Beyond Carbon Pricing:
Evaluating Policy Mixes for a Macro-Financially Stable Transition

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Summary

Goal: study the macro-financial policy mix for an orderly green transition.

How: we enrich the DSK macro-financial agent-based IAM (Lamperti et al., 2018; Reissl et al., 2025), endowed with a climate module, and test a variety of policies triggering energy transition in:

- The **energy sector** (power generation)
- The **manufacturing sector** (industry electrification)

via market and non-market based policies:

- Carbon pricing (CO_2 tax)
- Command-and-control: mandatory electrification (E) + brown ban (BB)
- Green financial policies: carbon-risk adjustment (CRA); green public guarantees (GG)

Key features: SFC implementation with full balance-sheet tracking; electrification extension following (Wieners et al., 2025); calibration on SSP2 (Middle of the Road) for EU27.

Motivation

Climate change poses a **dual threat** to economic stability:

1. **Physical risks** of unmitigated warming.
2. **Transition risks** inherent in the restructuring of energy and industrial systems.

Governments worldwide deploy ensembles of climate policies with promising results in emissions reduction (Stechemesser et al., 2024). However:

- Positive environmental outcomes may entail challenges to **financial system stability** and private sector competitiveness (Peñasco et al., 2021; Känzig, 2023).
- Medium-to-long-run consequences remain questionable: risks of **stranded assets**, sectoral slowdown, and financial fragility—especially in fossil-dependent regions and banking systems (Mercure et al., 2018; Semieniuk et al., 2021).
- Carbon taxation, while advocated by academics, is infrequently employed in practice (Peñasco et al., 2021) with mild yet unequal effects (Köppl and Schratzenstaller, 2023; Colmer et al., 2025).

Related Literature & Contribution

We contribute to two streams of the literature:

1. **Analysis of transition risks for the macroeconomy**
   - Mercure et al. (2018); Semieniuk et al. (2021); Campiglio and van der Ploeg (2022)
2. **Market vs. non-market based policies for energy transition**
   - Dafermos and Nikolaidi (2021); Stiglitz (2019)
   - Green financial policies alone may not suffice if not coupled with green fiscal/industrial policies (Lamperti et al., 2021)

Research Question & Preliminary Findings

Central Research Question

Which policy combination entails the **lowest macroeconomic and macro-financial risks** during the low-carbon transition, considering short-run implementation challenges, medium-run adjustments, and long-run structural transformations?

Model Overview

An **agent-based integrated assessment model** with full stock-flow consistency (Lamperti et al., 2018; Reissl et al., 2025).

Real side

- **K-firms** (N_1): produce heterogeneous capital goods; innovate via endogenous R&D
- **C-firms** (N_2): produce homogeneous consumption goods using labour, capital, energy
- **Households**: supply labour, consume, receive wages, dividends and benefits
- **Energy sector**: green and brown plants; endogenous capacity expansion and R&D

Financial side

- **Banks** (N_B): extend credit to C-firms; rank borrowers by debt-service ratio
- **Government**: collects taxes, pays benefits, bails out banks, issues bonds
- **Central Bank**: sets interest rate (Taylor rule); lender of last resort
- **Fossil fuel sector**: sells fuel to energy and K-firms; not connected to banking system

Production and Innovation

K-firms — Capital goods producers

- Use labour and energy as inputs; price via uniform mark-up over heterogeneous unit cost.
- Each firm characterised by: labour productivity, energy efficiency, environmental friendliness — for both its **own process** and the **machines it sells**.
- R&D spending (fixed share of revenue) $\rightarrow$ stochastic innovation/imitation $\rightarrow$ endogenous technological change drives long-run growth.

C-firms — Consumption goods producers

- Use labour, capital (from K-firms) and energy; heterogeneous mark-up evolves with market share.
- Investment: expansion + replacement; financed by retained earnings or **bank loans**.
- Choose K-firm supplier based on price and capital good characteristics.

Firms exit due to: small market share, inability to meet payments, or negative net worth. Exiting firms are replaced by entrants.

