deposits: $D_t = D_{t-1} + Y_{Ht} - CO_{PRI t} - (SEC_{Ht} - SEC_{Ht-1})$
- Gross disposable income of households: $Y_{HGt} = W_t + DP_t + BP_t + int_D D_{t-1} + int_S SEC_{Ht-1}$
- Net disposable income of households: $Y_{Ht} = Y_{HGt} - TAX_{Ht}$

Firms

- Output:
 $Y_t = CO_{PRI t} + I_t + CO_{GOV t}$
- Total gross profits of firms: $TP_{Gt} = Y_t - W_t - int_C L_{Ct-1} - int_G L_{Gt-1}$
- Total net profits of firms: $TP_t = TP_{Gt} - TAX_{Ft} - TAX_{Ct} + SUB_t$
- Conventional loans:
 $L_{Ct} = L_{Ct-1} + I_{Ct} + I_{Gt} - RP_t - (L_{Gt} - L_{Gt-1})$

Transactions flow matrix

	Households	Firms		Commercial banks		Government	Total
		Current	Capital	Current	Capital		
Private consumption expenditures	$-CO_{PRI t}$	$+CO_{PRI t}$					0
Government consumption expenditures		$+CO_{GOV t}$				$-CO_{GOV t}$	0
Green investment		$+I_{Gt}$	$-I_{Gt}$				0
Conventional investment		$+I_{Ct}$	$-I_{Ct}$				0
Wages	$+W_t$	$-W_t$					0
Green subsidies		$+SUB_t$				$-SUB_t$	0
Taxes	$-TAX_{Ht}$	$-TAX_{Ft} - TAX_{Ct}$				$+TAX_t$	0
Firms' profits	$+DP_t$	$-TP_t$	$+RP_t$				0
Banks' profits	$+BP_t$			$-BP_t$			0
Interest on deposits	$+int_D D_{t-1}$			$-int_D D_{t-1}$			0
Interest on green loans		$-int_G L_{Gt-1}$		$+int_G L_{Gt-1}$			0
Interest on conventional loans		$-int_C L_{Ct-1}$		$+int_C L_{Ct-1}$			0
Interest on government securities	$+int_S SEC_{Ht-1}$			$+int_S SEC_{Bt-1}$		$-int_S SEC_{Gt-1}$	0
Change in deposits	$-\Delta D_t$				$+\Delta D_t$		0
Change in green loans			$+\Delta L_{Gt}$		$-\Delta L_{Gt}$		0
Change in conventional loans			$+\Delta L_{Ct}$		$-\Delta L_{Ct}$		0
Change in government securities	$-\Delta SEC_{Ht}$				$-\Delta SEC_{Bt}$	$+\Delta SEC_{Gt}$	0
Total	0	0	0	0	0	0	0

Source: Own illustration.

Step 2: Specify the identities that stem from the accounting structure of the model

Banks

- Profits of banks:

$$BP_t = int_C L_{Ct-1} + int_G L_{Gt-1} + int_S SEC_{Bt-1} - int_D D_{t-1}$$

- Government securities held by banks: $SEC_{Bt} = D_t - L_{Gt} - L_{Ct}$

Government

- Government securities:

$$SEC_t = SEC_{t-1} + int_S SEC_{t-1} - TAX_t + SUB_t + CO_{GOVt}$$

Horizontal constraints

- Distributed profits:

$$DP_t = TP_t - RP_t$$
- Government securities held by banks (redundant identity):

$$SEC_{Bredt} = SEC_t - SEC_{Ht}$$

Transactions flow matrix

	Households	Firms		Commercial banks		Government	Total
		Current	Capital	Current	Capital		
Private consumption expenditures	$-CO_{PRt}$	$+CO_{PRt}$					0
Government consumption expenditures		$+CO_{GOVt}$				$-CO_{GOVt}$	0
Green investment		$+I_{Gt}$	$-I_{Gt}$				0
Conventional investment		$+I_{Ct}$	$-I_{Ct}$				0
Wages	$+W_t$	$-W_t$					0
Green subsidies		$+SUB_t$				$-SUB_t$	0
Taxes	$-TAX_{Ht}$	$-TAX_{Ft} - TAX_{Ct}$				$+TAX_t$	0
Firms' profits	$+DP_t$	$-TP_t$	$+RP_t$				0
Banks' profits	$+BP_t$			$-BP_t$			0
Interest on deposits	$+int_D D_{t-1}$			$-int_D D_{t-1}$			0
Interest on green loans		$-int_G L_{Gt-1}$		$+int_G L_{Gt-1}$			0
Interest on conventional loans		$-int_C L_{Ct-1}$		$+int_C L_{Ct-1}$			0
Interest on government securities	$+int_S SEC_{Ht-1}$			$+int_S SEC_{Bt-1}$		$-int_S SEC_{t-1}$	0
Change in deposits	$-\Delta D_t$				$+\Delta D_t$		0
Change in green loans			$+\Delta L_{Gt}$		$-\Delta L_{Gt}$		0
Change in conventional loans			$+\Delta L_{Ct}$		$-\Delta L_{Ct}$		0
Change in government securities	$-\Delta SEC_{Ht}$				$-\Delta SEC_{Bt}$	$+\Delta SEC_t$	0
Total	0	0	0	0	0	0	0

Source: Own illustration.

