DEFINE-GOV

Model Manual | Version 1.0

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1. Overview

The DEFINE-GOV 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] The model focuses on analysing the role of carbon taxes and green subsidies in the green transition, and the implications of green policies for public indebtedness. DEFINE-GOV consists of four sectors: firms, households, banks and the government sector. The government sector undertakes consumption spending, collects income taxes from households and firms, imposes carbon taxes and provides green subsidies. It also issues government securities that are bought by households and banks. The stock of these securities corresponds to public debt.

The balance sheet matrix of DEFINE-GOV is shown in Table 1. Symbols with a plus sign indicate assets, while symbols with a minus sign indicate liabilities. For example, government secutities (SEC_{Ht}) are an asset for households and a liability for the government, 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-GOV

	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	$-SEC_t$	$+K_t$

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, taxes are an outflow for households and an inflow for the government. 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.

[1] More information about the model is available here.

Table 2: Transactions flow matrix, DEFINE-GOV

	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	$+int_S SEC_{Ht-1}$			$+int_S SEC_{Bt-1}$		$-int_S SEC_{t-1}$	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

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 gross disposable income of households (Y_{HGt}); 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, D_t is the amount of deposits, int_S is the interest rate on government securities, SEC_{Ht} are the government securities held by households. Wage income is a proportion (s_W) of total output (Y_t), where s_W is the wage share (Eq. (2)). Eq. (3) defines the net disposable income of households (Y_{Ht}), which is equal to the gross disposable income minus the taxes on households' gross disposable income (T_{Ht}). Households' consumption (C_t) depends on lagged disposable income (which is a proxy for the expected one) and lagged wealth (Eq. (4)); c_1 is the propensity to consume out of disposable income and c_2 is the propensity to consume out of wealth.

$$Y_{HGt} = W_t + DP_t + BP_t + int_D D_{t-1} + int_S SEC_{Ht-1} \tag{1}$$

$$W_t = s_W Y_t \tag{2}$$

$$Y_{Ht} = Y_{HGt} - TAX_{Ht} \tag{3}$$

$$CO_{PRIt} = c_1 Y_{Ht-1} + c_2 V_{Ht-1} \tag{4}$$

Eq. (5) defines the wealth of households (V_{Ht}). Households invest their expected wealth in two different assets: government securities (SEC_{Ht}) and deposits. Eq. (6), shows that government securities are a proportion (λ) of households' wealth. Households deposit the income that has not been consumed and invested in new government securities (Eq. (7)).

$$V_{Ht} = SEC_{Ht} + D_t \tag{5}$$

$$SEC_{Ht} = \lambda V_{Ht-1} \tag{6}$$

$$D_t = D_{t-1} + Y_{Ht} - CO_{PRIt} - (SEC_{Ht} - SEC_{Ht-1}) \tag{7}$$

2.2. Firms

In line with the post-Keynesian tradition, actual output (Y_t) is demand-determined (Eq. (8)): it is equal to the sum of private consumption (CO_{PRIt}), investment (I_t), and government consumption (CO_{GOVt}). Firm total gross profits (TP_{Gt}) are equal to output minus wages and interest payments on conventional and green loans (Eq. (9)); 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. The net profits of firms (TP_t) are equal to gross profits plus the value of green subsidies provided by the government (SUB_t) minus the taxes on firms' profits (TAX_{Ft}) and the taxes on carbon emissions (TAX_{Ct}) (Eq. (10)). Firms' retained profits (RP_t) are a proportion (s_F) of their total profits (Eq. (11)). The distributed profits of firms (DP_t) are determined as a residual (Eq. (12)). Eq. (13) gives the profit rate (r_t).

$$Y_t = CO_{PRIt} + I_t + CO_{GOVt} \tag{8}$$

$$TP_{Gt} = Y_t - W_t - int_C L_{Ct-1} - int_G L_{Gt-1} \tag{9}$$

$$TP_t = TP_{Gt} - TAX_{Ft} - TAX_{Ct} + SUB_t \tag{10}$$

$$RP_t = s_F TP_t \tag{11}$$

$$DP_t = TP_t - RP_t \tag{12}$$

$$r_t = \frac{TP_t}{K_t} \tag{13}$$

Total investment (I_t) is affected by a number of factors (Eq. (14))(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. (15)). This proportion of green investment in total investment (β_t) depends on four factors (Eq. (16)). 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. The third factor is captured by the total unit cost of producing fossil energy ($tucf_t$), which increases when carbon taxes become higher. The fourth factor captured by the gov_{SUB} is the green subsidy rate funded by the government.

