DEFINE - HOUSING: Manual

Version 1.0

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1.1. Accounting matrices

DEFINE-HOUSING 1.0 comprises households, firms, commercial banks, a government sector and a central bank. The model distinguishes between two types of households: worker households and investor households (rentiers). Worker households receive their wage income from firms, have deposits and take out mortgages to buy a house. The housing loans can be green or conventional, depending on whether they are used to buy green houses or conventional houses, respectively.

Green houses are houses that are characterised by low carbon intensity due to high energy efficiency and the use of renewables/electricity for heating. Worker households receive only a proportion of green and conventional housing loans that they demand (i.e. there is quantity credit rationing in the model). At the aggregate level, some of the worker households are not able to buy a house, so they end up renting a house and paying rent. Investor households receive distributed profits from firms and banks, interest on deposits and interest on government securities.

Investor households also own houses that are available for sale or rent: some of these houses are sold to worker households, and some other houses are rented to workers. Investor households finance their housing purchases based on their wealth and buy both energy-efficient houses and conventional houses constructed by firms.

Table A.1 and Table A.2 show the balance sheet and transactions flow matrices, respectively. The balance sheet matrix shows the assets and the liabilities of the economy, while the transactions flow matrix shows the flows and changes in assets/liabilities between the sectors. The balance sheet matrix and the transactions flow matrix have been used to identify the identities of the model from each column and each row with more than two entries. Moreover, there are two equations that are derived by using the transactions flow matrix that refer to the same variable. Only one of them can be used in the simulations. The other one is used to make sure that the model is consistent. The equation linked to this is the redundant equation.[1] Government securities bought by the central bank is the variable that we use to check the consistency of the model.

Table A.1: Balance sheet matrix

	Worker households	Investor (rentier) households	Firms	Commercial banks	Government sector	Central bank	Total
Green houses	$+p_{Ht}H_{WOwnGt}$	$+p_{Ht}H_{IOwnGt}$ $+p_{Ht}H_{IRentGt}$ $+p_{Ht}H_{VacantGt}$ $-p_{Ht}H_{ConstrVacantGt}$	$+p_{Ht}H_{ConstrVacantGt}$				$+p_{Ht}H_{TotalGt}$
Conv. houses	$+p_{Ht}H_{WOwnCt}$	$+p_{Ht}H_{IOwnCt}$ $+p_{Ht}H_{IRentCt}$ $+p_{Ht}H_{VacantC}$ $-p_{Ht}H_{ConstrVacantCt}$	$+p_{Ht}H_{ConstrVacantCt}$				$+p_{Ht}H_{TotalCt}$
Green housing loans	$-L_{HGt}$			$+L_{HGt}$			0
Conv. housing loans	$-L_{HCt}$			$+L_{HCt}$			0
Conv. capital			$+K_{Ct}$				$+K_{Ct}$
Green capital			$+K_{Gt}$				$+K_{Gt}$
Deposits	$+D_{HWt}$	$+D_{HIt}$		$-D_t$			0
Conv. firm loans			$-L_{Ct}$	$+L_{Ct}$			0
Green firm loans			$-L_{Gt}$	$+L_{Gt}$			0
Gov. securities		$+SEC_{HIt}$		$+SEC_{Bt}$	$-SEC_t$	$+SEC_{CBt}$	0
High-powered money				$+HPM_t$		$-HPM_t$	0
Advances				$-A_t$		$+A_t$	0
Total (net worth)	$+V_{HWt}$	$+V_{HIt}$	$+V_{Ft}$	$+CAP_t$	$-SEC_t$	$+V_{CBt}$	$+K_{Gt}+K_{Ct}$ $+p_{Ht}H_{Totalt}$

Note: The table refers to annual flows in EUR trillion.

[1] This equation in SFC models is implied by the accounting identities and is therefore redundant (see e.g. Godley and Lavoie 2012).

Table A.2: Transactions flow matrix

	Worker households	Investor (rentier) households	Firms		Commercial banks		Government sector		Central bank		Total
			Current	Capital	Current	Capital	Current	Capital	Current	Capital	
Green housing investment			$+I_{ConstrGt}$	$-I_{ConstrGt}$							0
Conv. housing investment			$+I_{ConstrCt}$	$-I_{ConstrCt}$							0
Investment in refurbishment		$-I_{Refurbt}$	$+I_{Refurbt}$								0
Private consumption	$-CO_{HWt}$	$-CO_{HIt}$	$+CO_{HWt}+CO_{HIt}$								0
Government net savings							$-GNS_t$	$+GNS_t$			0
Government consumption			$+CO_{GOVt}$				$-CO_{GOVt}$				0
Green investment			$+I_{Gt}$	$-I_{Gt}$							0
Conv. investment			$+I_{Ct}$	$-I_{Ct}$							0
Rents	$-Rent_t$	$+Rent_t$									0
Green new houses	$-p_{Ht}H_{WNewOwnOccupGt}$	$-p_{Ht}H_{INewOwnOccupGt}$ $-p_{Ht}H_{INewRentedGt}$		$+p_{Ht}H_{WNewOwnOccupGt}$ $+p_{Ht}H_{INewOwnOccupGt}$ $+p_{Ht}H_{INewRentedGt}$							0
Conv. new houses	$-p_{Ht}H_{WNewOwnOccupCt}$	$-p_{Ht}H_{INewOwnOccupCt}$ $-p_{Ht}H_{INewRentedCt}$		$+p_{Ht}H_{WNewOwnOccupCt}$ $+p_{Ht}H_{INewOwnOccupCt}$ $+p_{Ht}H_{INewRentedCt}$							0
Green exist. houses	$-p_{Ht}H_{IRentedSoldGt}$ $-p_{Ht}H_{WOwnOccupGt}$	$+p_{Ht}H_{IRentedSoldGt}$ $+p_{Ht}H_{WOwnOccupGt}$									0
Conv. exist. houses	$-p_{Ht}H_{IRentedSoldCt}$ $-p_{Ht}H_{WOwnOccupCt}$	$+p_{Ht}H_{IRentedSoldCt}$ $+p_{Ht}H_{WOwnOccupCt}$									0
Green subsidies	$+SUB_t$							$-SUB_t$			0
Taxes	$-TAX_{HWt}$	$-TAX_{HIt}$	$-TAX_{Ft}-TAX_{Ct}$				$+TAX_t$				0
Wages	$+W_t$		$-W_t$								0
Firms profit		$+DP_t$	$-TP_t$	$+RP_t$							0
Interest on green housing loans	$-int_{LHGt-1}L_{HGt-1}$				$+int_{LHGt-1}L_{HGt-1}$						0
Interest on conv. housing loans	$-int_{LHCt-1}L_{HCt-1}$				$+int_{LHCt-1}L_{HCt-1}$						0
Banks' profits		$+BP_{Dt}$			$-BP_t$	$+BP_{Ut}$					0
Interest on deposits	$+int_D D_{HWt-1}$	$+int_D D_{HIt-1}$			$-int_D D_{t-1}$						0
Interest on green firm loans			$-int_G L_{Gt-1}$		$+int_{Gt}L_{Gt-1}$						0
Interests on conv. firm loans			$-int_C L_{Ct-1}$		$+int_{Ct}L_{Ct-1}$						0
Interests on gov. securities		$+int_S SEC_{HIt-1}$			$+int_S SEC_{Bt-1}$		$-int_S SEC_{t-1}$		$+int_S SEC_{CBt-1}$		0
Interests on advances					$-int_{At-1}A_{t-1}$				$+int_{At-1}A_{t-1}$		0
Central bank's profits							$+CBP_t$		$-CBP_t$		0
ΔDeposits	$-\Delta D_{HWt}$	$-\Delta D_{HIt}$				$+\Delta D_t$					0
ΔGreen housing loans	$+\Delta L_{HGt}$					$-\Delta L_{HGt}$					0
ΔConv. housing loans	$+\Delta L_{HCt}$					$-\Delta L_{HCt}$					0
ΔGreen firm loans				$+\Delta L_{Gt}$		$-\Delta L_{Gt}$					0
ΔConv. firm loans				$+\Delta L_{Ct}$		$-\Delta L_{Ct}$					0
ΔGov. securities		$-\Delta SEC_{HIt}$				$-\Delta SEC_{Bt}$		$+\Delta SEC_t$		$-\Delta SEC_{CBt}$	0
ΔAdvances						$+\Delta A_t$				$-\Delta A_t$	0
ΔHigh-powered money						$-\Delta HPM_t$				$+\Delta HPM_t$	0
Defaulted loans	$+DL_{HWt}$					$-DL_{HWt}$					0
Total	0	0	0	0	0	0	0	0	0	0	0

Note: The table refers to annual flows in EUR trillion.

We construct a housing stock-flow matrix. This is reflected in Table A.3 which shows the stock-flow interactions that take place between own occupied houses by workers (first column), owned occupied houses by rentiers (fourth column), vacant houses (third column) and houses owned by rentiers and rented to workers (second column). The last column in Table A.3 shows the total number of houses. The first horizontal line in the Table shows the opening stock of houses. These are the houses that already exist. However, these opening stocks of houses might change because workers want to buy new houses or because rentiers would like to sell some of the houses that they own or rent, amongst other reasons. The last horizontal line in Table A.3 shows the closing stock of houses. Similarly, to the balance sheet matrix and transactions flow matrix, the housing stock-flow matrix is used to formulate the identities from each column and each row with more than two entries.

There is also a redundant equation in the housing market that needs to be considered in order for the values in the housing market to be consistent. The last column can be used to identify the number of total houses (H_{Totalt}) that increases by the new houses built by the firms ($H_{Constrt}$) (Eq. A.103). There is also a horizontal constraint that can be used to identify the total number of houses (Eq. A.102). According to this constraint, the total number of houses is equal to the houses owned by workers, the houses owned by the rentiers, the houses that are rented by worker households and owned by the rentiers and vacant houses. Both Eqs. (A.102) and (A.103) need to hold. So, we name one of them the redundant equation in the housing market.

The rest of this section presents a description of the equations of the model. In Section 2 all the symbols for all variables and parameters are presented.

Table A.3: Housing stock-flow matrix

	Houses owned and occupied by workers	**Houses owned by rentiers and rented to workers**	**Vacant houses for sale or rent**	**Houses owned and occupied by rentiers**	**Total houses**
Opening stock	$H_{WOwnt-1}$	$H_{IRentt-1}$	$H_{Vacantt-1}$	$H_{IOwnt-1}$	$H_{Totalt-1}$
New houses	$+H_{WNewOwnOccupt}$	$+H_{INewRentedt}$	$+H_{ConstrVacantt}$	$+H_{INewOwnOccupt}$	$+H_{Constrt}$
Existing houses converted from rented to sold	$+H_{IRentedSoldt}$	$-H_{IRentedSoldt}$			0
Existing houses converted from owned-occupied to rented		$+H_{IOwnOccupRentedt}$		$-H_{IOwnOccupRentedt}$	0
Existing houses converted from owned-occupied to sold	$+H_{WOwnOccupt}$			$-H_{WOwnOccupt}$	0
Vacant houses that have not been rented to workers			$+H_{IRentedVacantt}$	$-H_{IRentedVacantt}$	0
Vacant houses that are rented but have not been sold		$-H_{IRentedSoldVacantt}$	$+H_{IRentedSoldVacantt}$		0
Vacant houses that have not been sold to workers			$+H_{WOwnOccupVacantt}$	$-H_{WOwnOccupVacantt}$	0
Closing stock	H_{WOwnt}	H_{IRentt}	$H_{Vacantt}$	H_{IOwnt}	H_{Totalt}

Note: The table refers to million houses.