Step 2: Specify the identities that stem from the accounting structure of the model

Balance sheet matrix

- Wealth of households:
 $V_{Ht} = SEC_{Ht} + D_t$
- Capital stock:
 $K_t = K_{Ct} + K_{Gt}$

	Households	Firms	Commercial banks	Government	Total
Deposits	$+D_t$		$-D_t$		0
Green loans		$-L_{Gt}$	$+L_{Gt}$		0
Conventional loans		$-L_{Ct}$	$+L_{Ct}$		0
Green capital		$+K_{Gt}$			$+K_{Gt}$
Conventional capital		$+K_{Ct}$			$+K_{Ct}$
Government securities	$+SEC_{Ht}$		$+SEC_{Bt}$	$-SEC_t$	0
Total (net worth)	$+V_{Ht}$	$+V_{Ft}$	0	$-SEC_t$	$+K_t$

Source: Own illustration.

Step 3: Specify the rest of the equations

Firms

- Investment: $I_t = (\alpha_0 + \alpha_1 r_{t-1}) K_{t-1}$
- Green investment: $I_{Gt} = \beta_t I_t$
- Share of green investment in total investment:
$$\beta_t = \beta_0 - \beta_1(int_G - int_C) + \beta_2 tucf_{t-1} + \beta_3 gov_{SUB}$$
- Total unit cost of producing fossil energy: $tucf_t = pucf + \tau_C \omega$
- Green capital stock: $K_{Gt} = K_{Gt-1} + I_{Gt}$

where r_t : rate of profit, K_t : capital stock, int_G : interest rate on green loans, int_C : interest rate on conventional loans, gov_{SUB} : green subsidy rate, $pucf$: unit cost of producing fossil energy without taxes (USD trillion/EJ), τ_C : carbon tax (USD trillion/GtCO₂), ω : CO₂ intensity of fossil energy (GtCO₂/EJ)

Step 3: Specify the rest of the equations

Government

- Government consumption expenditures: $CO_{GOVt} = gov_C Y_{t-1}$
- Green government subsidies: $SUB_t = gov_{SUB} I_{Gt-1}$
- Taxes on households' disposable income: $TAX_{Ht} = \tau_H Y_{HGt-1}$
- Taxes on firms' profits: $TAX_{Ft} = \tau_F TP_{Gt-1}$
- Revenues from carbon taxes: $TAX_{Ct} = \tau_C EMIS_{Ft-1}$

where Y_t : output, gov_C : share of government expenditure in output, gov_{SUB} : green subsidy rate, I_{Gt} : green investment, τ_H : household income tax rate, Y_{HGt} : gross disposable income, τ_F : firm income tax rate, TP_{Gt} : gross profits of firms, τ_C : carbon tax (USD trillion/GtCO₂), $EMIS_{Ft}$: fossil emissions (GtCO₂)

Step 3: Specify the rest of the equations

Households

- Private consumption expenditures: $CO_{PRIt} = c_1 Y_{Ht-1} + c_2 V_{Ht-1}$
- Government securities held by households: $SEC_{Ht} = \lambda V_{Ht-1}$
- Government securities-to-GDP ratio: $SEC_{Yt} = SEC_t / Y_t$

where Y_{Ht} : net disposable income, V_{Ht} : wealth of households, c_1 : propensity to consume out of income, c_2 : propensity to consume out of wealth, λ : share of household wealth held in government securities, SEC_t : government securities

Step 3: Specify the rest of the equations

Emissions

- Fossil CO₂ emissions: $EMIS_{Ft} = CI_t Y_t$

- Carbon intensity: $CI_t = CI_{\min} + \frac{CI_{\max} - CI_{\min}}{1 + ((K_{Gt-1}/K_{Ct-1})/c_{CI})^{k_{CI}}}$

where Y_t : output, K_{Gt} : green capital stock, K_{Ct} : conventional capital stock

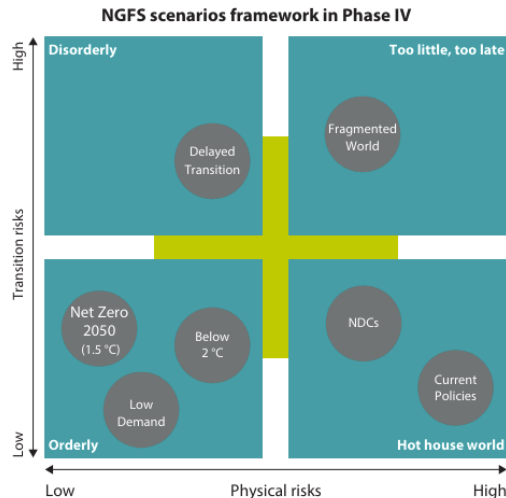
Step 4: Collect all equations

- The equations of DEFINE-GOV are available on the DEFINE model's website (<https://define-model.org/define-gov/>).

