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Luca Eduardo Fierro

fierro@iiasa.ac.at

International Institute for Applied Systems Analysis (IIASA) https://orcid.org/0000-0002-4378-1375

Severin Reissl

RFF-CMCC European Institute on Economics and the Environment

Francesco Lamperti

Sant'Anna School of Advanced Studies

Emanuele Campiglio

University of Bologna

Laurent Drouet

RFF-CMCC European Institute on Economics and the Environment (EIEE) https://orcid.org/0000-0002-4087-7662

Johannes Emmerling

RFF-CMCC European Institute on Economics and the Environment, Centro Euro-Mediterraneo sui Cambiamenti Climatici https://orcid.org/0000-0003-0916-9913

Elise Kremer

RFF-CMCC European Institute on Economics and the Environment

Massimo Tavoni

RFF-CMCC European Institute on Economics and the Environment https://orcid.org/0000-0001-5069-4707

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Macro-financial transition risks along mitigation pathways: evidence from a hybrid agent-based integrated assessment model*

Luca E. Fierro[1, 2], Severin Reissl[3, 4], Francesco Lamperti[1, 3, 4, 5], Emanuele Campiglio[3, 4, 6, 7], Laurent Drouet[3, 4], Johannes Emmerling[3, 4], Elise Kremer[3, 4], and Massimo Tavoni[3, 4, 8]

[1]Institute of Economics, Sant'Anna School of Advanced Studies, Pisa, Italy
[2]International Institute for Applied System Analysis, Laxenburg, Austria
[3]CMCC Foundation - Euro-Mediterranean Center on Climate Change, Lecce, Italy
[4]RFF-CMCC European Institute on Economics and the Environment, Milan, Italy
[5]EMbeDS, Sant'Anna School of Advanced Studies, Pisa, Italy
[6]University of Bologna, Bologna, Italy
[7]LSE Grantham Research Institute on Climate Change and the Environment, London, United Kingdom
[8]Politecnico di Milano, Milan, Italy

Abstract

Although the case for a swift climate transition is clear, its macro-financial viability remains uncertain. To shed light on the macroeconomic and financial response to deep mitigation trajectories controlled by carbon pricing, we integrate a process-based integrated assessment model into a macroeconomic agent-based model. The hybrid framework allows translating energy systems transformations into macro-financial outcomes at business cycle frequency and volatility. The results reveal that rapid transitions induced by fast-growing carbon prices significantly impact unemployment, inflation, and income distribution. Stabilization policies reduce these economic fluctuations, though not completely so in 1.5°C compatible scenarios. Our paper emphasizes the need for coordinating climate and macroeconomic policy during decarbonization. Additionally, it showcases how model integration can lead to a better understanding of the economic implications of low-carbon futures.

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As countries commit to decarbonisation plans, questions around implementation and robust policy design grow in importance. The current consensus is that the world possesses the technology and economic capacity to switch to low-carbon options in many sectors (IPCC, 2022). However, much less is understood about the macroeconomic and financial repercussions of climate neutrality goals at the frequencies of interest to policy-makers (Battiston et al., 2021; Semieniuk et al., 2021). This is a major shortcoming of existing model-based assessments, given the importance of macroeconomic conditions for the political and public support of climate policies and for effective policy design aimed at smoothing the transition and making it inclusive.

The major causes of this limited capacity are methodological and disciplinary boundaries. Model-based assessments of decarbonization policies - especially those performed at the community science level - have focused on technological and sectoral strategies as the main outcome variables. Models supporting these assessments, including detailed-process Integrated Assessment Models (IAMs) (Weyant, 2017), typically feature a stylised representation of economic and financial dynamics (Sanders et al., 2022). Though some have quantified the implications of decarbonization for dimensions such as competitiveness, trade, and sectoral employment, many scenarios only use changes in real GDP, typically at very low temporal frequency, to capture transition costs. Short-run dynamics and impacts on unemployment, balance sheets and the financial system, or inflation are typically not represented. Indeed, none of these macro-financial dimensions is reported in the 1,100 scenarios assessed in the Intergovernmental Panel on Climate Change's Sixth Assessment Report. Moreover, fiscal or monetary policy responses to macroeconomic costs induced by climate policy are not typically considered in ex-ante policy assessment. At the same time, such information is highly sought after by finance ministries and international organizations (e.g. the Network for Greening the Financial System, NGFS), and transition scenarios and their implications are becoming increasingly relevant for private financial sector agents (NGFS, 2023; TCFD, 2023).