1.2. Worker households

Worker households and mortgages

Eq. (A.1) shows the gross disposable income of the worker households (Y_{HWGt}) which is equal to their wages (W_t), plus the interest that receive from the deposits that worker hold, minus the interest payments on green and conventional housing loans and the rent that some worker households have to pay ($Rent_t$), where int_D is the interest rate on deposits, D_{HWt} is the amount of deposits held be workers, L_{HGt} is green housing loans, L_{HCt} is conventional housing loans, int_{LHGt} is the interest rate on green mortgages and int_{LHCt} is the interest rate on conventional mortgages.[2] Eq. (A.2) defines the net disposable income of worker households (Y_{HWt}), which is equal to the gross disposable income of households minus the taxes on worker households (TAX_{HWt}) plus the green government subsidies that households might receive (SUB_t). Eq. (A.3) reflects the consumption of worker households (CO_{HWt}), which depends on their lagged disposable income and their lagged wealth (V_{HWt}).[3] Eqs. (A.2) and (A.3) suggest that an increase in green subsidies or a reduction in green interest rates can have expansionary effects since it increases disposable income, which in turn increases consumption.

$$Y_{HWGt} = W_t + int_D D_{HWt-1} - int_{LHGt-1} L_{HGt-1} - int_{LHCt-1} L_{HCt-1} - Rent_t \tag{A.1}$$

$$Y_{HWt} = Y_{HWGt} - TAX_{HWt} + SUB_t \tag{A.2}$$

$$CO_{HWt} = c_{11} Y_{HWt-1} + c_{12} V_{HWt-1} \tag{A.3}$$

Eq. (A.4) shows that worker households hold a proportion ($prop_D$) of their disposable income in the form of deposits. Worker households wealth is defined in Eq. (A.5). It is equal to the value of green and conventional houses demanded minus the stock of green and conventional loans, where H_{WOwnGt} and H_{WOwnCt} are worker households demand for green and conventional houses, respectively and p_{Ht} is the price of houses. The model makes a distinction between the desired amount of new green/conventional housing loans and the actual amount of new green/conventional housing loans. The actual amount of the green and conventional loans depends on the credit rationing process: commercial banks reject a specific proportion of loan applications and this proportion depends positively both on their financial position and the creditworthiness of their borrowers. This implies that commercial banks can actively affect housing investment and the carbon footprint of the housing loans.

Eqs. (A.6) and (A.7) give the desired amount of new green loans ($NLHG_{Dt}$) and the desired amount of new conventional loans ($NLHC_{Dt}$), respectively. $NLHG_{Dt}$ is equal to the amount of worker households desired investment in green houses, the repayment of outstanding loans, minus a proportion (β_{Ht}) of their saving. Similarly, $NLHC_{Dt}$ is equal to the demand for conventional investment in housing, the repayment of conventional houses minus a proportion ($1-\beta_{Ht}$) of worker households saving, where $H_{DWOwnGt}$ is the desired demand for green houses, $H_{DWOwnCt}$ is the desired demand for conventional houses, rep_L is the loan repayment ratio, and β_{Ht} is the ratio of green investment in housing to total investment in the housing market. Eq. (A.8) shows that the green housing loans are equal to the sum of the green housing loans from the last period, a proportion ($1 - CR_{HGt}$) of new green housing loans, minus the default on green housing loans and the repayment of green housing loans, where def_{HWt} is the default rate on housing loans and CR_{HGt} is the proportion of green loans that banks ration.[4] Similarly, Eq. (A.9) shows the conventional loans for houses, where CR_{HCt} is the proportion of conventional loans that banks

[2] Zezza (2008) also formalises that workers pay rent to the rich households (capitalists).

[3] It's typical in SFC models to use the lagged income or/and wealth to determine consumption (see e.g. Dunz et al. 2021). An alternative way would be to include expected income or/and wealth in consumption (see e.g. Santos and Zezza 2004).

[4] See Dafermos and Nikolaidi (2022) for a similar approach for the firm sector.

ration. The amount of total housing loans (L_{Ht}) is equal to the sum of green and conventional housing loans (Eq. (A.10)).

$$D_{HWt} = prop_D Y_{HWt-1} \tag{A.4}$$

$$V_{HWt} = p_{Ht} H_{WOwnGt} + p_{Ht} H_{WOwnCt} + D_{HWt} - L_{HGt} - L_{HCt} \tag{A.5}$$

$$\begin{aligned} NLHG_{Dt} &= (H_{DWOwnGt} - H_{WOwnGt-1}) p_{Ht-1} + rep_L L_{HGt-1} \\ &- \beta_{Ht}(Y_{HWt} - CO_{HWt} - (D_{HWt} - D_{HWt-1})) \end{aligned} \tag{A.6}$$

$$\begin{aligned} NLHC_{Dt} &= (H_{DWOwnCt} - H_{WOwnCt-1}) p_{Ht-1} + rep_L L_{HCt-1} \\ &- (1 - \beta_{Ht})(Y_{HWt} - CO_{HWt} - (D_{HWt} - D_{HWt-1})) \end{aligned} \tag{A.7}$$

$$L_{HGt} = L_{HGt-1} + (1 - CR_{HGt}) NLHG_{Dt} - rep_L L_{HGt-1} - def_{HWt} L_{HGt-1} \tag{A.8}$$

$$L_{HCt} = L_{HCt-1} + (1 - CR_{HCt}) NLHC_{Dt} - rep_L L_{HCt-1} - def_{HWt} L_{HCt-1} \tag{A.9}$$

$$L_{Ht} = L_{HGt} + L_{HCt} \tag{A.10}$$

The amount of defaulted loans (DL_{HWt}), defined in Eq. (A.11), is a proportion (def_{HWt}) of total housing loans. Eq. (A.12) shows that the default rate depends on the illiquidity ratio ($illiq_{HWt}$). The higher the illiquidity ratio, the greater the households inability to repay their loans and the higher the rate of default.[5] The illiquidity ratio expresses the cash outflows of worker households relative to their cash inflows (Eq. A.13). Cash outflows include interest, loan repayments, rent, taxes net of subsidies, and consumption and housing investment expenditures. Cash inflows include wages and the funds obtained from bank loans. Eq. (A.14) shows that the debt service ratio (dsr_{HWt}) is equal to the interest and repayment on green and conventional loans relative to disposable income (before interest payments).[6] Its key difference from the illiquidity ratio is that the latter takes into account the new flow of credit. Eq. (A.15) reflects the leverage ratio (or else the loan-to-value ratio) of worker households (lev_{HWt}), which is the ratio of housing loans to the value of houses. Eq. (A.16) shows that worker households desired demand for houses (H_{DWOwnt}) depends negatively on their debt service and positively on the growth rate of housing prices (g_{PHt}), the growth rate of workers population (g_{POPWt}) and the rent that worker households pay to rentiers ($rent_t$).

$$DL_{HWt} = def_{HWt} L_{Ht-1} \tag{A.11}$$

$$def_{HWt} = \frac{def_{max}}{1 + def_0 e^{def_1 - def_2 illiq_{HWt-1}}} \tag{A.12}$$

$$\begin{aligned} illiq_{HWt} &= \frac{(int_{LHGt-1} + rep_L) L_{HGt-1} + (int_{LHCt-1} + rep_L) L_{HCt-1} + TAX_{HWt} + Rent_t}{W_t + (1 - CR_{HGt}) NLHG_{Dt} + (1 - CR_{HCt}) NLHC_{Dt}} \\ &+ \frac{-SUB_t + CO_{HWt} + (H_{WOwnGt} - H_{WOwnGt-1}) p_{Ht-1} + (H_{WOwnCt} - H_{WOwnCt-1}) p_{Ht-1}}{W_t + (1 - CR_{HGt}) NLHG_{Dt} + (1 - CR_{HCt}) NLHC_{Dt}} \end{aligned} \tag{A.13}$$

$$dsr_{HWt} = \frac{(int_{LHGt-1} + rep_L) L_{HGt-1} + (int_{LHCt-1} + rep_L) L_{HCt-1}}{Y_{HWt} + int_{LHGt-1} L_{HGt-1} + int_{LHCt-1} L_{HCt-1}} \tag{A.14}$$

$$lev_{HWt} = \frac{L_{Ht}}{p_{Ht} H_{WOwnt}} \tag{A.15}$$

[5] We use a logistic function, on similar lines as Caiani et al. (2016) and Dafermos and Nikolaidi (2022) do for the case of firms.

[6] This follows the definition used by BIS (2023) for the debt service ratio.

$$H_{DWOwnt} = H_{WOwnt-1} + (h_{10} - h_{11} dsr_{HWt-1} + h_{12} g_{PHt-1} + h_{13} g_{POPWt-1} + h_{14} rent_{t-1}) H_{WOwnt-1} \tag{A.16}$$

From the perspective of our analysis, an important decision for households is whether to invest in a green or a conventional house. In Eq. (A.17) we assume that investment in green houses is higher when the interest rate on green loans is lower and the interest rate on conventional loans is higher. The government can provide a subsidy to worker households that invest in green housing, increasing the savings of households and thereby inducing a higher desired investment in green houses. Eq. (A.18) shows that the desired amount of green houses for worker households ($H_{DWOwnGt}$) is a proportion (β_{Ht}) of the total desired housing demand, while the demanded amount of conventional houses ($H_{DWOwnCt}$) is equal to the total demand minus the demanded number of green houses (Eq. (A.19)).

$$\beta_{Ht} = \beta_{H0} - \beta_{H1}(int_{LHGt} - int_{LHCt}) + \beta_{H2} gov_{SUB} \tag{A.17}$$

$$H_{DWOwnGt} = \beta_{Ht} H_{DWOwnt} \tag{A.18}$$

$$H_{DWOwnCt} = H_{DWOwnt} - H_{DWOwnGt} \tag{A.19}$$

Since credit rationing is present, the desired housing demand deviates from the actual demand. Eq. (A.20) defines the actual total housing demand based on the budget constraint derived from the transactions flow matrix. This budget constraint indicates that the actual total housing demand increases when household savings rise or when banks increase their loan provision. The actual green housing demand (H_{WOwnGt}) is a proportion (β_{Ht}) of the total demand (Eq. (A.21)). The rest of the houses are conventional and are given by the difference between the owned occupied houses by workers and the demand for green houses (Eq. (A.22)).

$$H_{WOwnt} = H_{WOwnt-1} + \frac{Y_{HWt} - CO_{HWt} - \Delta D_{HWt} + \Delta L_{Ht} + DL_{HWt}}{p_{Ht}} \tag{A.20}$$

$$H_{WOwnGt} = \beta_{Ht} H_{WOwnt} \tag{A.21}$$

$$H_{WOwnCt} = H_{WOwnt} - H_{WOwnGt} \tag{A.22}$$

Allocation of purchased housing

Worker households decide how to allocate their purchased houses (H_{WOwnt}), explained earlier. Workers can purchase three types of houses: i) newly occupied houses, ii) previously rented properties sold by rentiers, and iii) existing owner-occupied properties sold by investor households. Each of them can be green or conventional. The proportion of green houses bought (β_{Ht}) is the same across the different types of houses that workers can buy.