The **NGFS scenarios** have been developed by the central banking community to explore different levels of transition and physical risks depending on what climate policies might be implemented in the coming decades.

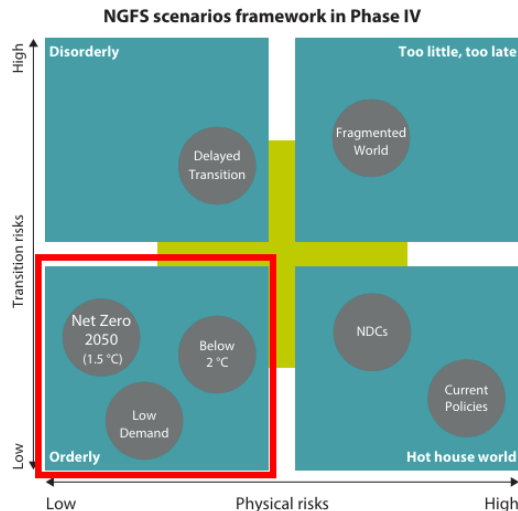
They include:

- Three orderly scenarios
- One disorderly scenario
- Two hot house world scenarios



Orderly scenarios assume climate policies are introduced early and become gradually more stringent. Both physical and transition risks are relatively subdued.

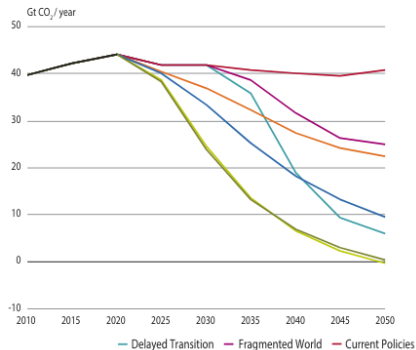
- The **Net Zero 2050** scenario limits global warming to 1.4°C through stringent climate policies and innovation, reaching global net zero CO₂ emissions around 2050.
- The **Below 2°C** scenario gradually increases the stringency of climate policies, limiting global warming to 1.6°C .



Source: NGFS (2023).

Global Yearly CO₂ Emissions

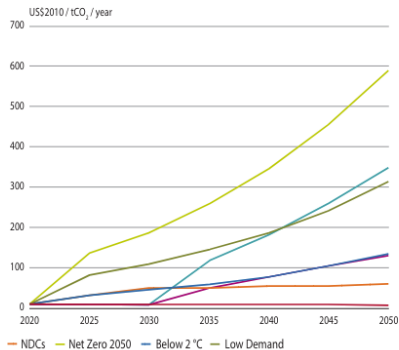
REMIND



Source: IIASA NGFS Climate Scenarios Database, REMIND model. World aggregates mask strong differences across sectors and jurisdictions. Regionally and sectorally granular information is available in the IIASA Portal. End of century warming outcomes shown. 5-year time step data.

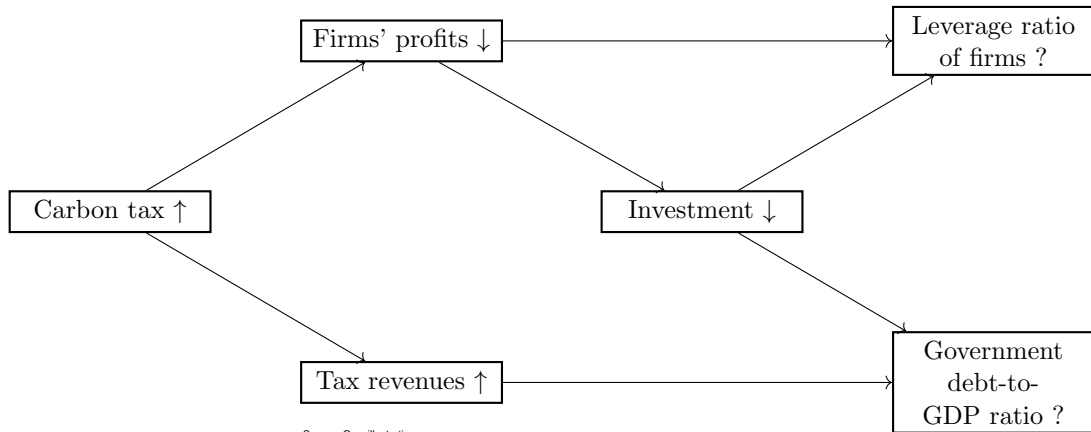
Shadow Carbon Price

REMIND



Source: IIASA NGFS Climate Scenarios Database, REMIND model. Shadow carbon prices are a weighted average of regional carbon prices at global level. Regionally and sectorally granular information is available in the IIASA Portal. End of century warming outcomes shown. 5-year time step data.