On the other side, different macroeconomic models have been extended to accommodate energy and climate sides, providing insights into the effects of monetary and fiscal policy for the low-carbon transition, and on the repercussions of moving away from fossil-fuel energy for the macroeconomy. These models include extensions of the dynamic stochastic general equilibrium framework (DSGE; e.g. Annicchiarico and Di Dio, 2015; Diluiso et al., 2020; Carattini et al., 2023; Comerford and Spiganti, 2023), post-keynesian ecological macroeconomic models (e.g. Dafermos et al., 2018; Monasterolo and Raberto, 2019; Mercure et al., 2018; Semieniuk et al., 2022), macroeconomic agent-based models (MABM; e.g. Lamperti et al., 2018; Wieners et al., 2024; Turco et al., 2023), non-linear behavioural macroeconomic frameworks (e.g. Campiglio et al., 2024) as well as network models (e.g. Gualdi and Mandel, 2019; Stangl et al., 2024; Cahen-Fourot et al., 2021). However, the majority of these approaches misses detailed transition dynamics, such as those depicted by process-based IAMs and included in IPCC mitigation pathways. Indeed, they typically feature only a "green" and a "brown" sector.

This gap presents an opportunity for fruitful cross-fertilization between modelling methodologies providing diverse yet complementary views on decarbonization dynamics. In this paper we provide - to the best of our knowledge - the first coupling of a macroeconomic agent-based model (DSK) and a process-based IAM (WITCH). Macroeconomic agent-based models offer comprehensive frameworks that integrate both long-term and short-term economic dynamics (Fagiolo and Roventini, 2017; Dawid and Delli Gatti, 2018), encompassing real-financial interactions (Delli Gatti et al., 2010) and balance sheet relationships among economic agents (Caiani et al., 2016). In principle, they enable the assessment of transition and climate costs at business cycle frequency, while also capturing growth implications and financial risks (Castro et al., 2020). Additionally, they report on a richer set of micro and macro variables than many other macroeconomic models (e.g. DSGEs), including unemployment, inflation, and distributional variables. Complementarily, IAMs offer a fine-grained depiction of decarbonization pathways, including the transformation of the energy and other emitting sectors, their mitigation costs, the investment requirements and energy mix of the economy accounting for all major energy technologies.

Soft-coupled models are not a novelty. In the mitigation literature, they have been employed to investigate R&D investment strategies for decarbonization (Aleluia Reis et al., 2023), climate-induced financial instability (Battiston et al., 2017; Roncoroni et al., 2021), macroeconomic effects of climate shocks (Yilmaz et al., 2023), and housing renovations decisions (Niamir et al., 2024). Focusing on transition risks, Allen et al. (2020) and Vermeulen et al. (2018) feed NGFS scenarios defined as carbon price and productivity shocks in a multi-country New Keynesian macro model (NiGEM), which is then linked to sectoral and financial models to perform stress tests. This method allows for studying the heterogeneous effects of climate policies across and within sectors and the dynamics of different financial assets. Comparatively, our IAM-MABM approach allows for a wider range of variables to define scenarios and a more detailed representation of the energy sector which, in particular, includes its balance sheet and cost structure. Moreover, our MABM approach allows us to analyze functional (and potentially personal) income distribution feedback, which remains hindered in standard macro models.

We use the WITCH[1] model (Bosetti et al., 2006; Emmerling et al., 2016; Drouet et al., 2021) to generate detailed transition pathways. This process-based integrated assessment model combines an inter-temporal Ramsey-type growth framework with a bottom-up representation of the energy sector. The model divides the world into 17 global regions, each playing a non-cooperative game to maximize welfare in response to climate policies. A key decision in this process is how to allocate R&D investments, which can be directed toward improving energy efficiency or developing carbon-free technologies.

The transition pathways produced by WITCH are then fed into the DSK agent-based model.[2] The DSK model depicts out-of-equilibrium economic dynamics, capturing both short-run fluctuations and long-run growth (Lamperti et al., 2018, 2019, 2021; Reissl et al., 2024). It includes seven types of agents interacting across five markets (see Figure 1). Key variables from the WITCH-generated transition scenarios serve as inputs for the DSK model (see Figure 1), allowing for an assessment of the macroeconomic implications of these transition pathways.