First, Eq. (A.23) shows that worker households purchase newly occupied houses ($H_{WNewOwnOccupt}$) as a proportion ($prop_W$) of the newly constructed houses by firms ($H_{Constrt}$). Eq. (A.24) shows that green newly occupied houses ($H_{WNewOwnOccupGt}$) are chosen as a proportion of the newly occupied houses that workers buy, while (A.25) gives the number of conventional ones ($H_{WNewOwnOccupCt}$).

$$H_{WNewOwnOccupt} = prop_W H_{Constrt} \tag{A.23}$$

$$H_{WNewOwnOccupGt} = \beta_{Ht} H_{WNewOwnOccupt} \tag{A.24}$$

$$H_{WNewOwnOccupCt} = H_{WNewOwnOccupt} - H_{WNewOwnOccupGt} \tag{A.25}$$

Second, Eq. (A.26) shows the number of the previously rented properties sold by rentiers ($H_{IRentedSoldt}$). This is a proportion ($prop_{RentedSold}$) of the total number of houses that workers stay in $(H_{WOwnt} + H_{IRentt})$.[7] Similarly to the newly occupied houses, some of the sold houses are green and the rest are conventional ones (Eqs. (A.27)–(A.28)). The proportion of rented houses that were sold and became green is β_{Ht}.

$$H_{IRentedSoldt} = prop_{RentedSold}(H_{WOwnt-1} + H_{IRentt-1}) \tag{A.26}$$

$$H_{IRentedSoldGt} = \beta_{Ht} H_{IRentedSoldt} \tag{A.27}$$

$$H_{IRentedSoldCt} = H_{IRentedSoldt} - H_{IRentedSoldGt} \tag{A.28}$$

Third, Eq. (A.29) shows the number of existing owner-occupied properties sold by investor households to worker households ($H_{WOwnedOccupt}$). This equation is an identity derived from Table A.3. Specifically, the $H_{WOwnedOccupt}$ is given by the change in worker-owned occupied houses minus the number of houses already purchased through other channels, i.e., newly constructed houses ($H_{WNewOwnOccupt}$) and previously rented properties that are sold ($H_{IRentedSoldt}$). The green owned occupied houses ($H_{WOwnedOccupGt}$) is a proportion (β_{Ht}) of the existing owned occupied houses (Eq.(A.30)). Eq. (A.31) shows the number of the conventional ones ($H_{WOwnedOccupCt}$).

$$H_{WOwnedOccupt} = H_{WOwnt} - H_{WOwnt-1} - H_{WNewOwnOccupt} - H_{IRentedSoldt} \tag{A.29}$$

$$H_{WOwnedOccupGt} = \beta_{Ht} H_{WOwnedOccupt} \tag{A.30}$$

$$H_{WOwnedOccupCt} = H_{WOwnedOccupt} - H_{WOwnedOccupGt} \tag{A.31}$$

Rented housing

There is a specific number of houses that worker households need to occupy. Therefore, once worker households buy the houses that they can afford based on the savings and loans provided, then they decide on the houses that they will rent. Eq. (A.32) shows that the total number of rented houses (H_{IRentt}) is equal to the number of houses that correspond to workers ($H_{Workerst}$) minus the number of houses that have already been bought. Some of these rented houses are green ($H_{IRentGt}$) and some of them are conventional ones ($H_{IRentCt}$). Eqs. (A.33)–(A.34) show the evolution of these houses.

$$H_{IRentt} = H_{Workerst} - H_{WOwnt} \tag{A.32}$$

$$H_{IRentGt} = \beta_{Ht} H_{IRentt} \tag{A.33}$$

$$H_{IRentCt} = H_{IRentt} - H_{IRentGt} \tag{A.34}$$

Worker households then decide which type of rented houses to occupy. They choose between newly rented houses ($H_{INewRentedt}$) and rental properties that were previously owner-occupied by rentiers ($H_{IOwnOccupRentedt}$).[8] Both of these rented houses can be green or conventional. The proportion of green houses in both cases is β_{Ht}.

First, worker households choose the number of newly rented houses ($H_{INewRentedt}$). This is a proportion ($prop_{NewRented}$) of the newly constructed houses by firms (Eq. (A.35)). Some of these newly rented houses are green and the rest are conventional (Eqs. (A.36)–(A.37)), where $H_{INewRentedGt}$ are the newly rented that are green houses and $H_{INewRentedCt}$ are the newly rented houses that are conventional ones.

[7] The total number of houses that worker households stay in ($H_{Workerst}$) is equal to the number of houses that workers buy and rent. See also Eq. (A.32).

[8] The rentiers buy the newly rented houses and then rent them out to worker households.

$$H_{INewRentedt} = prop_{NewRented} H_{Constrt} \tag{A.35}$$

$$H_{INewRentedGt} = \beta_{Ht} H_{INewRentedt} \tag{A.36}$$

$$H_{INewRentedCt} = H_{INewRentedt} - H_{INewRentedGt} \tag{A.37}$$

Second, workers choose how many of the houses originally owned by rentiers will be rented ($H_{IOwnOccupRentedt}$). The number of houses is defined by an accounting identity derived from the housing stock-flow matrix (see Table A.3). As shown, in Eq. (A.38) the number of these rented houses is equal to the new number of houses that are rented net of the newly rented houses ($H_{INewRentedt}$) plus previously rented houses that are not longer rented either because they have been sold ($H_{IRentedSoldt}$) or remain vacant and unsold ($H_{IRentedSoldVacantt}$).[9] Some of these rented houses are green and the rest of the total number of rented houses are conventional ones (Eqs. (A.39)–(A.40)), where $H_{IOwnOccupRentedt}$ is the total number of houses rented that were own occupied, $H_{IOwnOccupRentedGt}$ is the green number of houses rented and $H_{IOwnOccupRentedCt}$ are the conventional number of houses own occupied rented.

$$\begin{aligned} H_{IOwnOccupRentedt} = {} & H_{IRentt} - H_{IRentt-1} - H_{INewRentedt} + H_{IRentedSoldt} \\ & + H_{IRentedSoldVacantt} \end{aligned} \tag{A.38}$$

$$H_{IOwnOccupRentedGt} = \beta_{Ht} H_{IOwnOccupRentedt} \tag{A.39}$$

$$H_{IOwnOccupRentedCt} = H_{IOwnOccupRentedt} - H_{IOwnOccupRentedGt} \tag{A.40}$$

On average, worker households pay their rent every year to investor households. This is a proportion of the number of rented houses. This proportion changes in an endogenous way, taking into account the vacant houses in the rental market. When the vacant houses become relatively low the rent rate the workers have to pay increases. Eqs. (A.41)–(A.42) show that the rent ($Rent_t$) that worker households pay to the investor households increases when the growth rate of demanded rented houses (g_{HDRent}) is higher than the growth rate of the supplied rented houses (g_{HSRent}).[10] $rent_t$ is the rate that worker households pay to rentiers at the aggregate level.

$$Rent_t = rent_t H_{IRent-1} \tag{A.41}$$

$$rent_t = rent_{t-1} + (rent_0 + rent_1(g_{HDrentt-1} - g_{HSrentt-1}))rent_{t-1} \tag{A.42}$$

1.3. Investor (rentier) households

Housing and financial assets

As mentioned above, investor households have accumulated several financial and real assets. Eq. (A.43) shows the gross disposable income of the investor households (Y_{HIGt}), which is the sum of distributed profits of firms (DP_t), distributed profits of banks (BP_{Dt}), the interest on deposits, the interest on government securities and the rent that they receive from worker households ($Rent_t$), where D_{HIt} denotes the deposits of investor households and SEC_{HIt} represents the government securities held by investor households, while int_D and int_S denote the interest on deposits and on government securities, respectively. Eq. (A.44) defines the net disposable income of investor households (Y_{HIt}) as the gross disposable income minus taxes on investor households (TAX_{HIt}).

[9] Note that the sum of houses that were rented and have been sold ($H_{IRentedSoldt}$) and the rented houses that have not been sold ($H_{IRentedSoldVacantt}$), is equal to the number of rented houses by rentiers for selling ($H_{IRentedSoldMarkett}$). See also Eq. (A.90).

[10] Zezza (2008) assumes that the rent increases when the income of worker households becomes higher.

The consumption of investor households (CO_{HIt}) depends on their lagged disposable income and their wealth (Eq. (A.45)). Eq. (A.46) shows that investor households financial wealth (V_{HIt}) is composed of the demanded houses of investor households (H_{IOwnt}), rented houses that investor households own (H_{IRentt}), the vacant houses that they own and have not been sold/rented ($H_{Vacantt}$-$H_{ConstrVacantt}$), deposits, and government securities.

$$Y_{HIGt} = DP_t + BP_{Dt} + int_D D_{HIt-1} + int_S SEC_{HIt-1} + Rent_t \tag{A.43}$$

$$Y_{HIt} = Y_{HIGt} - TAX_{HIt} \tag{A.44}$$

$$CO_{HIt} = c_{21} Y_{HIt-1} + c_{22} V_{HIt-1} \tag{A.45}$$

$$\begin{aligned} V_{HIt} = {} & p_{Ht} H_{IOwnGt} + p_{Ht} H_{IOwnCt} + p_{Ht} H_{IRentGt} + p_{Ht} H_{IRentCt} \\ & + p_{Ht}(H_{Vacantt} - H_{ConstrVacantt}) + D_{HIt} + SEC_{HIt} \end{aligned} \tag{A.46}$$

According to Eqs. (A.47)–(A.49N), investor households allocate their wealth among government securities, own-occupied houses, and deposits following a Tobinsque principle.[11] The rate of return for houses (r_{HIt}) includes both the capital gains and the rent that rentiers receive (Eq. (A.50)). Therefore, an increase in the growth rate of housing prices or an increase in rents might induce investor households to buy more houses.

Note that the actual amount of deposits is determined by Eq. (A.49).[12] Investor households save the income that they don't consume or don't decide to invest in government securities in the form of deposits. They receive income from selling houses to workers, while they also spend some income to buy new houses from firms. Moreover, investor households choose to convert a share of their existing conventional houses that they own into green ones. The associated refurbishment expenditure ($I_{Refurbt}$) is financed through a reduction in their new deposits.

$$SEC_{HIt} = (\lambda_{10} + \lambda_{11} int_S + \lambda_{12} r_{HIt-1} + \lambda_{13} int_D + \lambda_{14} \frac{Y_{HIt-1}}{V_{HIt-1}}) V_{HIt-1} \tag{A.47}$$

$$H_{IOwnt} = (\lambda_{20} + \lambda_{21} int_S + \lambda_{22} r_{HIt-1} + \lambda_{23} int_D + \lambda_{24} \frac{Y_{HIt-1}}{V_{HIt-1}}) \frac{V_{HIt-1}}{p_{Ht}} \tag{A.48}$$

$$D_{HINt} = (\lambda_{30} + \lambda_{31} int_S + \lambda_{32} r_{HIt-1} + \lambda_{33} int_D + \lambda_{34} \frac{Y_{HIt-1}}{V_{HIt-1}}) V_{HIt-1} \tag{A.49N}$$

$$\begin{aligned} D_{HIt} = {} & D_{HIt-1} + Y_{HIt} - CO_{HIt} - (SEC_{HIt} - SEC_{HIt-1}) - p_{Ht} H_{INewOwnOccupt} \\ & - p_{Ht} H_{INewRentedt} + p_{Ht} H_{WOwnOccupt} + p_{Ht} H_{IRentedSoldt} - I_{Refurbt} \end{aligned} \tag{A.49}$$

$$r_{HIt} = rent_t + \frac{p_{Ht} - p_{Ht-1}}{p_{Ht-1}} \tag{A.50}$$

Allocation of purchased housing

The demanded amount of houses by investor households is split into green houses and conventional houses (Eqs. (A.51) and (A.52)). We assume that investor households split the total demanded amount of houses into green and conventional based on β_H. Therefore, the demanded green and conventional houses are affected by interest rate policies or green government subsidies.

$$H_{IOwnGt} = \beta_{Ht} H_{IOwnt} \tag{A.51}$$

[11] The Tobinsque principle relies on the work of Tobin to determine the investment in different assets based on the rate of return of each asset and is standard in SFC models (see Godley 1999).

[12] Investor households are the owners of commercial banks and receive their distributed profits. Investor households hold their capital, but don't invest it (see Godley and Lavoie 2012). We make sure that in the simulations, deposits are always positive.

$$H_{IOwnCt} = H_{IOwnt} - H_{IOwnGt} \tag{A.52}$$

Moreover, investor households decide how many houses they are willing to sell and how many houses they would like to rent.[13] In particular, they choose on i) on the number of owner-occupied houses to sell to worker households ($H_{WOwnOccupMarkett}$), ii) the number of rented houses to be sold ($H_{IRentedSoldMarkett}$), iii) the number of owner-occupied houses that could be rented ($H_{IOwnOccupRentedMarkett}$), and iv) the types of newly constructed houses they purchase.