Transmission channels of an increase in carbon taxes in DEFINE-GOV

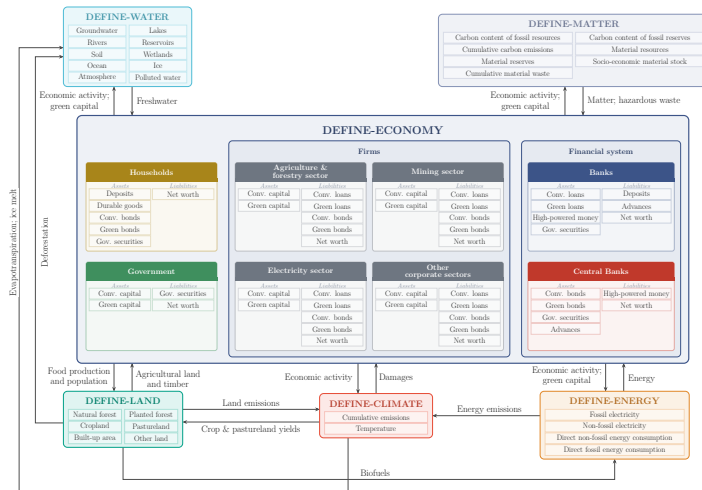


Source: Own illustration.

Outline

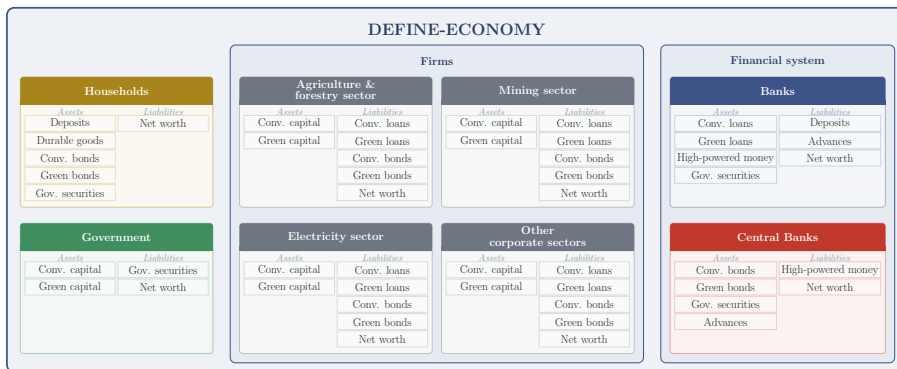
- 1 Accounting principles for stock-flow consistency
- 2 Principles for modelling macrofinancial and ecosystem processes
- 3 DEFINE-SIMPLE: model development and calibration
- 4 DEFINE-GOV: model development
- 5 **DEFINE-GLOBAL: land and water**
- 6 Areas for future research

DEFINE-GLOBAL: structure



Source: Own illustration.

DEFINE-GLOBAL: the economy module



Source: Own illustration.

DEFINE-LAND: physical stock-flow matrix

The physical stock-flow matrix for land shows conversion (physical flows) among different types of **land areas** (physical stocks).

Physical stock-flow matrix, land

	Natural forest	Planted forest	Cropland	Pastureland	Built-up area	Other land	Total
Opening stock	FOR_{Nt-1}	FOR_{Pt-1}	$CROP_{t-1}$	$PAST_{t-1}$	$BUILT_{t-1}$	$OTHER_{Lt-1}$	$LAND_T$
Deforestation for cropland	$-DEFOR_{Ct}$		$+DEFOR_{Ct}$				0
Deforestation for pastureland	$-DEFOR_{Pt}$			$+DEFOR_{Pt}$			0
Deforestation for other land	$-DEFOR_{Ot}$					$+DEFOR_{Ot}$	0
Deforestation for built-up area	$-DEFOR_B$				$+DEFOR_{Bt}$		0
Cropland reforestation/afforestation		$+REFOR_{Ct}$	$-REFOR_{Ct}$				0
Pastureland reforestation/afforestation		$+REFOR_{Pt}$		$-REFOR_{Pt}$			0
Cropland regenerated into natural forest	$+REGEN_{Ct}$		$-REGEN_{Ct}$				0
Pastureland regenerated into natural forest	$+REGEN_{Pt}$			$-REGEN_{Pt}$			0
Planted forest regenerated into natural forest	$+REGEN_{PFt}$	$-REGEN_{PFt}$					0
Other land regenerated into natural forest	$+REGEN_{Ot}$					$-REGEN_{Ot}$	0
Net conversion of natural forest to planted forest	$-CONV_{NPFt}$	$+CONV_{NPFt}$					0
Net conversion of pastureland to cropland			$+CONV_{PCt}$	$-CONV_{PCt}$			0
Net conversion of pastureland to built-up area				$-CONV_{PBt}$	$+CONV_{PBt}$		0
Net conversion of cropland to built-up area			$-CONV_{CBt}$		$+CONV_{CBt}$		0
Net conversion of other land to cropland			$+CONV_{OCt}$			$-CONV_{OCt}$	0
Net conversion of other land to pastureland				$+CONV_{OPt}$		$-CONV_{OPt}$	0
Closing stock	FOR_{Nt}	FOR_{Pt}	$CROP_t$	$PAST_t$	$BUILT_t$	$OTHER_{Lt}$	$LAND_T$

Source: Own illustration.

Note: The table captures annual global stocks and flows. Land is measured in million hectares.