We show that an *orderly*, i.e. low unemployment, and *just*, i.e., distributionally balanced, transition are mutually dependent, as the unemployment resulting from aggressive carbon pricing is influenced by how the tax burden is distributed between profit and wage incomes.[3] Furthermore, the unequal impact of the carbon tax on the energy sector presents a potential source of instability. While the carbon tax promotes profitability in renewable energy sectors, offering financial support for the transition, it simultaneously undermines profitability in fossil fuel-based sectors, rendering them more susceptible

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[1] World Induced Technical Change Hybrid.

[2] "Dystopian Schumpeter Meeting Keynes", which belongs to the "Keynes + Schumpeter" family of MABMs (e.g. Dosi et al., 2010, 2013, 2017).

[3] Here we use a loose definition of orderly and just transition. In our setting, an orderly transition is characterized by low unemployment levels, as a proxy for contained macroeconomic imbalances; a just transition is characterized by a relatively high and stable share of labour income, as a proxy for contained socio-economic inequality. See Newell and Mulvaney (2013) and Wang and Lo (2021) for additional discussion.

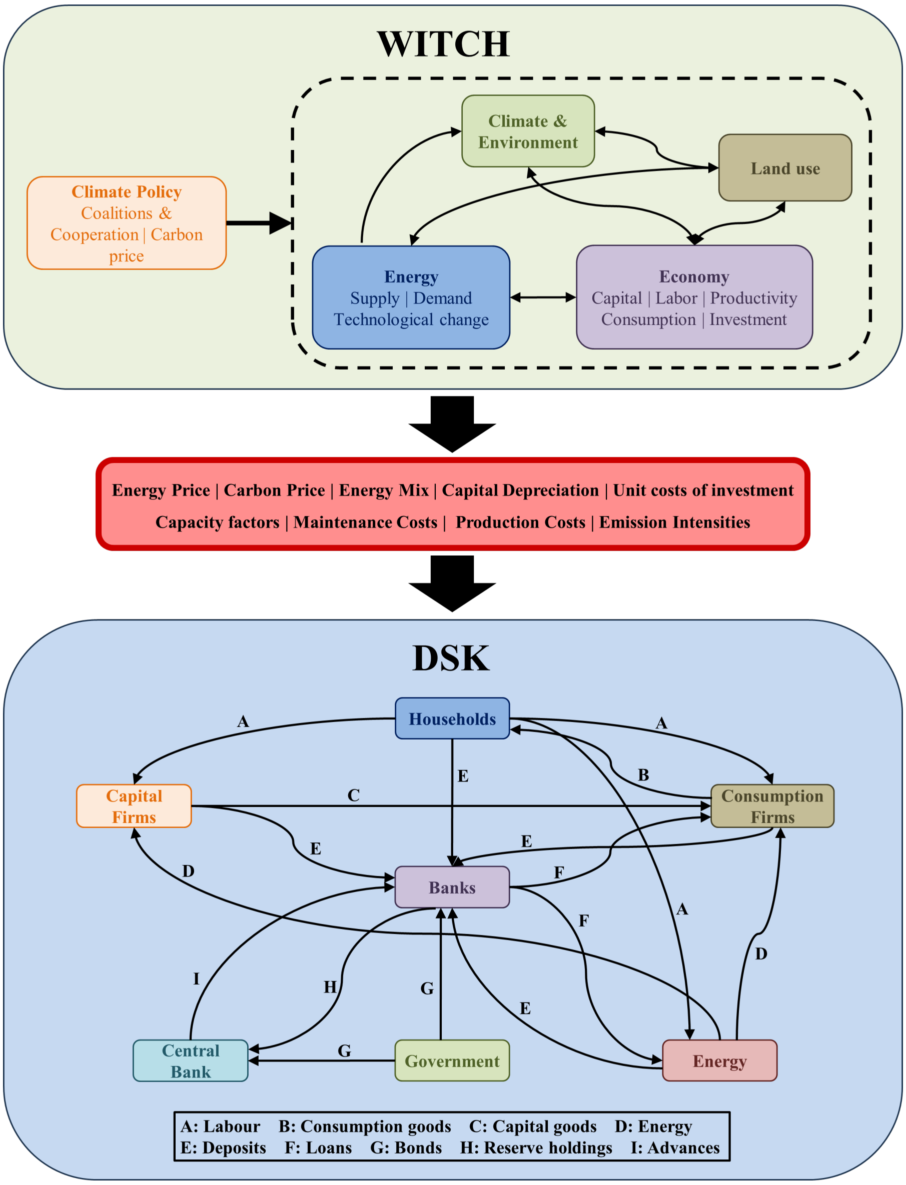
to bankruptcy.