Banking sector

- Banks allocate credit to C-firms up to a regulatory capital ratio.
- Borrowers ranked by **debt-service-to-revenue** ratio → determines both loan access and interest rate:

$$r^{l}_{b,c,t} = r^{l}_{b,t}\left(1 + \left(rank_{c,t} - 1\right)\mathfrak{M}\right)$$

- Bank failure → government bailout or acquisition by larger bank.

Energy sector

- Green plants: positive construction cost, zero running cost.
- Brown plants: zero construction cost, positive running cost (fossil fuel + possible carbon tax).
- Green plants dispatched first; capacity expanded based on cost-effectiveness comparison.
- Sector-level R&D improves green construction cost and brown efficiency.

Our Extension: Industry Electrification

We extend the DSK-SFC model following Wieners et al. (2025) by introducing **fossil fuel use in manufacturing**.

What changes:

- K-firms now use a **mix of electricity and fossil fuel** as energy input, governed by an electrification share $share_{el}(i) \in [0, 1]$.
- Unit cost becomes:

$$c = \frac{w}{A^L} + c_{en}\frac{share_{el}}{A^{EN}} + p_f\frac{(1 - share_{el})}{A^{EN}} + \tau_{CO_2}\left(\frac{A^{EF}}{A^{EN}} + \frac{A^{FF}}{A^{EN}}\right)$$

- **Fossil fuel sector** added: sells fuel to energy sector and K-firms; holds reserves at CB but is not connected to the banking system.
- **New SFC flows**: fuel payments (FF_k, FF_e) fully tracked in transaction-flow matrix.

This opens a new policy channel: regulations can target K-firm fuel use directly, not only the energy sector.

Stock-Flow Consistent Implementation

Balance Sheet Matrix:

	HH	C-Firms	K-Firms	Banks	Gov.	CB	Energy	Fossil	Σ
Bank Deposits	$+D_h$	$+D_c$	$+D_k$	$-D$			$+D_e$		0
Gov. Bonds				$+GB_b$	$-GB$	$+GB_{cb}$			0
Loans		$-L$		$+L$					0
CB Reserves				$+R_b$		$-R$		$+R_f$	0
CB Advances				$-A$		$+A$			0
Fixed Capital		$+K$					$+K_e$		$K+K_e$
Inventories		$+Inv$							Inv
Σ	NW_h	NW_c	NW_k	NW_b	NW_g	NW_{cb}	NW_e	NW_f	

Fossil fuel sector not directly connected to the banking system. It holds a non-remunerative reserve account at CB to make and receive payments.

Transaction-Flow Matrix

	HH	C-Firms	K-Firms	Banks	Gov.	CB	Energy	Fossil	Σ
Consumption	$-C$	$+C$							0
Investment		$-I$	$+I$						0
Benefits	$+UB$				$-UB$				0
Taxes	$-Tax_h$	$-Tax_c$	$-Tax_k$	$-Tax_b$	$+Tax$		$-Tax_e$		0
Wages	$+W$	$-W_C$	$-W_k$				$-W_e$		0
Fuel			$-FF_k$				$-FF_e$	$+FF$	0
Energy		$-E_c$	$-E_k$				$+E$		0
Dividends	$+Div$	$-Div_C$	$-Div_k$	$-Div_b$			$-Div_e$	$-Div_f$	0
Int. Loans		$-iL$		$+iL$					0
Int. Deposits	$+iD_h$	$+iD_C$	$+iD_k$	$-iD$			$+iD_e$		0
Bailout				$+Bail$	$-Bail$				0
Saving	(Sav_h)	(Sav_C)	(Sav_k)	(Sav_b)	(Sav_g)	(Sav_{cb})	(Sav_e)	(Sav_f)	0

Fuel payments (FF_k, FF_e) are the new SFC flows introduced by the electrification extension.

