

DEFINE-SIMPLE

Model Manual | Version 1.1

Yannis Dafermos¹ Maria Nikolaidi²

¹SOAS University of London, UK

²University of Greenwich, UK

Website: www.define-model.org

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1. Overview

The DEFINE-SIMPLE model is a simplified model of the DEFINE (Dynamic Ecosystem-FINance-Economy) modelling framework developed by Dafermos et al. (2017), Dafermos et al. (2018), Dafermos and Nikolaidi (2019), Dafermos and Nikolaidi (2021) and Dafermos and Nikolaidi (2022).¹ It 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.

Table 1 shows the balance sheet matrix of the DEFINE-SIMPLE model. Symbols with a plus sign indicate assets, while symbols with a minus sign indicate liabilities. For example, deposits (D_t) are an asset for households and a liability for banks, while green loans (L_{Gt}) are an asset for banks and a liability for firms. The bottom line shows the net worth of each sector. Since, at the aggregate level, financial assets are equal to financial liabilities, the total net worth of the economy is equal to the capital stock, which is the only real asset.

Table 1: Balance sheet matrix, DEFINE-SIMPLE

	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	$+K_t$

Note: All stocks are reported in monetary units. The cells highlighted in grey denote the stocks that act as residuals in the accounting identities.

Table 2 shows the transactions flow matrix that shows all the transactions that take place between the sectors of the economy. For each sector, inflows are denoted by a plus sign, while outflows are denoted by a minus sign. For example, consumption spending (CO_t) is an outflow for households, but it is an inflow for firms since the latter receive the money that households use to buy consumption goods. The columns represent the budget constraints of the sectors. For firms and banks, a distinction is made between the current account, which shows flows of revenues and disbursements, and the capital account, which captures how real and financial investment is financed. For instance, in the case of firms, the capital account shows that their (green and conventional) investment in real assets is financed via retained profits (RP_t) and (green and conventional) loans. Note that the bottom part of the matrix shows transactions related to changes in financial assets and liabilities.

¹More information about DEFINE is available here.

Table 2: Transactions flow matrix, DEFINE-GOV

	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

Note: All flows are reported in monetary units. The cells highlighted in grey denote the flows that act as residuals in the accounting identities.

2. Equations

2.1. Households

Eq. (1) gives the disposable income of households (Y_{Ht}); W_t is the wage income of households, DP_t denotes the distributed profits of firms, BP_t denotes the profits of banks, int_D is the interest rate on deposits and D_t is the amount of deposits. Wage income is a proportion (s_W) of total output (Y_t), where s_W is the wage share (Eq. (2)). Households' consumption (CO_t) depends on lagged disposable income (which is a proxy for the expected one) and lagged deposits (Eq. (3)); c_1 is the propensity to consume out of disposable income and c_2 is the propensity to consume out of deposits. Households deposit the income that has not been consumed (Eq. (4)).

$$Y_{Ht} = W_t + DP_t + BP_t + int_D D_{t-1} \quad (1)$$

$$W_t = s_W Y_t \quad (2)$$

$$CO_t = c_1 Y_{Ht-1} + c_2 D_{t-1} \quad (3)$$

$$D_t = D_{t-1} + Y_{Ht} - CO_t \quad (4)$$

2.2. Firms

Output (Y_t) is demand-determined and equal to the sum of consumption and investment (Eq. (5)). Firm total profits (TP_t) are equal to output minus wages and interest payments on conventional and green loans (Eq. (6)); int_C is the interest rate on conventional loans, int_G is the interest rate on green loans, L_{Ct} is the amount of conventional loans and L_{Gt} is the amount of green loans. Firms' retained profits (RP_t) are a proportion (s_F) of their total profits (Eq. (7)). The distributed profits of firms (DP_t) are determined as a residual (Eq. (8)). Eq. (9) gives the profit rate (r_t).

$$Y_t = CO_t + I_t \quad (5)$$

$$TP_t = Y_t - W_t - int_C L_{Ct-1} - int_G L_{Gt-1} \quad (6)$$

$$RP_t = s_F TP_t \quad (7)$$

$$DP_t = TP_t - RP_t \quad (8)$$

$$r_t = \frac{TP_t}{K_t} \quad (9)$$

Total investment (I_t) is affected by a number of factors (Eq. (10)) (see e.g. Blecker, 2002). For simplicity, we assume here that investment depends only on the rate of profit (r_t). Green investment (I_{Gt}) is a proportion of total investment (Eq. (11)). This proportion of green investment in total investment (β_t) depends on two factors (Eq. (12)). The first factor is captured by the term β_0 , which reflects exogenous developments such as environmental preferences or institutional changes linked with environmental regulation. The second factor, captured by the term $\beta_1(int_G - int_C)$, reflects the borrowing cost of investing in green capital relative to conventional capital. As the cost of borrowing for investing in green capital declines compared to the cost of borrowing for investing in conventional capital, firms tend to increase green investment. Conventional investment (I_{Ct}) is equal to total investment minus green investment (Eq. (13)).