The government can mitigate these dynamics by using carbon tax revenues to manage aggregate demand. Redistributing revenues to wage earners can address distributional effects and limit negative macroeconomic impacts, compensating for wage losses and sustaining aggregate demand.

We also find that the energy transition will require substantial credit provision for the build-up of renewable energy capacity and that fossil-intensive energy sectors will experience reduced profitability due to carbon pricing and the maintenance of costly stranded assets.

Our results contribute to the literature assessing the macroeconomic impacts of climate policies, regarding regressive effects of carbon pricing (Fremstad and Paul, 2019; Callan et al., 2009; Jiang and Shao, 2014; Farrell, 2017; Känzig, 2023) and the emergence of stranded assets (van der Ploeg and Rezai, 2020; Cahen-Fourot et al., 2021; Semieniuk et al., 2021, 2022). Empirical evidence regarding the macroeconomic effects of carbon pricing is somewhat mixed, with some studies finding no or even small positive effects on GDP (Metcalf, 2019; Metcalf and Stock, 2023) and others predicting negative impacts in the short run (Känzig, 2023). Model-based analyses often predict that aggressive carbon pricing may reduce GDP and employment, but highlight that appropriate revenue recycling can mitigate these outcomes (Brenner et al., 2007; Conefrey et al., 2013; Allan et al., 2014; Rivera et al., 2016; Vermeulen et al., 2018; Allen et al., 2020; Wieners et al., 2024). Further, they suggest that coordinating climate, monetary and prudential policy can help smooth transition risks, though the desirable mix of such instruments strongly depends on how emission intensive sectors transform (Annicchiarico et al., 2021; Diluiso et al., 2020; Lamperti et al., 2019, 2021). This calls for a more fine-grained modelling of the energy sector, at the very least. Since the carbon price trajectories we examine manifest in relatively sudden increases in the price of energy, our work also contributes to the macroeconomic literature on energy price shocks (Wildauer et al., 2023; Turco et al., 2023; Bodenstein et al., 2008; Auclert et al., 2023; Känzig, 2021). Finally, we contribute to the literature on MABMs (Fagiolo and Roventini, 2017; Dawid and Delli Gatti, 2018) and in particular to two sub-strands. The first regards the analysis of issues related to the green transition (e.g. Safarzyńska and van den Bergh, 2017; Ponta et al., 2018; Hötte, 2020; Rengs et al., 2020) and energy price shocks (van der Hoog and Deissenberg, 2011; Turco et al., 2023). The second sub-strand regards the assessment of the macroeconomic consequences of changes in the distribution of income (e.g. Dosi et al., 2018; Caiani et al., 2019; Terranova and Turco, 2022; Fierro et al., 2023).

Figure 1: Overview of the sectoral structure and inter-sectoral interactions depicted by DSK, the structure of the WITCH model, and the list of variables from WITCH scenarios used as exogenous inputs for DSK