Plus possible redistribution to households of carbon tax revenues and/or fines collected for non-compliant manufacturing firms

Policy Instruments — Overview

Policy	Target	Mechanism
Fiscal & regulatory instruments		
CO_2 Tax	Energy, K-firms	CPI-indexed price on emissions
Brown Ban (BB)	Energy sector	Ban on new fossil plants; halved brown lifespan
Electrification (E)	K-firms	Mandated electrification share; fines for gap
Green financial instruments		
Carbon-Risk Adj. (CRA)	Banks → C-firms	Loan ranking includes env. friendliness
Green Guarantees (GG)	Gov. → Banks	Gov. absorbs default risk on green loans

Carbon Tax — CPI-Indexed

A **market-based** instrument taxing emissions across energy and manufacturing sectors.

Design:

- **Activated** at $t_{\text{clim}} + 26$; applied to energy firms and K-firms.
- CPI-indexed to preserve real burden over time:

$$\tau^{CO_2}(t) = \frac{\pi(t)}{\pi_0} \cdot \tau_0^{CO_2}$$

- Carbon tax revenues accrue to the government budget.

Expected effects:

$\nearrow$ Energy costs $\Rightarrow$ incentivises green energy adoption and electrification.

$\searrow$ Firm profitability $\Rightarrow$ potential credit tightening and output contraction.

Brown Plant Construction Ban (BB)

A **command-and-control** regulation banning new fossil-fuel-fired power plants.

Design:

- **Enforced** from $t_{\text{clim}} + 26$: no new brown plants can be built.
- Existing brown plants **remain operational** until retirement, but their lifespan is **halved** relative to green plants upon announcement.
- New capacity expansion must be 100% green.

Expected effects:

- ↗ Green energy share accelerates through both forced entry and faster brown exit.
- ↗ Short-run energy costs may rise due to green plant construction costs.

Mandatory Electrification of Industry (E)

A **command-and-control** regulation banning fossil-fuel use in K-firm production.

Design:

- **Announced** at $t_{\text{start}} - \Delta t_{\text{react}}$ to allow firms adjustment time.
- **Enforced** from t_{start}: K-firms must achieve electrification share $\geq \bar{e}_{\text{reg}}$.
- Non-compliant firms face a **fine** proportional to their electrification gap:

$$c_1(i) = \tilde{c}_1(i) \cdot \Big(1 + \phi \cdot \big(\bar{e}_{\text{reg}} - share_{el}(i)\big)\Big) \quad \text{if } share_{el}(i) < \bar{e}_{\text{reg}}$$

- Fine revenues enter government budget.

Green Financial Policy 1: Carbon-Risk Adjustment (CRA)

Banks incorporate **environmental friendliness** of C-firms into credit allocation.

Implementation:

- Banks rank C-firms by **debt-service-to-sales** ($Rank^{DS}$) and by **energy efficiency** ($Rank^{EF}$).
- A composite rating determines credit access and loan pricing:

$$CRA(j) = \frac{Rank_j^{DS} + Rank_j^{EF}}{2}$$

- CRA replaces the standard debt-service ranking in setting quartile-based interest rates.

Expected effects:

$\nearrow$ Credit access for greener firms $\Rightarrow$ steers investment toward cleaner capital.

$\nearrow$ Bank exposure to riskier (but greener) borrowers $\Rightarrow$ potential financial fragility.

- Does **not** expand total credit volume—only **reallocates** it.

Green Financial Policy 2: Green Public Guarantees (GG)

The government absorbs default risk on loans to **green firms**.

Implementation:

- Banks rank C-firms using a two-tier rule:
  - **Top 25%** by energy efficiency: priority credit access.
  - **Remaining 75%**: ranked by standard debt-service ratio.
- If a green firm defaults, the **government covers** the outstanding loan:

$$\text{Bailout}(j) = \text{Loans}(j)$$

- Green bailouts enter fiscal expenditure (SFC-consistent via the deficit equation).

Expected effects:

$\searrow$ Bank losses from green lending $\Rightarrow$ stabilises banking sector.

$\nearrow$ Public debt if green firm defaults are frequent.

- Makes green loans effectively **risk-free** for banks.