Eqs. (A.53)–(A.55) show that the first three types of houses are a proportion of the total houses that investor households own (H_{IOwnt}).[14] In the model, these houses might not be rented or sold by worker households. This depends on the demand that worker households have. So, in each of these cases, there are vacant houses (see Section 1.4 for the number of vacant houses).

$$H_{WOwnOccupMarkett} = prop_{WExisting} H_{IOwnt} \tag{A.53}$$

$$H_{IRentedSoldMarkett} = prop_{IRented} H_{IOwnt} \tag{A.54}$$

$$H_{IOwnOccupRentedMarkett} = prop_{IOwnOccup} H_{IOwnt} \tag{A.55}$$

Finally, the number of newly occupied houses is determined using the housing stock-flow matrix (see Table A.3). As shown in Eq. (A.56), the newly occupied houses ($H_{INewOwnOccupt}$) are calculated as the change in the total demanded houses by the rentiers, plus the houses that were previously owner-occupied but rented by rentiers ($H_{IOwnOccupRentt}$), plus the houses purchased by worker households from rentiers ($H_{WOwnOccupt}$) plus the vacant houses that in the end were neither rented ($H_{IRentedVacantt}$) nor sold ($H_{WOwnOccupVacantt}$). Similar to what has been explained above, some of these newly bought houses are green ($H_{INewOwnOccupGt}$) and the rest are conventional ones ($H_{INewOwnOccupCt}$). Eqs. (A.57)–(A.58) describe how these variables are defined.

$$\begin{aligned} H_{INewOwnOccupt} &= H_{IOwnt} - H_{IOwnt-1} + H_{IOwnOccupRentedt} + H_{WOwnOccupt} \\ &+ H_{IRentedVacantt} + H_{WOwnOccupVacantt} \end{aligned} \tag{A.56}$$

$$H_{INewOwnOccupGt} = \beta_{Ht} H_{INewOwnOccupt} \tag{A.57}$$

$$H_{INewOwnOccupCt} = H_{INewOwnOccupt} - H_{INewOwnOccupGt} \tag{A.58}$$

1.4. Firms

The output of the economy consists of consumption of worker and investor households, investment (I_t), government consumption expenditures (CO_{GOVt}), green housing investment ($I_{ConstrGt}$), conventional housing investment ($I_{ConstrCt}$) and investment in refurbishment of existing houses into green ($I_{Refurbt}$) (Eq. (A.59)). Firms play an important role in the decarbonisation process since they decide whether to invest in green or conventional loans. Eq. (A.60) defines the gross profits of firms (TP_{Gt}), which are equal to sales minus the wage bill and the interest on green and conventional loans; green loans (L_{Gt}) and conventional loans (L_{Ct}) have green interest rate (int_G) and conventional interest rates (int_C), respectively. Eq. (A.61) shows that wages are a proportion (s_W) of output. Eq. (A.62) gives the net profits of firms (TP_t), which are equal to total profits minus the taxes on profits paid to the government (TAX_{Ft}) and the taxes on carbon emissions (TAX_{Ct}). Retained profits (RP_t) are provided in Eq. (A.63), where firms keep a fraction (s_F) of their profits and distribute the remainder to investor households. Eq. (A.64) shows the distributed profits of

[13] An alternative specification would be to define both the own-occupied houses by rentiers and the rented houses based on the portfolio allocation described above.

[14] These proportions can become endogenous and become higher when the rents or the growth rate of prices become higher.

firms (DP_t), Eq. (A.65) defines the rate of profits (r_t), Eq. (A.66) shows the capacity utilisation (u_t) and Eq. (A.67) the potential output (Y_{pott}); v is the potential output-to-capital stock.

$$Y_t = CO_{HWt} + CO_{HIt} + I_t + CO_{GOVt} + I_{ConstrGt} + I_{ConstrCt} + I_{Refurbt} \tag{A.59}$$

$$TP_{Gt} = Y_t - W_t - int_C L_{Ct-1} - int_G L_{Gt-1} \tag{A.60}$$

$$W_t = s_W Y_t \tag{A.61}$$

$$TP_t = TP_{Gt} - TAX_{Ft} - TAX_{Ct} \tag{A.62}$$

$$RP_t = s_F TP_{t-1} \tag{A.63}$$

$$DP_t = TP_t - RP_t \tag{A.64}$$

$$r_t = \frac{TP_t}{K_t} \tag{A.65}$$

$$u_t = \frac{Y_t}{Y_{pott}} \tag{A.66}$$

$$Y_{pott} = vK_t \tag{A.67}$$

Eq. (A.68) shows that investment depends on the rate of profit (see, e.g., Blecker 2002) and capacity utilisation. We consider that the rate of profit and capacity utilisation affect investment in a non-linear way in general line with the tradition that draws on Kaldor (1940). As a result of this, once the profit rate and the capacity utilisation are very low or very high, their effects on investment become rather small.[15] Eq. (A.69) indicates that the share of green investment in total investment (β_t) depends on the difference in interest rates between green and conventional loans. Eq. (A.70) shows that green investment (I_{Gt}) is a proportion (β_t) of total investment, while conventional investment (I_{Ct}) is the difference between total investment and green investment. Eqs. (A.72), (A.73) and (A.74) respectively show the value for green capital stock (K_{Gt}), conventional capital stock (K_{Ct}) and total capital stock (K_t).[16] According to Eq. (A.75), the change in green loans is equal to green investment in capital and green housing investment minus a share (β_t) of retained profits and a share of revenues from selling the houses. Similarly, Eq. (A.76) shows that the change in conventional loans is equal to total investment in capital and housing investment minus the retained profits of firms, the change in green loans, and the revenues from selling houses to worker and investor households.[17] The total amount of firm loans is equal to the sum of green and conventional loans (Eq. (A.77)).[18]

$$I_t = \frac{\alpha_{00}}{1 + e^{\alpha_{01} - \alpha_1 u_{t-1} - \alpha_2 r_{t-1}}} K_{t-1} \tag{A.68}$$

$$\beta_t = \beta_0 - \beta_1 (int_G - int_C) \tag{A.69}$$

$$I_{Gt} = \beta_t I_t \tag{A.70}$$

$$I_{Ct} = I_t - I_{Gt} \tag{A.71}$$

$$K_{Gt} = K_{Gt-1} + I_{Gt} \tag{A.72}$$

$$K_{Ct} = K_{Ct-1} + I_{Ct} \tag{A.73}$$

[15] See Dafermos and Nikolaidi (2022) for a similar formulation.

[16] We assume that there is no depreciation of capital stock. See Dafermos and Nikolaidi (2022) for an investment with depreciation of capital stock.

[17] We make sure that in our simulations, loans are non-negative.

[18] We assume for simplicity that there is no credit rationing in firms' loans. See Dafermos and Nikolaidi (2022) for credit rationing applied to the firm sector.

$$K_t = K_{Ct} + K_{Gt} \tag{A.74}$$

$$L_{Gt} = L_{Gt-1} + I_{Gt} + I_{ConstrGt} - \beta_t RP_t - \beta_t p_{Ht}(H_{WNewOwnOccupt} + H_{INewOwnOccupt} + H_{INewRentedt}) \tag{A.75}$$

$$L_{Ct} = L_{Ct-1} + I_{Ct} + I_{Gt} + I_{ConstrGt} + I_{ConstrCt} - RP_t - (L_{Gt} - L_{Gt-1}) - p_{Ht}(H_{WNewOwnOccupt} + H_{INewOwnOccupt} + H_{INewRentedt}) \tag{A.76}$$

$$L_t = L_{Ct} + L_{Gt} \tag{A.77}$$

The new number of houses that are constructed (in million houses) is given by Eq. (A.78). More houses are built as the demand for houses and house prices increase.[19] The stock of constructed houses (in million houses) increases by this new number of constructed houses (Eq. (A.79)).[20] Eqs. (A.80) and (A.81) show how the green and conventional houses built by firms are split. $New_{Constrt}$ are the new constructed houses, $H_{Constrt}$ is the stock of constructed houses, $H_{ConstrGt}$ and $H_{ConstrCt}$ are the green and conventional houses respectively.

$$New_{Constrt} = (h_{20} + h_{21}\frac{H_{WNewOwnOccupt-1} + H_{INewOwnOccupt-1} + H_{INewRentedt-1}}{H_{Constrt-1}} + h_{22} g_{PHt-1}) H_{Constrt-1} \tag{A.78}$$

$$H_{Constrt} = H_{Constrt-1} + New_{Constrt} \tag{A.79}$$

$$H_{ConstrGt} = \beta_{Ht} H_{Constrt} \tag{A.80}$$

$$H_{ConstrCt} = H_{Constrt} - H_{ConstrGt} \tag{A.81}$$

Investment in constructed houses (in EUR trillion) is the value of the stock of constructed houses (Eq. (A.82)), where $I_{Constrt}$ is the investment in constructed houses and p_{Constr} is the constant price for construction (in EUR trillion /million houses). Eqs. (A.83)–(A.84) shows the green and the conventional investment in construction that takes place; $I_{ConstrGt}$ is the investment in green constructed houses and $I_{ConstrCt}$ is the investment in the conventional constructed houses.

$$I_{Constrt} = p_{Constr} H_{Constrt} \tag{A.82}$$

$$I_{ConstrGt} = \beta_{Ht} I_{Constrt} \tag{A.83}$$

$$I_{ConstrCt} = I_{Constrt} - I_{ConstrGt} \tag{A.84}$$

The model makes a distinction between green residential investment associated with the construction of green houses and residential investment associated with refurbishment that transforms conventional houses into green houses. We implicitly assume that, when β_{Ht} increases, green refurbishment also increases to transform existing conventional houses into green houses. The new number of houses that are refurbished (in million houses) is given by Eq. (A.85), $New_{Refurbt}$ is the new number of refurbished houses. These are the conventional houses that are transformed into green (e.g. the rented houses that are not new and some owner-occupied houses). The stock of refurbished houses ($H_{Refurbt}$) increases by this new number of houses (Eq. (A.86)). The value of refurbished houses ($I_{Refurbt}$) is given by Eq. (A.87), where p_{Refurb} is the constant price of refurbished houses.[21]

[19] Jackson and Victor (2019) and Byrialsen et al. (2024a,b) include other factors in housing investment such as economic activity. Other factors could affect the supply of houses, such as land and construction costs.

[20] We assume that there is no depreciation of the housing capital stock. See Jackson and Victor (2019) and Byrialsen et al. (2024a,b) for a housing market with depreciation of the housing stock.

[21] In the simulations we make sure that p_{Refurb} is lower than the p_{Constr} to capture the higher cost associated with new housing construction.

$$NewRefurb_t = H_{IRentedSoldGt-1} + H_{WOwnOccupGt-1} + H_{IOwnOccupRentedGt-1} + H_{IRentedVacantGt-1} + H_{IRentedSoldVacantGt-1} + H_{WOwnOccupVacantGt-1} \tag{A.85}$$

$$H_{Refurbt} = H_{Refurbt-1} + New_{Refurbt} \tag{A.86}$$

$$I_{Refurbt} = p_{Refurb} H_{Refurbt} \tag{A.87}$$

Eq. (A.88) defines that the growth rate in housing prices is affected by the difference between the growth rate of demanded houses and the growth rate of supplied houses for sale (see Eatwell et al. 2008 and Nikolaidi 2015).[22]

$$p_{Ht} = p_{Ht-1} + (h_{33} + h_3(g_{HDt-1} - g_{HSt-1}))p_{Ht-1} \tag{A.88}$$

As mentioned earlier, there is no equilibrium in the housing market (e.g. there are vacant houses that are not rented). In our model, different types of vacant houses exist. First, there are newly built vacant houses. Second, there are vacant houses that are rented and have not been sold. Third, there are vacant houses that are owned and occupied by investor households and are not sold. These vacant houses are identified by the difference between the houses provided by firms or rentiers and the houses given by worker households in each case.