$$I_t = (\alpha_0 + \alpha_1 r_{t-1}) K_{t-1} \quad (10)$$

$$I_{Gt} = \beta_t I_t \quad (11)$$

$$\beta_t = \beta_0 - \beta_1 (int_G - int_C) \quad (12)$$

$$I_{Ct} = I_t - I_{Gt} \quad (13)$$

The change in the green capital stock is equal to green investment (Eq. (14)). This is also the case for the change in conventional capital stock (Eq. (15)). The total capital stock is the sum of green and conventional capital (Eq. (16)).

$$K_{Gt} = K_{Gt-1} + I_{Gt} \quad (14)$$

$$K_{Ct} = K_{Ct-1} + I_{Ct} \quad (15)$$

$$K_t = K_{Ct} + K_{Gt} \quad (16)$$

As retained profits are not in general sufficient to cover investment expenditures, firms need external finance obtained via bank loans. The amount of loans demanded by firms is provided by banks — the model assumes no quantity rationing of credit.² The change in green loans is given by Eq. (17). Conventional loans are determined as an identity (Eq. (18)). Total loans are the sum of green and conventional loans (Eq. (19)).

$$L_{Gt} = L_{Gt-1} + I_{Gt} - \beta_t RP_t \quad (17)$$

$$L_{Ct} = L_{Ct-1} + I_{Ct} + I_{Gt} - RP_t - (L_{Gt} - L_{Gt-1}) \quad (18)$$

$$L_t = L_{Ct} + L_{Gt} \quad (19)$$

2.3. Commercial banks

Bank profits (BP_t) are equal to the income that banks receive on green and conventional loans minus the interest on deposits that they have to pay (Eq. (20)). Eq. (21) shows that deposits should be equal to total loans. This is the redundant equation of the model, which is not included in the simulations of the model – it is only used to check that the model is stock-flow consistent.

$$BP_t = int_C L_{Ct-1} + int_G L_{Gt-1} - int_D D_{t-1} \quad (20)$$

$$D_{redt} = L_t \quad (21)$$

2.4. Emissions

Total fossil CO₂ emissions are given by Eq. (22); CI_t is the carbon intensity of the economy and Y_t is output. Green capital is conducive to a lower carbon intensity. Hence, we postulate that the efficiency related to carbon intensity increases when the ratio of green capital (K_{Gt}) to conventional capital (K_{Ct}) rises, as shown in Eq. (23). CI_{\min} is the minimum potential value of carbon intensity, which is approached when green capital becomes sufficiently high relative to conventional capital. CI_{\max} is the maximum potential value of carbon intensity, which is approached when K_{Gt}/K_{Ct} becomes sufficiently low. The use of a logistic function allows us to take into account learning processes which play a key role in the diffusion and efficiency of new technologies.³

$$EMIS_{Ft} = CI_t Y_t \quad (22)$$

$$CI_t = CI_{\min} + \frac{CI_{\max} - CI_{\min}}{1 + ((K_{Gt-1}/K_{Ct-1})/c_{CI})^{k_{CI}}} \quad (23)$$

²See Dafermos (2012), Nikolaidi (2014) and Jakab and Kumhof (2019) for models with credit rationing.

³For the importance of these processes in energy systems and renewable energy technologies, see e.g. Kahouli-Brahmi (2009) and Tang and Popp (2016).

2.5. Auxiliary equations

The potential output (Y_{Pt}) is capital-determined and is higher the higher the capital stock (K_t) and the productivity of capital (v) (Eq. (24)). The capacity utilisation rate (u_t) is the ratio of actual to potential output (Eq. (25)). The leverage ratio (lev_t) is defined in Eq. (26), while the growth rate of output (g_{Yt}) is given by Eq. (27).

$$Y_{Pt} = vK_t \tag{24}$$

$$u_t = Y_t/Y_{Pt} \tag{25}$$

$$lev_t = L_t/K_t \tag{26}$$

$$g_{Yt} = (Y_t - Y_{t-1})/Y_{t-1} \tag{27}$$

3. Symbols and values for variables and parameters

Table 3: Symbols and initial values for endogenous variables (baseline scenario)