Green Financial Policy 2: Green Public Guarantees

The government backs loans to green firms, absorbing their default risk

Implementation:

- Banks rank C-firms using a two-tier rule:
  - **Top 25%** by energy efficiency: priority credit access
  - **Remaining 75%**: re-ranked by standard DS_2-rating.
- If a green firm cannot meet its debt service, the **government bails out**:

$$\text{Bailout}_2(j) = \text{Loans}_2(j)$$

- In this case, the loan is recorded to aggregate government expenditure (SFC-consistency).

Parameter Changes: New Parameters

Parameter	Description	Value
Electrification regulation		
`elfrac_reg_val`	Mandated electrification fraction ($\bar{e}_{reg}$)	1.0
`fine_elect_reg`	Fine rate per unit of electrification gap (ϕ)	0.3
Energy coefficients & technical change		
`A0_el`	Initial electricity share in K-firm energy mix	0.3
`ff2em`	Emissions per unit fossil fuel in industry	2500[a]
`xi_en`	R&D allocation to energy-related innovation	0.5
`o1en1`	Search capability — energy dimension	0.15
`o1lab1`	Search capability — labour dimension	0.15
`pm_en`	K/C energy efficiency ratio	0.0275
Innovation draw supports (electrification)		
`uu72`, `uu82`	Electrification ratio bounds, K-mach	−0.15; 0.15
`b_a4`, `b_b4`	Beta shape params for Electrification	2.83, 3
Policy flags & sectoral parameters		
`flag_C_firms_emitting`	Toggle C-firm emissions	0

[a] 1100 in Wieners et al. (2025)

Parameter Changes: Modified Values

Parameter	Description	New	Old	Rationale
pf0	Initial fossil fuel price	2×10^{-5}	1×10^{-5}	Higher to reflect some relevance in K-firm Fuel/electricity decisions.
CF_ge0	Initial green plant construction cost	0.02	0.05	Lower initial cost reflecting of Green energy plants
t_CO2_0	Initial carbon tax on K-firms	0.0005	0	Non-zero baseline tax to enable CPI-indexed scaling
t_CO2_en_0	Initial carbon tax on energy sector	0.0005	2.5×10^{-5}	Harmonised with K-firm tax level

Replaced Parameter

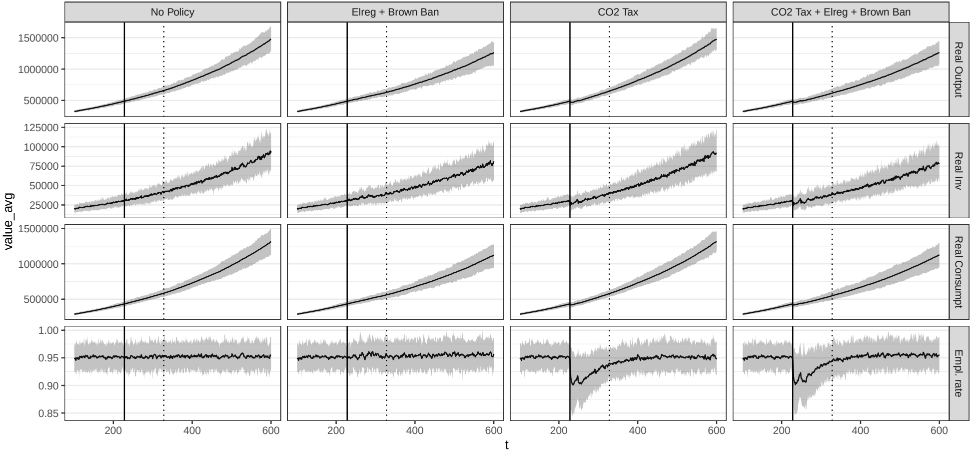
Old	New	Old val.	New val.	Rationale
o1	o1en1, o1lab1	0.05	0.15, 0.15	Single search capability split into energy and labour dimensions