$tucf_t$ is given by Eq. (17). The equation shows that the $tucf_t$ depends on the pre-tax unit cost of producing fossil energy ($pucf$, measured in USD trillion/EJ), the carbon tax (τ_C) and the CO_2 intensity of fossil energy (ω, measured in GtCO_2/EJ). Conventional investment (I_{Ct}) is equal to total investment minus green investment (Eq. (18)).

$$I_t = (\alpha_0 + \alpha_1 r_{t-1})K_{t-1} \tag{14}$$

$$I_{Gt} = \beta_t I_t \tag{15}$$

$$\beta_t = \beta_0 - \beta_1(int_G - int_C) + \beta_2 tucf_{t-1} + \beta_3 gov_{SUB} \tag{16}$$

$$tucf_t = pucf + \tau_C \omega \tag{17}$$

$$I_{Ct} = I_t - I_{Gt} \tag{18}$$

The change in the green capital stock is equal to green investment (Eq. (19)). This is also the case for the change in conventional capital stock (Eq. (20)). The total capital stock is the sum of green and conventional capital (Eq. (21)).

$$K_{Gt} = K_{Gt-1} + I_{Gt} \tag{19}$$

$$K_{Ct} = K_{Ct-1} + I_{Ct} \tag{20}$$

$$K_t = K_{Ct} + K_{Gt} \tag{21}$$

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. (22). Conventional loans are determined as an identity (Eq. (23)). Total loans are the sum of green and conventional loans (Eq. (24)).

$$L_{Gt} = L_{Gt-1} + I_{Gt} - \beta_t RP_t \tag{22}$$

$$L_{Ct} = L_{Ct-1} + I_{Ct} + I_{Gt} - RP_t - (L_{Gt} - L_{Gt-1}) \tag{23}$$

$$L_t = L_{Ct} + L_{Gt} \tag{24}$$

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

2.3. Commercial banks

Bank profits (BP_t) are equal to the income that banks receive on green and conventional loans and their investment in government securities minus the interest on deposits that they have to pay (Eq. (25)); SEC_{Bt} are the government securities held by banks. The government securities bought by banks are equal to the deposits held minus the loans provided (Eq. (26)). Eq. (27) shows that government securities held by banks should be equal to total government securities minus the government securities held by households. This is the redundant equation of the model, which is not included in the solving process.

$$BP_t = int_C L_{Ct-1} + int_G L_{Gt-1} + int_S SEC_{Bt-1} - int_D D_{t-1} \tag{25}$$

$$SEC_{Bt} = D_t - L_{Gt} - L_{Ct} \tag{26}$$

$$SEC_{Bredt} = SEC_t - SEC_{Ht} \tag{27}$$

2.4. Government

The government sector issues securities (SEC_t) to finance its deficit. The government debt is therefore equal to the outstanding amount of securities. The revenues of the government sector include taxes on household income, taxes on firms' profits and taxes on carbon. Current government expenditures comprise government consumption, green subsidies and the interest paid on government debt. Eq. (28) shows that the change in government securities is equal to the current government expenditures minus the revenues of the government; TAX_t are the total taxes, SUB_t are the green government subsidies and CO_{GOVt} are the government consumption expenditures.

Government consumption expenditures are set exogenously as a fraction, gov_C, of output (Eq. (29)). Green subsidies that are used to finance the production of renewable energy (Eq. (30)) are a proportion (gov_{SUBit}) of green private investment.

$$SEC_t = SEC_{t-1} + int_S SEC_{t-1} - TAX_t + SUB_t + CO_{GOVt} \tag{28}$$

$$CO_{GOVt} = gov_C Y_{t-1} \tag{29}$$

$$SUB_t = gov_{SUB} I_{Gt-1} \tag{30}$$

The taxes on households' disposable income are a proportion (τ_H) of the gross disposable income (Eq. (31)), the taxes on firms' profits are a proportion (τ_F) of total gross profits of firms (see Eq. (32)) and the revenues from carbon taxes are given by the carbon tax (τ_{Ct}) times the fossil carbon emissions (Eq. (33)). The total taxes are equal to the sum of taxes on households, the taxes on firms and the revenues from carbon taxes (Eq. (34)); TAX_{Ht} are the taxes on households' disposable income, TAX_{Ft} are the taxes on firms' profits, TAX_{Ct} are the revenues from carbon taxes.