Symbol	Description	Variable category	Initial value	Source/remarks
β	Share of green investment in total investment	Model-constrained	0.0643	Calculated using Eq. (11)
BP	Profits of banks (USD trillion)	Model-constrained	4.8326	Calculated using Eq. (20)
CI	Carbon intensity (GtCO ₂ per USD trillion)	Model-constrained	0.3537	Calculated using Eq. (22)
CO	Consumption expenditures (USD trillion)	Model-constrained	79.2425	Calculated using Eq. (5)
D	Deposits (USD trillion)	Free	99.4542	Determined by the redundant equation
D_{red}	Deposits redundant (USD trillion)	Model-constrained	99.4542	Calculated using Eq. (21)
DP	Distributed profits (USD trillion)	Model-constrained	14.5298	Calculated using Eq. (8)
$EMIS_F$	Fossil carbon emissions (GtCO ₂)	Free	37.82	Taken from Global Carbon Budget
g_D	Growth rate of deposits	Free	0.029	Determined based on the initial growth rate of output
g_K	Growth rate of capital stock	Free	0.029	Determined based on the initial growth rate of output
g_{KC}	Growth rate of conventional capital stock	Free	0.029	Determined based on the initial growth rate of output
g_{KG}	Growth rate of green capital stock	Free	0.029	Determined based on the initial growth rate of output
g_L	Growth rate of total loans	Free	0.029	Determined based on the initial growth rate of output
g_{LC}	Growth rate of conventional loans	Free	0.029	Determined based on the initial growth rate of output
g_{LG}	Growth rate of green loans	Free	0.029	Determined based on the initial growth rate of output
g_Y	Growth rate of output	Free	0.029	Based on World Bank
g_{YH}	Growth rate of household income	Free	0.029	Determined based on the initial growth rate of output
I	Investment (USD trillion)	Free	27.6975	Calculated from the identity $I=I/Y*Y$; where I/Y is the proportion of total investment in GDP (taken from World Bank)
I_C	Conventional investment (USD trillion)	Model-constrained	25.9175	Calculated using Eq. (13)
I_G	Green investment (USD trillion)	Free	1.78	Based on CPI (2024)
K	Capital stock (USD trillion)	Model-constrained	982.7823	Calculated using Eq. (16)
K_C	Conventional capital stock (USD trillion)	Model-constrained	919.623	Calculated using Eq. (15)
K_G	Green capital stock (USD trillion)	Model-constrained	63.1593	Calculated using Eq. (14)
L	Total loans (USD trillion)	Free	99.4542	Calculated from the identity $L=L/Y*Y$; where L/Y is the credit to non-financial corporations in percent of GDP taken from BIS (Bank for International Settlements)
L_C	Conventional loans (USD trillion)	Model-constrained	93.0627	Calculated using Eq. (18)
L_G	Green loans (USD trillion)	Model-constrained	6.3915	Calculated using Eq. (19)
lev	Leverage ratio	Model-constrained	0.1012	Calculated using Eq. (27)
r	Rate of profit	Model-constrained	0.0401	Calculated using Eq. (9)
RP	Retained profits (USD trillion)	Model-constrained	24.8946	Calculated using Eq. (17)
TP	Total profits of firms (USD trillion)	Model-constrained	39.4244	Calculated using Eq. (6)
u	Capacity utilisation rate	Free	0.73	Based on World Bank, Enterprise Surveys
W	Wage income (USD trillion)	Model-constrained	58.817	Calculated using Eq. (2)
Y	Output (USD trillion)	Free	106.94	Taken from World Bank data (2023 prices)

Y_H	Disposable income of households (USD trillion)	Model-constrained	82.0454	Calculated using Eq. (1)
Y_P	Potential output (USD trillion)	Model-constrained	146.4932	Calculated using Eq. (25)

Table 4: Symbols and values for parameters (baseline scenario)

Symbol	Description	Parameter category	Value	Source/remarks
α_0	Parameter related to autonomous investment	Model-constrained	0.025	Calculated using Eq. (10)
α_1	Sensitivity of investment rate to profit rate	Free	0.1	Selected from a reasonable range of values
β_0	Autonomous share of green investment	Model-constrained	0.0643	Calculated using Eq. (12)
β_1	Sensitivity of green investment share to interest rate differential	Free	1	Selected from a reasonable range of values
c_1	Propensity to consume out of disposable income	Model-constrained	0.9454	Calculated using Eq. (3)
c_2	Propensity to consume out of deposits	Free	0.04	Selected from a reasonable range of values
c_{CI}	Green-to-conventional capital ratio at which carbon intensity takes its mean value	Model-constrained	0.2261	Calculated using Eq. (23)
CI_{max}	Maximum potential value of carbon intensity	Free	0.4244	Selected from a reasonable range of values
CI_{min}	Minimum potential value of carbon intensity	Free	0.1768	Selected from a reasonable range of values
int_C	Interest rate on conventional loans	Free	0.09	Based on World Bank
int_D	Interest rate on deposits	Free	0.04	Based on World Bank
int_G	Interest rate on green loans	Free	0.09	Based on World Bank
k_{CI}	Steepness of carbon intensity improvement	Free	0.769	Selected from a reasonable range of values
s_F	Retention rate of firms	Model-constrained	0.6315	Calculated using Eq. (7)
s_W	Wage share	Free	0.55	Based on Penn World Table 10.0
v	Capital productivity	Model-constrained	0.1491	Calculated using Eq. (24)

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