Baseline Summary Statistics - Baseline (No Policy) Scenario

	This work		Reissl et al. (2025)	
	MC Mean	MC Std. Dev.	MC Mean	MC Std. Dev.
GDP growth rate (%)	1.4	0.083	1.35	0.076
Unemployment rate (%)	4.8	0.002	5.2	0.002
Emissions growth (%)	-0.203	0.131	0.225	0.119
Green energy share (%)	42.2	43.8	21.8	0
Electrification (%)	32.6	18.4	-	-
Bad Debt / GDP (%)	0.78	0.028	0.81	0.027
Public debt / GDP (%)	22.	1.3	21.8	1.08

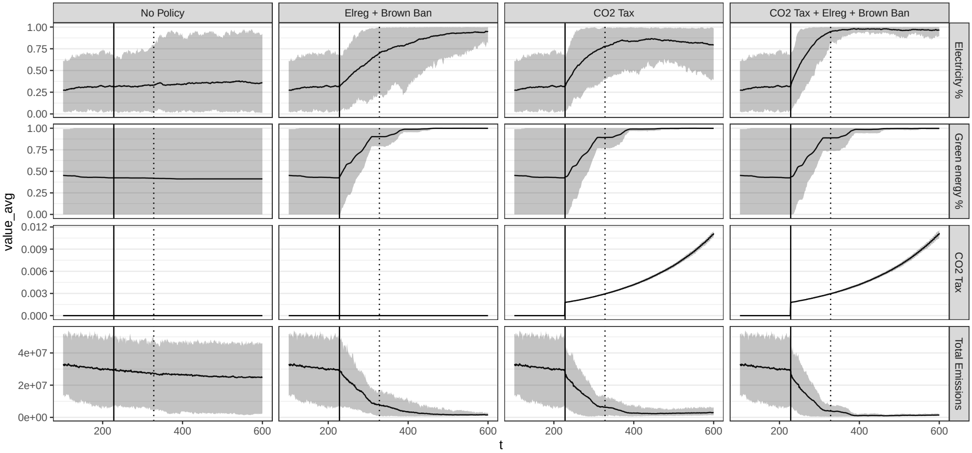
Values based on $N = 80$ Monte Carlo runs

Climate Policies - Real Side (MC Avg with 10-90th quintile bands)



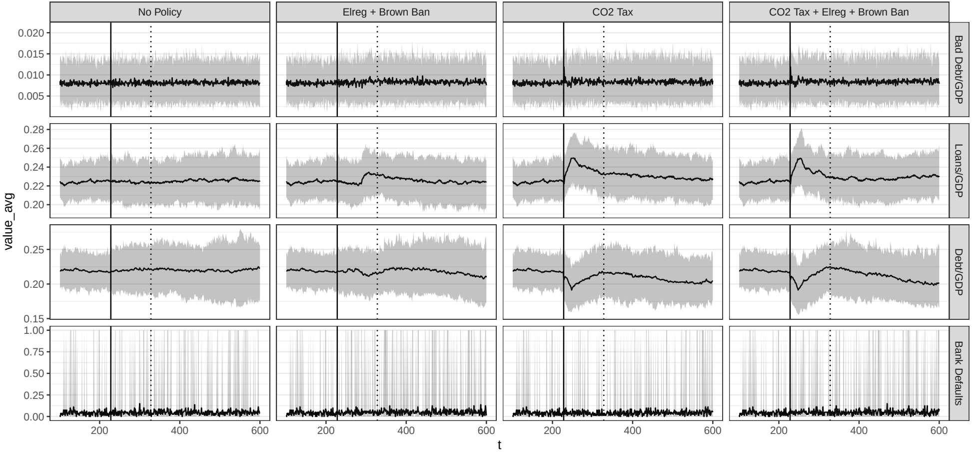
Takeaway: E+BB achieves comparable output growth with lower short-run disruption; CO_2 tax triggers unemployment. Solid line = $t_{climbox}$, dotted line $t_{climbox}$ + 25 years.