DEFINE-WATER: physical stock-flow matrix

The physical stock-flow matrix for water shows the flow of water between available and unavailable **water stocks**.

Physical stock-flow matrix, water

	Groundwater	Lakes	Rivers	Reservoirs	Soil	Wetlands	Ocean	Ice	Atmosphere	Polluted water stock	Total
Opening stock	<i>GRW_{t-1}</i>	<i>LAKE_{t-1}</i>	<i>RIVE_{t-1}</i>	<i>RES_{t-1}</i>	<i>SOIL_{t-1}</i>	<i>WETLANDS_{t-1}</i>	<i>OCEAN_{t-1}</i>	<i>ICE_{t-1}</i>	<i>ATMO_{t-1}</i>	<i>PWS_{t-1}</i>	<i>WATER_T</i>
Precipitation		<i>+prec_{laket}</i>	<i>+prec_{rivet}</i>	<i>+prec_{rest}</i>	<i>+prec_{soilt}</i>	<i>+prec_{wett}</i>	<i>+prec_{oceant}</i>		<i>-prec_{totalt}</i>		0
Evapotranspiration		<i>-evap_{laket}</i>	<i>-evap_{rivet}</i>	<i>-evap_{rest}</i>	<i>-evap_{soilt}</i>	<i>-evap_{wett}</i>	<i>-evap_{oceant}</i>		<i>+evap_{totalt}</i>		0
Groundwater recharge	<i>+soil_{grwt}</i>				<i>-soil_{grwt}</i>						0
Groundwater discharge	<i>-disc_{grwt}</i>						<i>+disc_{grwt}</i>				0
River discharge			<i>-disc_{rivet}</i>				<i>+disc_{rivet}</i>				0
Reservoir inflow			<i>-rive_{rest}</i>	<i>+rive_{rest}</i>							0
River-based irrigation			<i>-rive_{irrt}</i>		<i>+rive_{irrt}</i>						0
Groundwater-based irrigation	<i>-grw_{irrt}</i>				<i>+grw_{irrt}</i>						0
Irrigation of wetlands			<i>-rive_{wett}</i>			<i>+rive_{wett}</i>					0
Thaw							<i>+ice_{decayt}</i>	<i>-ice_{decayt}</i>			0
Water pollution	<i>-PW_{grwt}</i>	<i>-PW_{lake}</i>	<i>-PW_{rive}</i>	<i>-PW_{res}</i>	<i>-PW_{At}</i>	<i>-PW_{wet}</i>				<i>+PW_t</i>	0
Water treatment			<i>+TW_t</i>							<i>-TW_t</i>	0
Closing stock	<i>GRW_t</i>	<i>LAKE_t</i>	<i>RIVE_t</i>	<i>RES_t</i>	<i>SOIL_t</i>	<i>WETLANDS_t</i>	<i>OCEAN_t</i>	<i>ICE_t</i>	<i>ATMO_t</i>	<i>PWS_t</i>	<i>WATER_T</i>

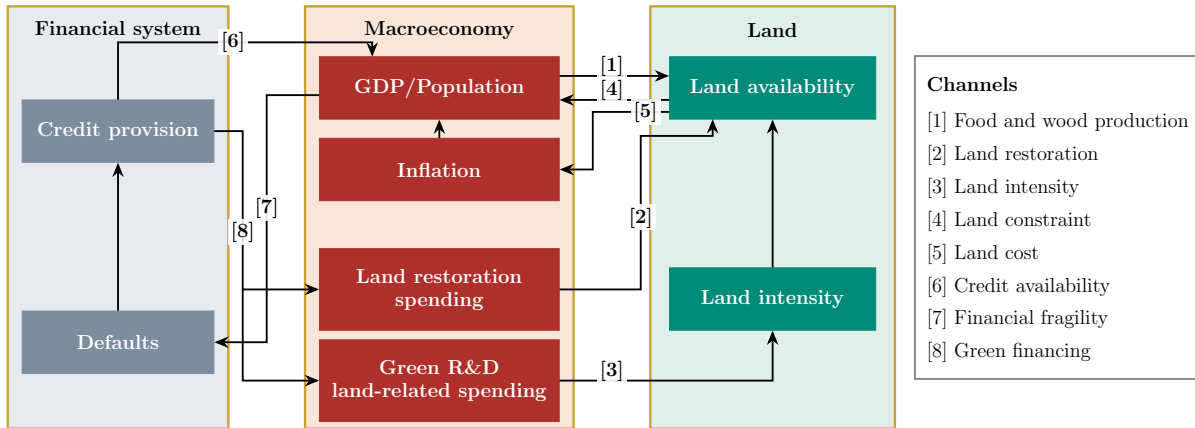
Note: The table captures annual global stocks and flows. Water is measured in trillion m³. The cells highlighted in grey denote the stocks or flows that act as residuals in the physical accounting identities.

Source: Own illustration.