Eq. (A.89) expresses newly built houses that have not been sold ($H_{ConstrVacantt}$) as the new houses built minus the ones that have already been bought by worker households ($H_{WNewOwnOccupt}$), by investor households to own occupy ($H_{INewOwnOccupt}$), or houses bought by investor households to rent out ($H_{INewRentedt}$). Eq. (A.90) shows the number of vacant houses that were rented and were not sold. This number is equal to the difference between the number of houses that rentiers decide to sell instead of renting them ($H_{IRentedSoldMarkett}$) and the houses that worker households decide to buy ($H_{IRentedSoldt}$). Eq. (A.93) similarly indicates that the vacant houses that rentiers have not sold are equal to the number of houses offered ($H_{WOwnOccupMarkett}$) minus the number of houses that are bought by worker households ($H_{WOwnOccup}$). Overall, the evolution of total vacant houses ($H_{Vacantt}$) takes into account the vacant houses mentioned above. In particular, the change in total vacant houses depends on the newly built houses that have not been sold, the existing houses that were rented, but were not sold ($H_{IRentedSoldVacantt}$), the existing houses that have not been rented to workers ($H_{IRentedVacantt}$) and the owned occupied houses that have not been sold to workers ($H_{IOwnOccupVacantt}$) (Eq. (A.99)). Eq. (A.89) and (A.99) are identities derived from the housing stock-flow matrix (Table A.3).

$$H_{ConstrVacantt} = H_{Constrt} - H_{WNewOwnOccupt} - H_{INewOwnOccupt} - H_{INewRentedt} \tag{A.89}$$

$$H_{IRentedSoldVacantt} = H_{IRentedSoldMarkett} - H_{IRentedSoldt} \tag{A.90}$$

$$H_{IRentedSoldVacantGt} = \beta_{Ht} H_{IRentedSoldVacantt} \tag{A.91}$$

$$H_{IRentedSoldVacantCt} = H_{IRentedSoldVacantt} - H_{IRentedSoldVacantGt} \tag{A.92}$$

$$H_{WOwnOccupVacantt} = H_{WOwnOccupMarkett} - H_{WOwnOccupt} \tag{A.93}$$

$$H_{WOwnOccupVacantGt} = \beta_{Ht} H_{WOwnOccupVacantt} \tag{A.94}$$

$$H_{WOwnOccupVacantCt} = H_{WOwnOccupVacantt} - H_{WOwnOccupVacantGt} \tag{A.95}$$

[22] The demanded houses include the new houses bought by workers and rentiers and the existing/rented houses workers bought from the rentiers. The supplied houses are the new houses constructed by the firms, plus the houses sold by the rentiers.

Eq. (A.96) shows that the difference between the supply and the demand for rentals corresponds to the number of houses that have not been rented by workers ($H_{IRentedVacantt}$). Eqs. (A.97)–(A.98) show the green and conventional. The overall number of vacant houses is given by Eq. (A.99), while the number of green and conventional vacant houses is given by Eqs. (A.100)–(A.101).

$$H_{IRentedVacantt} = H_{INewRentedt} + H_{IOwnOccupRentedMarkett} - H_{IOwnOccupRentedt} \tag{A.96}$$

$$H_{IRentedVacantGt} = \beta_{Ht} H_{IRentedVacantt} \tag{A.97}$$

$$H_{IRentedVacantCt} = H_{IRentedVacantt} - H_{IRentedVacantGt} \tag{A.98}$$

$$\begin{aligned} H_{Vacantt} = {} & H_{Vacantt-1} + H_{ConstrVacantt} + H_{IRentedSoldVacantt} + H_{IRentedVacantt} \\ & + H_{WOwnOccupVacantt} \end{aligned} \tag{A.99}$$

$$H_{VacantGt} = \beta_{Ht} H_{Vacantt} \tag{A.100}$$

$$H_{VacantGt} = \beta_{Ht} H_{Vacantt} \tag{A.101}$$

Eq. (A.102) defines the total housing stock (H_{Totalt}) as the previous total stock plus newly completed houses ($H_{Constrt}$). Eq. (A.103) states that the total housing stock ($H_{Totalredt}$) comprises houses owned and occupied by worker households (H_{WOwnt}), houses owned and occupied by investor households (H_{IOwnt}), houses owned by investor households and rented to worker households (H_{IRentt}), and vacant houses ($H_{Vacantt}$). Both of these equations define the same variable (H_{Totalt}). We have chosen one of them as the redundant equation. We use this equation to check that the housing market is consistent. Both Eqs. (A.102)–(A.103) are identities taken from the housing stock-flow matrix (Table A.3).

$$H_{Totalt} = H_{Totalt-1} + H_{Constrt} \tag{A.102}$$

$$H_{Totalredt} = H_{WOwnt} + H_{IOwnt} + H_{IRentt} + H_{Vacantt} \tag{A.103}$$

The total number of houses that are green and conventional is shown in Eqs. (A.104)-(A.105); $H_{TotalGt}$ is the total number of green houses and $H_{TotalCt}$ is the total number of conventional houses. Decarbonising the housing stock requires an expansion in the number of green houses.

$$H_{TotalGt} = H_{WOwnGt} + H_{IOwnGt} + H_{IRentGt} + H_{VacantGt} \tag{A.104}$$

$$H_{TotalCt} = H_{Totalt} - H_{TotalGt} \tag{A.105}$$

In the model, we link the number of houses to the population of worker and rentier households (Eqs. (A.106)-(A.107)). Eq. (A.106) shows that the number of houses required by worker households ($H_{Workerst}$) is a proportion ($size$) of their population (POP_{Wt}). Similarly, Eq. (A.107) indicates that the number of houses associated with rentier households ($H_{Rentierst}$) is a proportion of the rentier population (POP_R).

$$H_{Workerst} = \frac{POP_{Wt}}{size} \tag{A.106}$$

$$H_{Rentierst} = \frac{POP_R}{size} \tag{A.107}$$

Eq. (A.108) shows a simple wealth inequality index ($WealthIndex_t$) that compares the wealth of the rentiers per person to the wealth of workers per person. The higher the $WealthIndex_t$, the higher the wealth inequality.

$$WealthIndex_t = \frac{V_{HIt}/POP_{Rt}}{V_{HWt}/POP_{Wt}} \tag{A.108}$$

The evolution of the worker and rentier populations over time is described in Eqs. (A.109)–(A.111). Total population (POP_t) grows at an exogenous rate (g_{POP}) according to (A.109). Eq. (A.110) describes the dynamics of worker population (POP_{Wt}) and Eq. (A.111) defines the rentier population as the residual, equal to the difference between the total population and the worker population.

$$POP_t = (1 + g_{POP})POP_{t-1} \tag{A.109}$$

$$POP_{Wt} = prop_{Workers}POP_t \tag{A.110}$$

$$POP_{Rt} = POP_t - POP_{Wt} \tag{A.111}$$

1.5. Commercial banks

The total profits of banks (BP_t) are given by Eq. (A.112). They are equal to the sum of the interest on conventional firm loans, the interest on green firm loans, the interest on green housing loans, the interest on conventional housing loans, and the interest on banks securities, minus the interest on deposits and the interest on advances; SEC_{Bt} denotes the government securities held by banks, A_t represents the advances held by banks, and int_{At} is the interest rate on advances. Both worker and rentier households have deposits (Eq. (A.113)). Eq. (A.114) shows the capital of banks (CAP_t), which is equal to the previous amount of capital plus the undistributed bank profits (BP_{Ut}) minus the default on total housing loans (DL_{HWt}). Eq. (A.115) defines the undistributed bank profits as a share (s_B) of the total profits of banks. By definition, the distributed profits of banks are equal to the total profits minus the undistributed bank profits (Eq. (A.116)).

$$\begin{aligned} BP_t = {} & int_C L_{Ct-1} + int_G L_{Gt-1} + int_{LHGt-1} L_{HGt-1} + int_{LHCt-1} L_{HCt-1} + int_S SEC_{Bt-1} \\ & - int_D D_{t-1} - int_{At-1} A_{t-1} \end{aligned} \tag{A.112}$$

$$D_t = D_{HWt} + D_{HIt} \tag{A.113}$$

$$CAP_t = CAP_{t-1} + BP_{Ut} - DL_{HWt} \tag{A.114}$$

$$BP_{Ut} = s_B BP_{t-1} \tag{A.115}$$

$$BP_{Dt} = BP_t - BP_{Ut} \tag{A.116}$$

The amount of high-powered money (HPM_t) and the amount of government securities held by banks are proportional to deposits and are given by Eqs. (A.117) and (A.118), respectively. Banks will increase their advances when the change in high-powered money, the change in housing and firm loans, the change in government securities held by banks, and the defaulted amount of housing loans exceed the change in deposits and the undistributed profits (Eq. (A.119)).[23]

$$HPM_t = h_1 D_t \tag{A.117}$$

$$SEC_{Bt} = h_2 D_t \tag{A.118}$$

$$\begin{aligned} A_t = A_{t-1} + (HPM_t - HPM_{t-1}) + (L_{Gt} - L_{Gt-1}) + (L_{Ct} - L_{Ct-1}) + (L_{HGt} - L_{HGt-1}) \\ +(L_{HCt} - L_{HCt-1}) + (SEC_{Bt} - SEC_{Bt-1}) - (D_t - D_{t-1}) - BP_{Ut} + DL_{HWt} \end{aligned} \tag{A.119}$$

[23] If advances become negative, the government securities bought by banks (SEC_{Bt}) become the buffer variable.

The leverage ratio of banks (lev_{Bt}) and the capital adequacy ratio of banks (CAR_t) are given by Eqs. (A.120) and (A.121), respectively; w_L, w_S, and w_H are the weights for loans, government securities, and high-powered money, respectively.[24] Banks provide only an amount of green and conventional housing loans. Eq. (A.122) shows that total credit rationing for household loans (CR_{Ht}) depends negatively on the debt service ratio of worker households and positively on the capital adequacy ratio of commercial banks relative to the minimum capital adequacy ratio (CAR_{min}) determined by the regulatory authority.[25] In the baseline scenario, total credit rationing is equal to both green and conventional credit rationing. However, credit rationing on green and conventional loans can differ once the central bank announces different interest rates on advances (Eqs. (A.123) and (A.124)). Here, int_{min} and int_{max} denote the minimum and maximum interest rates on advances, CR_{HGt} is the credit rationing on green housing loans, and CR_{HCt} is the credit rationing on conventional housing loans.

$$lev_{Bt} = \frac{HPM_t + L_{Ct} + L_{Gt} + L_{HGt} + L_{HCt} + SEC_{Bt}}{CAP_t} \tag{A.120}$$

$$CAR_t = \frac{CAP_t}{w_L(L_{Ct} + L_{Gt} + L_{HGt} + L_{HCt}) + w_S SEC_{Bt} + w_H HPM_t} \tag{A.121}$$

$$CR_{Ht} = \frac{CR_{max}}{1 + r_0 e^{r_1 - r_2 dsr_{HWt-1} + r_3(CAR_{t-1} - CAR_{min})}} \tag{A.122}$$

$$CR_{HGt} = (1 - l_{H3}(int_{ref} - int_{min}))CR_{Ht} \tag{A.123}$$

$$CR_{HCt} = (1 + l_{H3}(int_{max} - int_{ref}))CR_{Ht} \tag{A.124}$$

The interest rate on the green and conventional housing loans is set as a spread over the policy interest rate determined by the central bank (Eqs. (A.125) and (A.126)). The total spread (spr_{Ht}) depends on the capital adequacy ratio and the debt service ratio of worker households (Eq. (A.127)). The same factors that affect total credit rationing also affect the total spread. In the baseline scenario, the total spread of housing loans is the same for green and conventional housing loans. However, the announcement of green differentiated refinancing operations can reduce the spread on green housing loans and increase the spread on conventional housing loans. This is shown in Eqs. (A.128) and (A.129). Here, spr_{HGt} is the lending spread on green housing loans and spr_{HCt} is the lending spread on conventional housing loans.

$$int_{LHGt} = spr_{HGt} + int_{At} \tag{A.125}$$

$$int_{LHCt} = spr_{HCt} + int_{At} \tag{A.126}$$

$$spr_{Ht} = spr_{H0} - spr_{H1}(CAR_{t-1} - CAR_{min}) + spr_{H2} dsr_{HWt-1} \tag{A.127}$$

$$spr_{HGt} = (1 - spr_{H3}(int_{ref} - int_{min}))spr_{Ht} \tag{A.128}$$

$$spr_{HCt} = (1 + spr_{H3}(int_{max} - int_{ref}))spr_{Ht} \tag{A.129}$$

1.6. Government sector

Eq. (A.130) shows the government net saving (GNS_t), which is the difference between the governments revenues and expenditures. The government revenues consist of taxes (TAX_t) and central bank profits (CBP_t), while government spending comprises government consumption, green subsidies, and interest on securities; SEC_t denotes the securities issued by the government. According to Eq. (A.131), the government issues securities when the government net saving is negative. Govern-

[24] See BCBS (2025) for the weights of the different assets.