Climate Policies - Energy (MC Avg with 10-90th quintile bands)



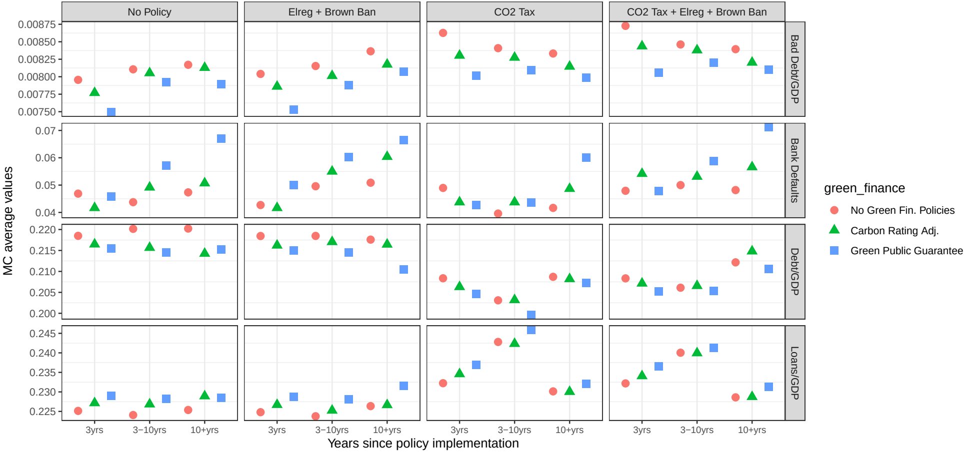
Takeaway: CO_2 tax scenarios reach near-full green energy share earlier, at the cost of higher emission volatility during transition. Solid line = $t_{climbox}$, dotted line $t_{climbox}$ + 25 years.

Climate Policies - Macro-Financial (MC Avg with 10-90th quintile bands)



Takeaway: Bad debt and public debt rise sharply under carbon taxation; command-and-control policies preserve macro-financial stability. Solid line = $t_{climbox}$, dotted line $t_{climbox} + 25$ years.

Green Financial Policies during the transition



Takeaway: CRA and GG lower firm-level fragility across all climate policy scenarios, but banks bear more transition risk.

Green Financial Policies — Macro-Financial Impacts

		CRA	GG		CRA	GG
No Policy	Bad Debt/GDP	0.994	0.969***	Debt/GDP	0.976*	0.979
E + BB		0.98***	0.966***		0.995	0.972**
CO_2 Tax		0.979***	0.96***		0.998	0.992
CO_2 Tax + E + BB		0.98***	0.966***		1.01	0.993
No Policy	Loans/GDP	1.014*	1.014*	K-Firm Exits	1.001	1.032**
E + BB		1.002	1.021***		1.034*	1.011
CO_2 Tax		1	1.009		1.025*	1.027**
CO_2 Tax + E + BB		1.001	1.01		1.031	1.041**
No Policy	Bank Defaults	1.068	1.362***	C-Firms Exits	0.998	0.981***
E + BB		1.159***	1.273***		0.99***	0.98***
CO_2 Tax		1.138**	1.343***		0.991**	0.978***
CO_2 Tax + E + BB		1.146***	1.389***		0.989***	0.98***

Results show ratios relative to a baseline where no green financial policies are in place.

E = Electricity regulation; BB = Brown Ban; CRA = Carbon-Risk Adjustment; GG = Green Guarantees;

Summary of Findings

1. **Command-and-control policies drive rapid decarbonisation with contained macro-financial costs.** Brown bans and electrification mandates achieve emission reductions while preserving output stability and stable public and private debt ratios. Carbon taxation accelerates the transition but at higher macroeconomic cost.
2. **Green financial policies reduce transition risk.** CRA and GG lower bad-debt ratios and redirect credit toward energy-efficient capital, decreasing firm bankruptcies across all climate policy scenarios.
3. **Short-run financial instability is manageable and does not compromise public-finance sustainability.** Bank defaults rise as lenders finance the transition, but the increase remains contained. Public debt ratios stay stable, even under green guarantees.

Policy Implication

A **climate policy mix** is the engine of decarbonisation; **green financial policies** are the stabilisers that keep the transition on track.

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