Connecting green investment with finance

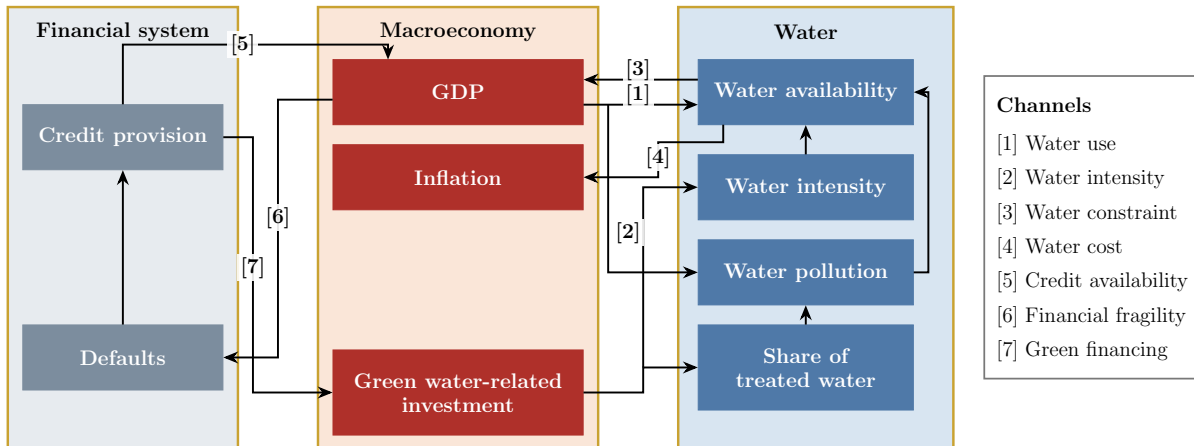
- There are four different non-financial corporate sectors with **input-output** interactions: 1) agriculture & forestry, 2) mining, 3) electricity and 4) other corporate sectors.
- Each sector has a **desired overall investment** which depends positively on the profit rate and sales.
- A part of this investment is **green** (i.e. it is conducive to lower water intensity, higher use of renewables etc.). The proportion of green investment depends on the carbon tax, green subsidies, the interest rate differential etc..
- Firms finance desired green investment via 1) retained profits, 2) green bonds, and 3) green bank loans.
- There is **credit rationing**: only a proportion of the demanded loans $(1-CR_{it})$ are provided by banks; CR_{it} is the degree of credit rationing for sector i .

Land conversion macrofinancial channels



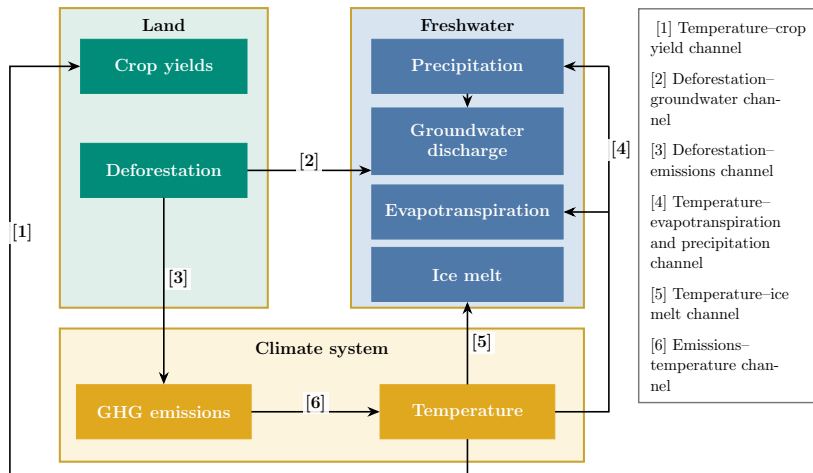
Source: Own illustration.

Water macrofinancial channels



Source: Own illustration.

Land conversion, water and climate feedback loop channels



Source: Own illustration.

Sectoral ecological efficiency index of sectors

- To assess the environmental performance of sectors, we use a sectoral ecological efficiency index that includes both **direct and indirect** environmental effects, allowing us to capture the environmental footprint of downstream activities.
- The **sectoral ecological efficiency index** ($SEEI_{it}$) takes values between 0 (maximum ecological efficiency) and 1 (minimum ecological efficiency).
- For each sector, the sectoral ecological efficiency index is a **weighted average of several environmental metrics**, such as CO_2 intensity, land intensity and water intensity.
- The sectoral ecological efficiency index is important for the ‘**penalising**’ **aspect of macrofinancial policies**.

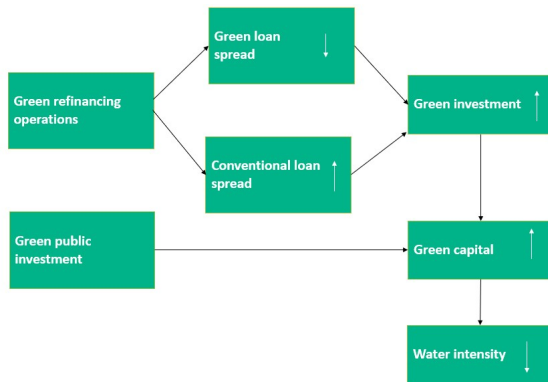
Sectoral ecological efficiency index - Direct and total effects