[25] See Dafermos and Nikolaidi (2022) for a similar formulation for the case of firms. The loan-to-value ratio (or the leverage of worker households) is an alternative indicator that could be used (see e.g. Grovenstein et al. 2005).

ment consumption spending is a proportion of output (Eq. (A.132)). Green subsidies (SUB_t) is a proportion of green housing investment (Eq. (A.133)). Eqs. (A.134), (A.135), (A.136), and (A.137) show, respectively, worker households taxes (TAX_{HWt}), investor households taxes (TAX_{HIt}), taxes on firms profits (TAX_{Ft}), and carbon taxes that firms have to pay (TAX_{Ct}).[26] Carbon taxes are a proportion (τ_C) of other emissions.[27] Total taxes are equal to the sum of the taxes collected from worker households, investor households, and firms (Eq. (A.138)).

$$GNS_t = TAX_t + CBP_t - CO_{GOVt} - SUB_t - int_S SEC_{t-1} \tag{A.130}$$

$$SEC_t = SEC_{t-1} - GNS_t \tag{A.131}$$

$$CO_{GOVt} = gov_C Y_{t-1} \tag{A.132}$$

$$SUB_t = gov_{SUB}(H_{TotalGt} - H_{TotalGt-1}) \tag{A.133}$$

$$TAX_{HWt} = \tau_{HW} Y_{HWGt-1} \tag{A.134}$$

$$TAX_{HIt} = \tau_{HI} Y_{HIGt-1} \tag{A.135}$$

$$TAX_{Ft} = \tau_F TP_{Gt-1} \tag{A.136}$$

$$TAX_{Ct} = \tau_C EMIS_{Ot-1} \tag{A.137}$$

$$TAX_t = TAX_{HWt} + TAX_{HIt} + TAX_{Ft} + TAX_{Ct} \tag{A.138}$$

1.7. Central bank

Eq. (A.139) shows the central banks net profits, which are composed of the interest payments on advances and the interest on the central banks securities; SEC_{CBt} denotes the government securities held by the central bank. These government securities are equal to those not held by households and banks (Eq. (A.140)). Eq. (A.141-red) is a redundant equation of the model.[28] The wealth of the central bank (V_{CBt}) is given by the sum of advances and the government securities held by the central bank minus the high-powered money (Eq. (A.141)). Finally, Eq. (A.142) shows the interest rate on advances, which adjusts according to the greenness or dirtiness of banks' mortgage portfolios (see van't Klooster and van Tilburg 2020, Krebel and van Lerven 2022 and Jourdan et al. 2024).

$$CBP_t = int_{At-1} A_{t-1} + int_S SEC_{CBt-1} \tag{A.139}$$

$$SEC_{CBt} = SEC_t - SEC_{HIt} - SEC_{Bt} \tag{A.140}$$

$$SEC_{CBredt} = SEC_{CBt-1} + (HPM_t - HPM_{t-1}) - (A_t - A_{t-1}) \tag{A.141-red}$$

$$V_{CBt} = A_t + SEC_{CBt} - HPM_t \tag{A.141}$$

$$int_{At} = int_{ref} + (int_{max} - int_{ref})\frac{L_{HCt}}{L_{Ht}} - (int_{ref} - int_{min})\frac{L_{HGt}}{L_{Ht}} \tag{A.142}$$

1.8. Emissions

Eq. (A.143) shows that housing emissions ($EMIS_{Ht}$) depend on the housing stock. Here, CI_{Ht} represents the carbon intensity of the housing stock, which can become lower as the proportion of green houses increases relative to conventional houses (see Eq. (A.144)). Eq. (A.145) defines the

[26] In 2027, the European Union will apply an explicit carbon price to fuels used in buildings and road transport through a separate emissions trading system known as EU ETS2 (see e.g. European Commission 2025). In our future work, we could investigate the incorporation of carbon taxes in the household sector.

[27] In the simulations, τ_C is considered constant, but could become endogenous (see e.g. NGFS 2025).

[28] In our simulations, we always make sure that the redundant equation is satisfied.

rest of carbon emissions ($EMIS_{Ot}$) as a function of output. In this case, CI_{Ot} denotes the carbon intensity associated with these emissions, and it decreases when firms invest more in green capital compared to conventional capital (see Eq. (A.146)).

$$EMIS_{Ht} = CI_{Ht} H_{Totalt} \tag{A.143}$$

$$CI_{Ht} = CI_{Hmax} - \frac{CI_{Hmax} - CI_{Hmin}}{1 + e^{-\kappa_{CIH}(H_{TotalGt-1}/H_{TotalCt-1} - 1/(H_{TotalGt-1}/H_{TotalCt-1}) - c_{CIH})}} \tag{A.144}$$

$$EMIS_{Ot} = CI_{Ot} Y_t \tag{A.145}$$

$$CI_{Ot} = CI_{Omax} - \frac{CI_{Omax} - CI_{Omin}}{1 + e^{-\kappa_{CIO}(K_{Gt-1}/K_{Ct-1} - 1/(K_{Gt-1}/K_{Ct-1}) - c_{CIO})}} \tag{A.146}$$

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

Table A.4: Symbols and initial values for endogenous variables (baseline scenario)

A	Advances (EUR trillion)	Model-constrained	5.5955	Calculated from Eq. (155)
BP	Profit of the banks (EUR trillion)	Model-constrained	0.277	Calculated from Eq. (114)
BP_D	Distributed profit of the banks (EUR trillion)	Model-constrained	0.0774	Calculated from Eq. (118)
BP_U	Undistributed profit of the banks (EUR trillion)	Model-constrained	0.1995	Calculated from Eq. (117)
CAP	Capital of banks (EUR trillion)	Model-constrained	2.0059	Calculated from Eq. (122)
CAR	Capital adequacy ratio	Model-constrained	0.1146	Calculated from Eq. (123)
CBP	Central bank profits (EUR trillion)	Model-constrained	0.2473	Calculated from Eq. (141)
CI_H	Carbon intensity of houses (GtCO2/Million houses)	Model-constrained	0.0042	Calculated from Eq. (146)
CI_O	Carbon intensity of other emissions (GtCO2/EUR trillion)	Model-constrained	0.1091	Calculated from Eq. (148)
CO_{GOV}	Government expenditure (EUR trillion)	Free	3.0639	The proportion of government expenditure in GDP is based on Eurostat
CO_{HI}	Consumption of investor households (EUR trillion)	Model-constrained	2.4087	Calculated from Eq. (59)
CO_{HW}	Consumption of worker households (EUR trillion)	Model-constrained	5.9076	Calculated from Eq. (20)
CR_H	Degree of total credit rationing on housing loans	Model-constrained	0.2	Calculated from Eq. (124)
CR_{HC}	Degree of conv. credit rationing on housing loans	Model-constrained	0.2	Calculated from Eq. (126)
CR_{HG}	Degree of green credit rationing on housing loans	Model-constrained	0.2	Calculated from Eq. (125)
D	Deposits (EUR trillion)	Free	21.885	Selected from a reasonable range of values
D_{HI}	Deposits held by investor households (EUR trillion)	Model-constrained	19.6965	Calculated from Eq. (115)
D_{HW}	Deposits held by worker households (EUR trillion)	Free	2.1885	Selected from a reasonable range of values
def_{HW}	Default rate on housing loans	Free	0.02	Based on Eurostat
DL_{HW}	Amount of defaulted loans (EUR trillion)	Model-constrained	0.1602	Calculated from Eq. (11)
DP	Distributed profits (EUR trillion)	Model-constrained	3.8677	Calculated from Eq. (64)
dsr_{HW}	Debt service ratio of worker households	Model-constrained	0.1834	Calculated from Eq. (14)
$EMIS_H$	Housing emissions (GtCO2), 0.33 EEA proportion of building emissions	Free	0.7841	Based on NGFS (2025) and EEA (2025)
$EMIS_O$	Other emissions (GtCO2), 0.33 EEA proportion of building emissions	Free	1.5919	Based on NGFS (2025) and EEA (2025)
GNS	Government net saving (EUR trillion)	Model-constrained	-0.2489	Calculated from Eq. (132)
H_{Constr}	Number of constructed houses (Million houses)	Model-constrained	3.6788	Calculated from Eq. (102)
$H_{ConstrC}$	Conv. new houses (Million houses)	Model-constrained	2.428	Calculated from Eq. (81)
$H_{ConstrG}$	Green new houses (Million houses)	Model-constrained	1.2508	Calculated from Eq. (80)
$H_{ConstrVacant}$	Vacant new houses (Million houses)	Model-constrained	0.2755	Calculated from Eq. (89)
H_{DWOwn}	Number of houses workers desire to buy (Million houses)	Model-constrained	39.5241	Calculated from Eq. (10),(8),(9), (151) and (152)
H_{DWOwnC}	Number of conv. houses workers desire to buy (Million houses)	Model-constrained	26.0859	Calculated from Eq. (19)
H_{DWOwnG}	Number of green houses workers desire to buy (Million houses)	Model-constrained	13.4382	Calculated from Eq. (18)
$H_{INewOwnOccup}$	Number of new own-occupied houses by rentiers (Million houses)	Model-constrained	2.9736	Calculated from Eq. (56)
$H_{INewOwnOccupC}$	Number of new conv. own-occupied houses by rentiers (Million houses)	Model-constrained	1.9626	Calculated from Eq. (58)
$H_{INewOwnOccupG}$	Number of new green own-occupied houses by rentiers (Million houses)	Model-constrained	1.011	Calculated from Eq. (57)