$$TAX_{Ht} = \tau_H Y_{HGt-1} \tag{31}$$

$$TAX_{Ft} = \tau_F TP_{Gt-1} \tag{32}$$

$$TAX_{Ct} = \tau_C EMIS_{INt-1} \tag{33}$$

$$TAX_t = TAX_{Ht} + TAX_{Ft} + TAX_{Ct} \tag{34}$$

2.5. Emissions

Total fossil CO_2 emissions are given by Eq. (35); 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. (36). $CI_{\min}$ 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]

$$EMIS_{Ft} = CI_t Y_t \tag{35}$$

$$CI_t = CI_{\min} + \frac{CI_{\max} - CI_{\min}}{1 + ((K_{Gt-1}/K_{Ct-1})/c_{CI})^{k_{CI}}} \tag{36}$$

2.6. 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. (37)). The capacity utilisation rate (u_t) is the ratio of actual to potential output (Eq. (38)). The leverage ratio (lev_t) and the government securities-to-GDP are defined in Eqs. (39) and (40) respectively. The growth rate of output (g_{Yt}) is given by Eq. (41).

$$Y_{Pt} = vK_t \tag{37}$$

$$u_t = Y_t/Y_{Pt} \tag{38}$$

$$lev_t = L_t/K_t \tag{39}$$

$$SEC_{Yt} = SEC_t/Y_t \tag{40}$$

$$g_{Yt} = \left(Y_t - Y_{t-1}\right)/Y_{t-1} \tag{41}$$

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

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. (15)
BP	Profits of banks	Model-constrained	4.3992	Calculated using Eq. (25)
CI	Carbon intensity	Model-constrained	0.3537	Calculated using Eq. (35)
CO_{GOV}	Government expenditure	Free	18.1798	Taken from World Bank data for the global economy (2023 prices)
CO_{PRI}	Private consumption expenditures	Model-constrained	61.0627	Calculated using Eq. (8)
D	Deposits	Free	130	Based on Allianz (2024)
DP	Distributed profits	Model-constrained	8.8188	Calculated using Eq. (12)
$EMIS_F$	Fossil carbon emissions	Free	37.82	Taken from CDIAC (Carbon Dioxide Information Analysis Center)
g_D	Growth rate of deposits	Free	0.029	Determined based on the initial growth rate of output
g_{EMISF}	Growth rate of emissions	Free	0.029	Determined based on the initial growth rate of output
g_{IG}	Growth rate of green investment	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_{SEC}	Growth rate of government securities	Free	0.029	Determined based on the initial growth rate of output
g_{SECB}	Growth rate of bank-held government securities	Free	0.029	Determined based on the initial growth rate of output
g_{SECH}	Growth rate of household-held government securities	Free	0.029	Determined based on the initial growth rate of output
g_{TPG}	Growth rate of gross profits	Free	0.029	Determined based on the initial growth rate of output
g_{VH}	Growth rate of household wealth	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 disposable household income	Free	0.029	Determined based on the initial growth rate of output
g_{YHG}	Growth rate of gross household income	Free	0.029	Determined based on the initial growth rate of output
I	Investment	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	Model-constrained	25.9175	Calculated using Eq. (18)
I_G	Green investment	Free	1.78	Based on CPI (2024)
K	Capital stock	Model-constrained	982.7823	Calculated using Eq. (21)
K_C	Conventional capital stock	Model-constrained	919.623	Calculated using Eq. (20)
K_G	Green capital stock	Model-constrained	63.1593	Calculated using Eq. (19)