	Direct emissions-to-output ratio ($GtCO_2$ /trillion EUR)	Direct land-to-output ratio (million hectares/trillion EUR)	Direct water-to-output ratio (trillion m^3 /trillion EUR)	Sectoral ecological efficiency index (direct)	Total emissions-to-output ratio ($GtCO_2$ /trillion EUR)	Total land-to-output ratio (million hectares/trillion EUR)	Total water-to-output ratio (trillion m^3 /trillion EUR)	Sectoral ecological efficiency index (total)
Agriculture & forestry sector	0.138	917.268	0.275	<i>0.522</i>	0.259	1042.736	0.312	<i>0.808</i>
Mining sector	0.734	0.046	0.0001	<i>0.117</i>	1.108	14.697	0.005	<i>0.727</i>
Electricity sector	3.614	0.001	0.005	<i>0.259</i>	4.490	19.461	0.011	<i>0.736</i>
Other corporate sectors	0.116	0.095	0.001	<i>0.005</i>	3.481	581.557	0.180	<i>0.525</i>

Note: CO_2 emissions, land (cropland and pastureland), water and gross output are calculated based on EXIOBASE data

Effects of green public investment and green refinancing operations

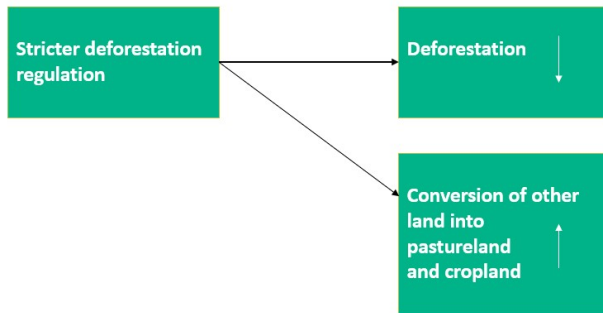
- **Scenario 1 - Green public investment:** Green public investment (including water-related investment) increases after 2027.
- **Scenario 2 – Green refinancing operations:** After 2027, the policy interest rate increases/decreases based on the environmental profile of the bank loan portfolio.



Source: Own illustration.

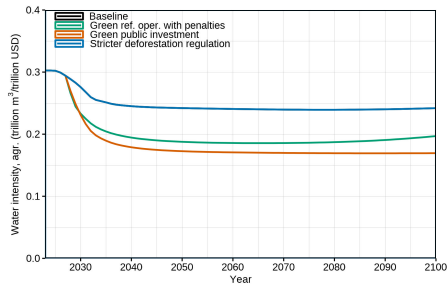
Effects of deforestation regulation

- **Scenario 3 – Stricter deforestation regulation:** After 2027, stricter deforestation regulation restricts the amount of natural forest that is deforested every year.



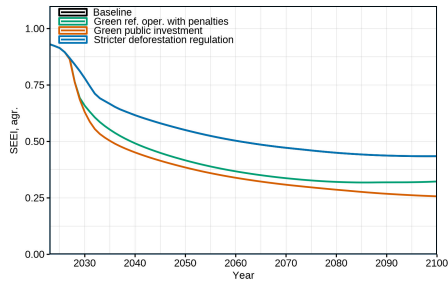
Source: Own illustration.

Effects of green public investment, green refinancing operations and deforestation regulation



Source: Own illustration.

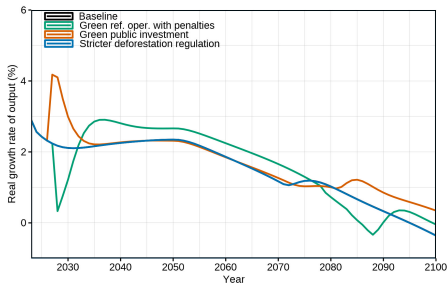
**Water intensity,
agriculture**



Source: Own illustration.

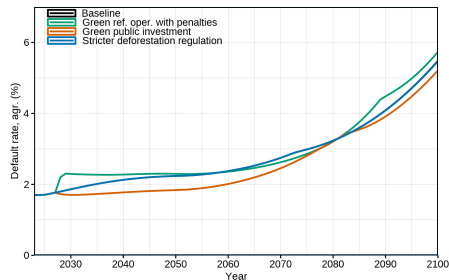
**Sectoral Ecological Efficiency
Index, agriculture ($SEEI_A$)**

Effects of green public investment, green refinancing operations and deforestation regulation



Source: Own illustration.

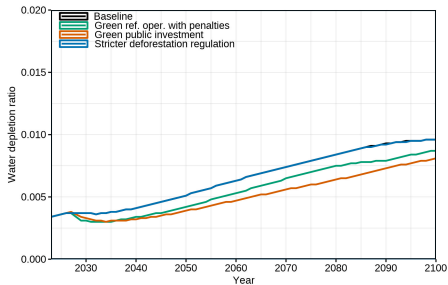
**Real growth rate of
output (%)**



Source: Own illustration.