$H_{INewRented}$	Number of new rented houses (Million houses)	Model-constrained	0.2036	Calculated from Eq. (38) and Eq. (90)
$H_{INewRentedC}$	Number of new conv. rented houses (Million houses)	Model-constrained	0.1344	Calculated from Eq. (37)
$H_{INewRentedG}$	Number of green new rented houses (Million houses)	Model-constrained	0.0692	Calculated from Eq. (36)
H_{IOwn}	Number of houses investors own (Million houses)	Free	66.5739	Selected from a reasonable range of values
H_{IOwnC}	Number of conv. own-occupied houses by rentiers (Million houses)	Model-constrained	43.9388	Calculated from Eq. (52)
H_{IOwnG}	Number of green own-occupied houses by rentiers (Million houses)	Model-constrained	22.6351	Calculated from Eq. (51)
$H_{IOwnOccupRented}$	Number of owned houses that are rented (Million houses)	Free	0.8931	Selected from a reasonable range of values
$H_{IOwnOccupRentedC}$	Number of conv. rented houses that were own-occupied by rentiers (Million houses)	Model-constrained	0.5894	Calculated from Eq. (40)
$H_{IOwnOccupRentedG}$	Number of green rented houses that were own-occupied by rentiers (Million houses)	Model-constrained	0.3036	Calculated from Eq. (39)
$H_{IOwnOccupRentedMarket}$	Number of own-occupied houses by rentiers for renting (Million houses)	Model-constrained	0.7989	Calculated from Eq. (55)
H_{IRent}	Total number of rented houses (Million houses)	Free	52.5329	Based on ECB
H_{IRentC}	Number of conv. rented houses (Million houses)	Model-constrained	34.6717	Calculated from Eq. (34)
$H_{IRentedSold}$	Number of rented houses that are sold (Million houses)	Model-constrained	0.0645	Calculated from Eq. (90)
$H_{IRentedSoldC}$	Number of conv. rented houses that were sold (Million houses)	Model-constrained	0.0426	Calculated from Eq. (28)
$H_{IRentedSoldG}$	Number of green rented houses that were sold (Million houses)	Model-constrained	0.0219	Calculated from Eq. (27)
$H_{IRentedSoldMarket}$	Number of rented houses by rentiers for selling (Million houses)	Model-constrained	0.0666	Calculated from Eq. (54)
$H_{IRentedSoldVacant}$	Number of rented houses that are vacant and are not sold (Million houses)	Free	0.0021	Based on ECB
$H_{IRentedSoldVacantC}$	Number of conv. rented houses that are vacant (Million houses)	Model-constrained	0.0014	Calculated from Eq. (92)
$H_{IRentedSoldVacantG}$	Number of green rented houses that are vacant (Million houses)	Model-constrained	7e-04	Calculated from Eq. (91)
$H_{IRentedVacant}$	Number of rented houses that are vacant (Million houses)	Model-constrained	0.1094	Calculated from Eq. (96)
$H_{IRentedVacantC}$	Number of conv. rented houses that are vacant (Million houses)	Model-constrained	0.0722	Calculated from Eq. (98)
$H_{IRentedVacantG}$	Number of green rented houses that are vacant (Million houses)	Model-constrained	0.0372	Calculated from Eq. (97)
H_{IRentG}	Number of green rented houses (Million houses)	Model-constrained	17.8612	Calculated from Eq. (33)
H_{Refurb}	Number of refurbished houses (Million houses)	Model-constrained	29.4911	Calculated from Eq. (86)
$H_{Rentiers}$	Number of houses rentiers live in (Million houses)	Model-constrained	60.5217	Calculated from Eq. (109)
H_{Total}	Total number of houses (Million houses)	Model-constrained	187.6174	Calculated from Eq. (103)
H_{TotalC}	Total number of conv. houses (Million houses)	Model-constrained	123.8275	Calculated from Eq. (107)
H_{TotalG}	Total number of green houses (Million houses)	Model-constrained	63.7899	Calculated from Eq. (106)
$H_{Totalred}$	Total number of houses (Million houses)	Free	187.6174	Based on ECB
H_{Vacant}	Total number of vacant houses (Million houses)	Model-constrained	30.2609	Calculated from Eq. (99)
$H_{VacantC}$	Number of conv. vacant houses (Million houses)	Model-constrained	19.9722	Calculated from Eq. (101)

$H_{VacantG}$	Number of green vacant houses (Million houses)	Model-constrained	10.2887	Calculated from Eq. (100)
$H_{WNewOwnOccup}$	Number of new own-occupied houses of workers (Million houses)	Model-constrained	0.2261	Calculated from Eq. (29)
$H_{WNewOwnOccupC}$	Number of new conv. houses workers buy (Million houses)	Model-constrained	0.1492	Calculated from Eq. (25)
$H_{WNewOwnOccupG}$	Number of new green houses workers buy (Million houses)	Model-constrained	0.0769	Calculated from Eq. (24)
$H_{Workers}$	Number of houses workers live in (Million houses)	Model-constrained	90.7826	Calculated from Eq. (108)
H_{WOwn}	Number of houses workers own (Million houses)	Model-constrained	38.2497	Calculated from Eq. (32)
H_{WOwnC}	Number of conv. houses workers buy (Million houses)	Model-constrained	25.2448	Calculated from Eq. (22)
H_{WOwnG}	Number of green houses workers buy (Million houses)	Model-constrained	13.0049	Calculated from Eq. (21)
$H_{WOwnOccup}$	Number of houses workers own occupy (Million houses)	Model-constrained	0.4594	Calculated from Eq. (93)
$H_{WOwnOccupC}$	Number of new conv. own-occupied houses of workers (Million houses)	Model-constrained	0.3032	Calculated from Eq. (31)
$H_{WOwnOccupG}$	Number of new green own-occupied houses of workers (Million houses)	Model-constrained	0.1562	Calculated from Eq. (30)
$H_{WOwnOccupMarket}$	Number of own-occupied houses by rentiers for selling (Million houses)	Model-constrained	0.6657	Calculated from Eq. (53)
$H_{WOwnOccupVacant}$	Number of owned houses that are vacant and are not sold (Million houses)	Free	0.2064	Based on ECB
$H_{WOwnOccupVacantC}$	Conv. vacant workers own occupied houses (Million houses)	Model-constrained	0.1362	Calculated from Eq. (95)
$H_{WOwnOccupVacantG}$	Number of green vacant houses own occupied houses (Million houses)	Model-constrained	0.0702	Calculated from Eq. (94)
HPM	High-powered money (EUR trillion)	Free	8.6081	The high-powered money in GDP is based on Eurostat
I	Investment (EUR trillion)	Free	2.349	The proportion of total investment in GDP is based on Eurostat
I_C	Conv. investment of firms (EUR trillion)	Model-constrained	1.4768	Calculated from Eq. (71)
I_{Constr}	Investment in new houses (EUR trillion)	Free	0.3529	The proportion of investment in construction in GDP is based on Eurostat and EOS (2024)
$I_{ConstrC}$	Investment in new conv. houses (EUR trillion)	Model-constrained	0.2329	Calculated from Eq. (84)
$I_{ConstrG}$	Investment in new green houses (EUR trillion)	Model-constrained	0.12	Calculated from Eq. (83)
I_G	Green investment (EUR trillion)	Free	0.8722	Green investment refers to renewable energy investment based on NGFS (2025), 0.89 is the exchange rate
I_{Refurb}	Investment in refurbishment (EUR trillion)	Free	0.5079	The proportion of investment in dwellings in GDP is based on Eurostat
$illiq_{HW}$	Worker households' illiquidity ratio	Model-constrained	1	Calculated from Eq. (13)
int_A	Interest rate on advances	Model-constrained	0.03	Calculated from Eq. (145)
int_{LHC}	Interest rate on conv. housing loans	Free	0.04	Based on ECB
int_{LHG}	Interest rate on green housing loans	Free	0.04	Based on ECB
K	Capital stock of firms (EUR trillion)	Model-constrained	119.7985	Calculated from Eq. (74)
K_C	Conv. capital of firms (EUR trillion)	Model-constrained	75.3163	Calculated from Eq. (73)
K_G	Green capital of firms (EUR trillion)	Model-constrained	44.4822	Calculated from Eq. (72)
L	Total loans (EUR trillion)	Free	9.3376	The loans to the non-financial corporations in GDP is based on Eurostat
L_C	Firms conv. loans (EUR trillion)	Model-constrained	5.8705	Calculated from Eq. (77)
L_G	Green loans (EUR trillion)	Free	3.4671	Selected from a reasonable range of values

L_H	Household debt, consolidated including Non-profit institutions serving households (NPISH) (EUR trillion)	Free	8.1704	The loans to the households in GDP is based on Eurostat
L_{HC}	Conv. housing loans (EUR trillion)	Model-constrained	5.3925	Calculated from Eq. (10)
L_{HG}	Green housing loans (EUR trillion)	Free	2.7779	Selected from a reasonable range of values
lev	Firms' leverage ratio	Model-constrained	0.0779	Calculated from Eq. (157)
lev_B	Leverage ratio of banks	Free	14.7	Based on Eurostat
lev_{HW}	Leverage ratio of worker households	Model-constrained	0.9709	Calculated from Eq. (15)
New_{Constr}	Number of new houses constructed (Million houses)	Model-constrained	0.0721	Calculated from Eq. (79)
New_{Refurb}	Number of refurbished houses (Million houses)	Model-constrained	0.5783	Calculated from Eq. (85)
$NLHC_D$		Model-constrained	0.9252	Calculated from Eq. (152)
$NLHG_D$		Model-constrained	0.4766	Calculated from Eq. (151)
p_H	Price of houses (EUR million)	Free	0.22	Based on ECB
POP	Population (Million people)	Free	348	Based on Eurostat
POP_R	Population of rentiers (Million people)	Model-constrained	139.2	Calculated from Eq. (113)
POP_W	Population of workers (Million people)	Model-constrained	208.8	Calculated from Eq. (112)
r	Rate of profit	Model-constrained	0.0471	Calculated from Eq. (65)
r_{HI}	Rate of return for houses	Model-constrained	0.0187	Calculated from Eq. (50)
$rent$	Rent rate (EUR million)	Model-constrained	0.0187	Calculated from Eq. (41)
$Rent$	Expenditure for rent (EUR trillion)	Free	0.9647	Based on ECB
RP	Retained profits (EUR trillion)	Model-constrained	1.7701	Calculated from Eq. (63)
SEC	Total outstanding amount of government securities (EUR trillion)	Free	12.6933	The government securities in GDP is based on Eurostat
SEC_B	Government securities held by banks (EUR trillion)	Free	3.3703	The government securities held by banks in GDP is based on Eurostat and EBA
SEC_{CB}	Government securities held by central bank (EUR trillion)	Model-constrained	3.0126	Calculated from Eq. (143)
SEC_{CBred}	Government securities held by central bank (EUR trillion)	Model-constrained	3.0126	Calculated from Eq. (143)
SEC_{HI}	Government securities held by investor households (EUR trillion)	Model-constrained	6.3104	Calculated from Eq. (142)
spr_H	Spread on housing loans	Model-constrained	0.01	Calculated from Eq. (130)
spr_{HC}	Spread on conv. housing loans	Model-constrained	0.01	Calculated from Eq. (128)
spr_{HG}	Spread on green housing loans	Model-constrained	0.01	Calculated from Eq. (127)
SUB	Green subsidy (EUR trillion)	Free	0.0102	Based on OECD (2024)
TAX	Total taxes (EUR trillion)	Model-constrained	2.9264	Calculated from Eq. (140)
TAX_C	Carbon tax revenues (EUR trillion)	Free	0.032	Based on ERCST (2025)
TAX_F	Taxes on firms' profits (EUR trillion)	Model-constrained	0.438	Calculated from Eq. (138)
TAX_{HI}	Taxes on investor households' disposable income (EUR trillion)	Free	1.459	Selected from a reasonable range of values
TAX_{HW}	Taxes on worker households' disposable income (EUR trillion)	Model-constrained	0.9974	Calculated from Eq. (136)
TP	Total profit of firms (EUR trillion)	Model-constrained	5.6378	Calculated from Eq. (62)
TP_G	Total gross profit of firms (EUR trillion)	Model-constrained	6.1078	Calculated from Eq. (60)
u	Capacity utilisation rate	Free	0.79	Based on Eurostat
V_{CB}	Wealth of central bank (EUR trillion)	Model-constrained	0	Calculated from Eq. (144)
V_{HI}	Wealth of investor households (EUR trillion)	Model-constrained	58.8072	Calculated from Eq. (46)
V_{HW}	Wealth of worker households (EUR trillion)	Model-constrained	2.433	Calculated from Eq. (5)
W	Wage income (EUR trillion)	Model-constrained	8.0245	Calculated from Eq. (61)
$WealthIndex$	Ratio of rentiers to workers wealth	Model-constrained	36.2553	Calculated from Eq. (110)
Y	Output (EUR trillion)	Free	14.59	Based on Eurostat
Y_{HI}	Disposable income of the investor households (EUR trillion)	Model-constrained	4.0102	Calculated from Eq. (44)
Y_{HIG}	Gross disposable income of the investor households (EUR trillion)	Model-constrained	5.4692	Calculated from Eq. (43)