L	Total loans (USD trillion)	Free	99.4542	Calculated from the identity L=L/Y*Y; where L/Y is the credit to the 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. (24)
L_G	Green loans (USD trillion)	Model-constrained	6.3915	Calculated using Eq. (23)
lev	Leverage ratio	Model-constrained	0.1012	Calculated using Eq. (40)
r	Rate of profit	Model-constrained	0.0343	Calculated using Eq. (14)
RP	Retained profits	Model-constrained	24.8946	Calculated using Eq. (22)
SEC	Government securities	Free	100.5236	Taken from IMF
SEC_B	Government securities held by banks	Model-constrained	30.5458	Calculated using Eq. (26)
SEC_{Bred}	Redundant government securities held by banks	Free	30.5458	Redundant equation
SEC_H	Government securities held by households	Model-constrained	69.9778	Calculated using Eq. (27)
SEC_Y	Government securities-to-GDP ratio	Model-constrained	0.94	Calculated using Eq. (41)
SUB	Green government subsidies	Free	0.14	Based on World Bank
TAX	Total taxes	Model-constrained	17.9681	Calculated using Eq. (28)
TAX_C	Carbon tax revenues	Free	0.104	Taken from World Bank (2024)
TAX_F	Taxes on firms' profits	Model-constrained	5.747	Calculated using Eq. (32)
TAX_H	Taxes on households	Model-constrained	12.1171	Calculated using Eq. (34)
TP	Total profits of firms	Model-constrained	33.7134	Calculated using Eq. (10)
TP_G	Gross profits of firms	Model-constrained	39.4244	Calculated using Eq. (9)
$tucf$	Total unit cost of fossil energy production	Model-constrained	0.0212	Calculated using Eq. (17)
u	Capacity utilisation rate	Free	0.73	Based on World Bank data (Enterprise Surveys) for the global economy
V_H	Household wealth	Model-constrained	199.9778	Calculated using Eq. (6)
W	Wage income	Model-constrained	58.817	Calculated using Eq. (2)
Y	Nominal output	Free	106.94	Taken from World Bank data (2023 prices)
Y_H	Disposable income of households	Model-constrained	66.6986	Calculated using Eq. (3)
Y_{HG}	Gross disposable income of households	Model-constrained	78.8158	Calculated using Eq. (1)
Y_P	Potential output	Model-constrained	146.4932	Calculated using Eq. (38)

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	0.0256	Calculated using Eq. (13)
α_1	Sensitivity of the investment rate to the profit rate	Free	0.1	Selected from a reasonable range of values
β_0	Autonomous share of green investment in total investment	Model-constrained	-0.4407	Calculated using Eq. (16)
β_1	Sensitivity of the green investment share to the interest rate differential	Free	1	Selected from a reasonable range of values
β_2	Sensitivity of the green investment share to the carbon tax	Free	20	Selected from a reasonable range of values
β_3	Sensitivity of the green investment share to the green subsidies	Free	1	Selected from a reasonable range of values
λ	Parameter of households' portfolio choice	Model-constrained	0.3601	Calculated using Eq. (5)
ω	CO2 intensity of fossil energy (GtCO2/EJ)	Free	0.072	Based on global data for emissions and fossil energy
τ_C	Carbon tax	Model-constrained	0.0028	Calculated using Eq. (33)
τ_F	Firms' tax rate	Free	0.15	Selected from a reasonable range of values
τ_H	Households' tax rate	Model-constrained	0.1582	Calculated using Eq. (31)
c_1	Propensity to consume out of disposable income	Model-constrained	0.7921	Calculated using Eq. (4)
c_2	Propensity to consume out of deposits	Free	0.05	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. (36)
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
gov_C	Share of government expenditure in output	Model-constrained	0.1749	Calculated using Eq. (29)
gov_{SUB}	Share of green government subsidies	Model-constrained	0.0809	Calculated using Eq. (30)
int_C	Interest rate on conventional loans	Free	0.09	Based on World Bank data for the global economy
int_D	Interest rate on deposits	Free	0.04	Based on World Bank data for the global economy
int_G	Interest rate on green loans	Free	0.09	Based on World Bank data for the global economy
int_S	Interest rate on government securities	Free	0.0254	Based on FTSE Russell (2025)
k_{CI}	Steepness of carbon intensity improvement	Free	0.769	Calibrated such that the model generates the baseline scenario
$pucf$	Pre-tax unit cost of producing fossil energy (USD trillion/EJ)	Free	0.021	Based on IRENA (2021)
s_F	Retention rate of firms	Model-constrained	0.7384	Calculated using Eq. (11)
s_W	Wage share	Free	0.55	Based on Penn World Table data for the global economy
v	Capital productivity	Model-constrained	0.1491	Calculated using Eq. (37)

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