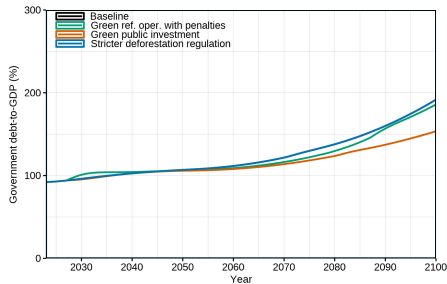
**Default rate (%) of the
non-financial corp. sector**

Effects of green public investment, green refinancing operations and deforestation regulation



Source: Own illustration.

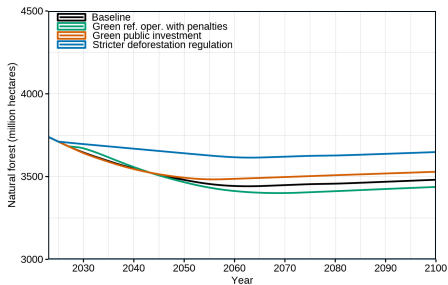
Water depletion ratio (water use/available water stock)



Source: Own illustration.

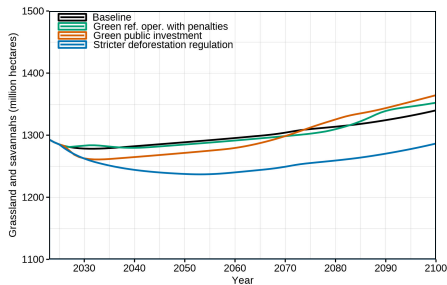
Government debt-to-GDP ratio (%)

Effects of green public investment, green refinancing operations and deforestation regulation



Source: Own illustration.

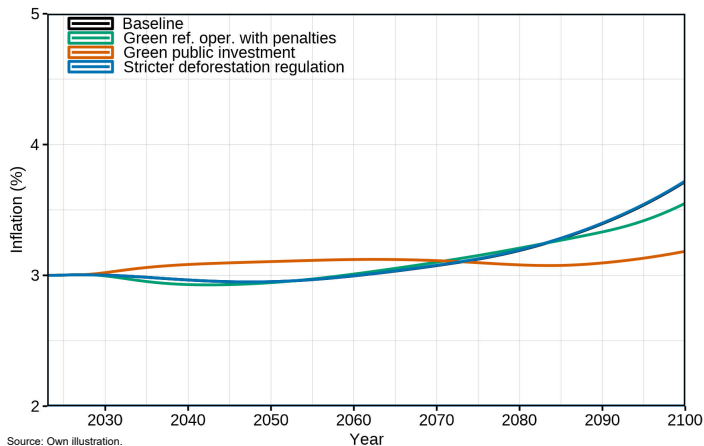
Natural forest
(million hectares)



Source: Own illustration.

Grassland and savannas
(million hectares)

Effects of green public investment, green refinancing operations and deforestation regulation



Outline

- 1 Accounting principles for stock-flow consistency
- 2 Principles for modelling macrofinancial and ecosystem processes
- 3 DEFINE-SIMPLE: model development and calibration
- 4 DEFINE-GOV: model development
- 5 DEFINE-GLOBAL: land and water
- 6 Areas for future research**

Areas for future research in E-SFC modelling

- Degrowth, consumption patterns and environmental regulation
- Environmental damages and adaptation
- Links between environmental policies and balance of payments constraints
- Sectoral dynamics (e.g. through input-output tables) and inequality
- Country-specific E-SFC models
- Global North-Global South interactions and global climate justice

Required readings

- Dafermos, Y. and Nikolaidi, M. (forthcoming). Ecological stock-flow consistent modelling: a theoretical and practical guide.
- Dafermos, Y., Nikolaidi, M. and Galanis, G. (2017). ‘A stock-flow-fund ecological macroeconomic model’, *Ecological Economics*, 131, 191–207.
- Nikiforos, M. and Zezza, G. (2017). ‘Stock-flow consistent macroeconomic models: a survey’, *Journal of Economic Surveys*, 31 (5), 1204–1239.

Additional readings

- Bovari, E., Giraud, G. and Mc Isaac, F. (2018). ‘Coping with collapse: a stock-flow consistent monetary macrodynamics of global warming’, *Ecological Economics*, 147, 383–398.
- Dafermos, Y. and Nikolaidi, M. (2021). ‘How can green differentiated capital requirements affect climate risks? A dynamic macrofinancial analysis’, *Journal of Financial Stability*, 54, 100871.
- Dafermos, Y., Nikolaidi, M. and Galanis, G. (2018). ‘Climate change, financial stability and monetary policy’, *Ecological Economics*, 152, 219–234.
- Dafermos, Y. and Nikolaidi, M. (2022). ‘Assessing climate policies: an ecological stock-flow consistent perspective’, *European Journal of Economics and Economic Policies: Intervention*, 19 (3), 338–356.
- Godley, W. and Lavoie, M. (2012). *Monetary Economics: An Integrated Approach to Credit, Money, Production and Wealth*. Palgrave Macmillan, Basingstoke, UK, chapter 2.
- Zezza, G. and Zezza, F. (2019). ‘On the design of empirical stock-flow consistent models’, *European Journal of Economics and Economic Policies: Intervention*, 16 (1), 134–158.