Y_{HW}	Disposable income of the worker households (EUR trillion)	Model-constrained	5.7951	Calculated from Eq. (2)
Y_{HWG}	Gross disposable income of the worker households (EUR trillion)	Model-constrained	6.7823	Calculated from Eq. (1)
Y_{pot}	Potential output (EUR trillion)	Model-constrained	18.4684	Calculated from Eq. (67)
β	Share of green investment in total investment	Model-constrained	0.3713	Calculated from Eq. (70)
β_H	Share of green houses to total houses	Free	0.34	Based on BPIE (2022)

Table A.5: Symbols and values for parameters and exogenous variables (baseline scenario)

Symbol	Description	Parameter category	Value	Source/remarks
c_{11}	Propensity to consume out of disposable income for worker households	Model-constrained	1.0356	Calculated from Eq. (3)
c_{12}	Propensity to consume out of wealth for worker households	Free	0.01	Selected from a reasonable range of values
c_{21}	Propensity to consume out of disposable income for investor households	Model-constrained	0.466	Calculated from Eq. (45)
c_{22}	Propensity to consume out of wealth for investor households	Free	0.01	Selected from a reasonable range of values
c_{CIH}	Parameter linking the green to conventional housing stock with carbon housing intensity	Free	-1.4203	Selected from a reasonable range of values
c_{CIO}	Parameter linking the green to conv. capital stock with carbon other emissions intensity	Free	-1.1026	Selected from a reasonable range of values
CAR_{min}	Minimum capital adequacy ratio	Free	0.08	Based on the Basel III regulatory framework
CI_{H2035}	Carbon housing intensity target	Free	0.0033	Selected from a reasonable range of values
CI_{Hmax}	Maximum intensity rate for carbon intensity of houses	Free	0.005	Selected from a reasonable range of values
CI_{Hmin}	Minimum intensity rate for carbon intensity of houses	Free	0.0021	Selected from a reasonable range of values
CI_{O2035}	Carbon other emission intensity target	Free	0.0873	Selected from a reasonable range of values
CI_{Omax}	Maximum intensity rate for carbon intensity of other emissions	Free	0.1309	Selected from a reasonable range of values
CI_{Omin}	Minimum intensity rate for carbon intensity of other emissions	Free	0.0546	Selected from a reasonable range of values
$CR_{initial}$	Initial degree of credit rationing	Free	0.2	Selected from a reasonable range of values
CR_{max}	Maximum degree of credit rationing	Free	0.5	Selected from a reasonable range of values
def_0	Parameter in the default rate function	Free	14	Selected from a reasonable range of values
def_1	Parameter in the default rate function	Free	13.3929	Selected from a reasonable range of values
def_2	Parameter in the default rate function	Free	13.3929	Selected from a reasonable range of values
def_{max}	Maximum default rate of housing loans	Free	0.3	Selected from a reasonable range of values
gov_C	Share of government expenditures in output	Model-constrained	0.2142	Calculated from Eq. (134)
gov_{SUB}	Green subsidy rate	Model-constrained	0.0083	Calculated from Eq. (135)
h_1	Banks' reserve ratio	Model-constrained	0.3933	Calculated from Eq. (119)
h_{10}	Parameter in the worker households' desired demand for houses	Model-constrained	0.0719	Calculated from Eq. (16)
h_{10}	Parameter in the worker households' desired demand for houses	Model-constrained	0.0719	Calculated from Eq. (16)
h_{13}	Parameter in the worker households' desired demand for houses (growth rate of workers population)	Free	0.01	Selected from a reasonable range of values
h_{14}	Parameter in the worker households' desired demand for houses (rents)	Free	0.01	Selected from a reasonable range of values
h_2	Banks' government securities-to-deposits ratio	Model-constrained	0.154	Calculated from Eq. (154)
h_{20}	Parameter in the housing investment function	Model-constrained	0.0107	Calculated from Eq. (78)
h_3	Parameter in housing prices	Free	0.02	Selected from a reasonable range of values
h_{33}	Parameter in the housing price equation	Model-constrained	0	Calculated from Eq. (88)

HG_{HC2034}	Housing intensity target	Free	0.5167	Selected from a reasonable range of values
int_C	Interest rate on conventional loans	Free	0.05	Based on ECB
int_D	Interest rate on deposits	Free	0.02	Based on ECB
int_G	Interest rate on green loans	Free	0.05	Based on ECB
int_{max}	Maximum interest rate on advances	Free	0.03	There is no policy in the first year
int_{min}	Minimum interest rate on advances	Free	0.03	There is no policy in the first year
int_{ref}	Reference interest rate on advances	Free	0.03	Selected from a reasonable range of values
int_S	Interest rate on government securities	Free	0.028	Based on ECB
KG_{KC2034}	Capital stock intensity target	Free	0.5906	Selected from a reasonable range of values
p_{Constr}	Price of constructed houses (EUR trillion per million houses)	Model-constrained	0.0959	Calculated from Eq. (82)
p_{Refurb}	Price of refurbished houses (EUR trillion per million houses)	Model-constrained	0.0172	Calculated from Eq. (87)
$prop_D$	Proportion of workers' deposits to income	Model-constrained	0.3852	Calculated from Eq. (4)
$prop_{HIRent}$	Proportion of rented houses, percent of total houses	Free	0.28	Based on ECB
$prop_{IOwnOccup}$	Proportion of owned houses rentiers wish to rent	Free	0.012	Selected from a reasonable range of values
$prop_{IRented}$	Proportion of rented houses rentiers wish to sell	Free	0.001	Selected from a reasonable range of values
$prop_{NewRented}$	Proportion of new rented houses	Model-constrained	0.0553	Calculated from Eq. (35)
$prop_{RentedSold}$	Proportion of rented houses that were sold	Model-constrained	7e-04	Calculated from Eq. (26)
$prop_{Vacancy}$	Vacancy rate, percent of total houses	Free	0.11	Based on ECB
$prop_W$	Proportion of new own-occupied houses by workers to total new houses	Model-constrained	0.0615	Calculated from Eq. (23)
$prop_{WExisting}$	Proportion of owned houses rentiers wish to sell	Free	0.01	Selected from a reasonable range of values
$prop_{Workers}$	Share of workers	Free	0.6	Selected from a reasonable range of values
r_0	Parameter in the credit rationing of housing loans	Free	1.5	Selected from a reasonable range of values
r_1	Parameter in the credit rationing of housing loans	Model-constrained	-1.3148	Calculated from Eq. (124)
r_2	Parameter in the credit rationing of housing loans	Free	8.5397	Selected from a reasonable range of values
$r_{2dCRddsrmax}$	Parameter in the credit rationing of housing loans	Free	1.0248	Selected from a reasonable range of values
r_3	Parameter in the credit rationing of housing loans	Free	83.3333	Selected from a reasonable range of values
$r_{3dCRdCARmax}$	Parameter in the credit rationing of housing loans	Free	-10	Selected from a reasonable range of values
$rent_0$	Parameter linked to the rent equation	Model-constrained	0	Calculated from Eq. (42)
$rent_1$	Parameter linked to the rent equation	Free	0.01	Selected from a reasonable range of values
rep_L	Repayment of loans	Free	0.1	Selected from a reasonable range of values
s_B	Banks' retention rate	Model-constrained	0.7349	Calculated from Eq. (116)
s_F	Firms' retention rate	Model-constrained	0.3203	Calculated from Eq. (76), (153), (77), (68) and (63)
s_W	Wage share	Free	0.55	Based on Penn World Table 10.0 (see Feenstra, 2015)
$size$	Average household size	Free	2.3	Based on Eurostat
spr_{H0}	Parameter in the lending spread on housing loans	Model-constrained	0.0069	Calculated from Eq. (129)
spr_{H2}	Parameter in the lending spread on housing loans (debt service ratio)	Free	0.0232	Selected from a reasonable range of values

v	Capital productivity	Model-constrained	71	Calculated from Eq. (66) and (67)
w_H	Risk weight on high-powered money	Free	0	Based on BCBS (2023)
w_L	Risk weight on loans	Free	1	Based on BCBS (2023)
w_S	Risk weight on government securities	Free	0	Based on BCBS (2023)
α_{00}	Parameter in investment function	Free	0.04	Selected from a reasonable range of values
α_{01}	Parameter in the investment function	Model-constrained	1.0534	Calculated from Eq. (68)
α_1	Parameter in the investment function (related to the sensitivity to the capacity utilisation)	Free	0.69	Selected from a reasonable range of values
α_2	Parameter in the investment function (related to the sensitivity to the profit rate)	Free	10.8	Selected from a reasonable range of values
β_0	Parameter for the green investment share	Model-constrained	0.3713	Calculated from Eq. (69)
β_1	Parameter for the green investment share to the interest rate differential	Free	1	Selected from a reasonable range of values
β_{H0}	Parameter in share of green houses	Model-constrained	0.3317	Calculated from Eq. (17)
κ_{CIH}	Parameter linking the green to conventional housing stock with carbon housing intensity	Free	159.7463	Selected from a reasonable range of values
κ_{CIO}	Parameter linking the green to conventional capital stock with carbon other emissions intensity	Free	465865584.3035	Selected from a reasonable range of values
λ_{10}	Parameter of investor households' portfolio choice	Model-constrained	0.11	Calculated from Eq. (47)
λ_{11}	Parameter of investor households' portfolio choice	Free	0.02	Calculated from the constraint
λ_{12}	Parameter of households' portfolio choice	Free	-0.01	Selected from a reasonable range of values
λ_{13}	Parameter of households' portfolio choice	Free	-0.01	Selected from a reasonable range of values
λ_{14}	Parameter of households' portfolio choice	Free	-0.01	Selected from a reasonable range of values
λ_{20}	Parameter of investor households' portfolio choice	Model-constrained	0.2548	Calculated from Eq. (48)
λ_{21}	Parameter of investor households' portfolio choice	Free	-0.01	Calculated from the constraint
λ_{22}	Parameter of investor households' portfolio choice	Free	0.02	Calculated from the constraint
λ_{23}	Parameter of investor households' portfolio choice	Free	-0.01	Selected from a reasonable range of values
λ_{24}	Parameter of investor households' portfolio choice	Free	-0.01	Selected from a reasonable range of values
λ_{30}	Parameter of investor households' portfolio choice	Model-constrained	0.3403	Calculated from Eq. (150)
λ_{31}	Parameter of investor households' portfolio choice	Free	-0.01	Calculated from the constraint
λ_{32}	Parameter of investor households' portfolio choice	Free	-0.01	Calculated from the constraint
λ_{33}	Parameter of investor households' portfolio choice	Free	0.02	Calculated from the constraint
λ_{34}	Parameter of investor households' portfolio choice	Free	0.02	Calculated from the constraint
τ_C	Carbon tax (EUR trillion/GtCO2)	Model-constrained	0.0205	Calculated from Eq. (139)
τ_F	Firms' tax rate	Model-constrained	0.0731	Calculated from Eq. (133) and (132)
τ_{HI}	Investor households' tax rate	Model-constrained	0.2721	Calculated from Eq. (137)
τ_{HW}	Worker households tax rate	Free	0.15	Selected from a reasonable range of values

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