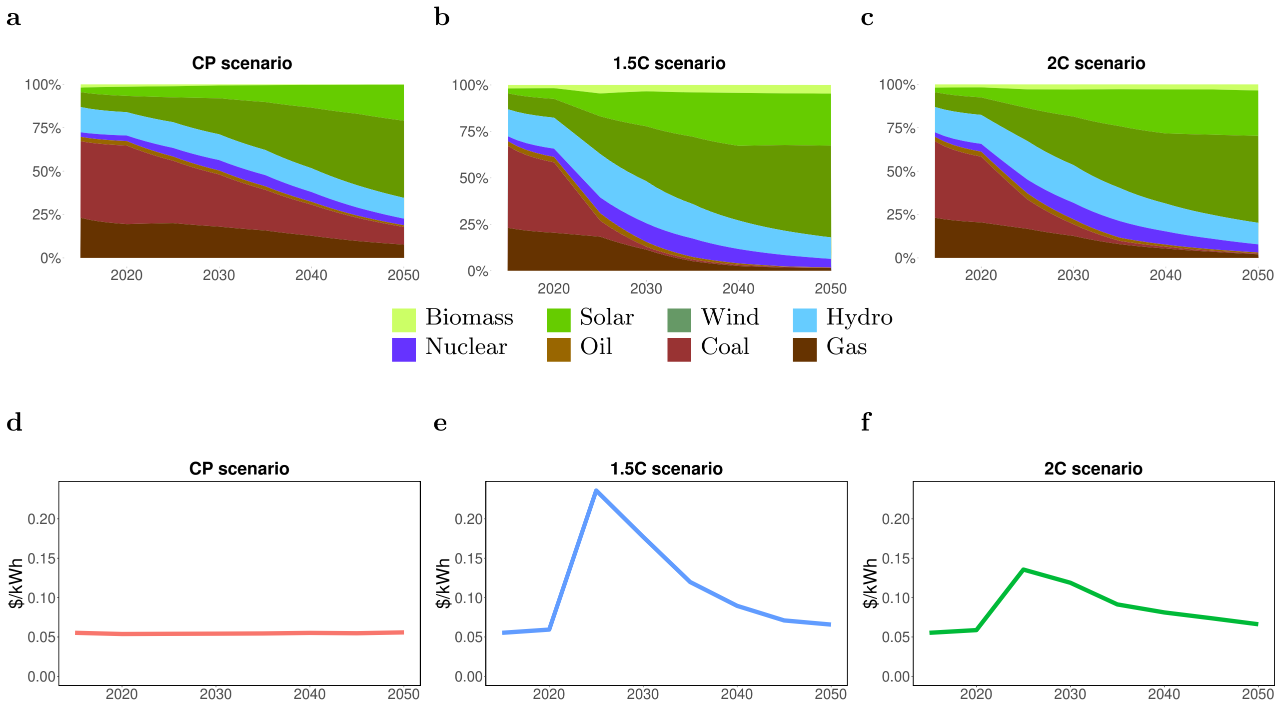


Results

Macro-financial impacts of the transition

We analyze three climate transition scenarios. The "Current Policy" (CP) scenario incorporates policies implemented by 2020 and serves as a baseline. The other two scenarios are designed to limit temperature increases to specific values by imposing carbon budgets from 2020 onward. One features a carbon budget of 1000 GtCO2, leading to a 2°C temperature increase (2°C), and the other a carbon budget of 500 GtCO2, leading to a 1.5°C temperature increase (1.5°C). In both cases, carbon budgets are met by imposing a global carbon tax. Regarding the DSK policy setting, we initially assume that carbon tax revenues are entirely retained by the government and that the central bank adopts a

Figure 2: Energy price and transition dynamics. **a-c**, energy mix, defined as the share of total energy produced by each technology, for the three WITCH scenarios. **d-f**, energy price in (2005) dollars per kilowatt-hour in the three WITCH scenarios. X-axes always refer to years.



single-mandate Taylor rule, i.e. it adjusts the interest rate to stabilise inflation (section 1.1.6 in SI); these assumptions will be relaxed in the policy experiments.

Figure 2 shows the energy mix and price dynamics for each transition scenario. Keeping temperature in line with the goals of the Paris Agreement purely through a carbon price leads to a temporary but sharp increase in energy prices. This is especially the case for the most stringent climate target of 1.5°C where fossil fuels are phased out rapidly during this decade (Figure 2 upper panel).

The energy price shock induced by climate policy leads to a series of macroeconomic adjustments and fluctuations that emerge from the properties of DSK. Figure 3 illustrates these adjustments by comparing scenarios. The main macroeconomic outcome is that of temporary stagflation (Figures 3a-3c) and low wage shares (Figure 3d). Unemployment and low economic growth emerge during this decade in the Paris-compliant scenarios;[4] the negative impacts on the real economy are accompanied by periods of high inflation.

Figure 4 delves into the mechanisms underlying the dynamics depicted in Figure 3. We find that a key role is played by the wage share, which significantly declines during the early phase of the transition when energy prices are high. Moreover, its dynamics closely mirror the unemployment rate (Figure 4a). By pooling all simulations across the three scenarios and calculating the quasi-elasticities of unemployment and the wage share with respect to the energy price, we find that high energy prices are associated with high unemployment and a low wage share (Figures 4c and 4d).

Largely unchanged aggregate markups (assumed in the DSK model) imply that carbon pricing and energy price shocks shift aggregate income from labour to the government (via carbon tax revenue) and the "green" energy sectors, while firms' income share remains unchanged. This also triggers a

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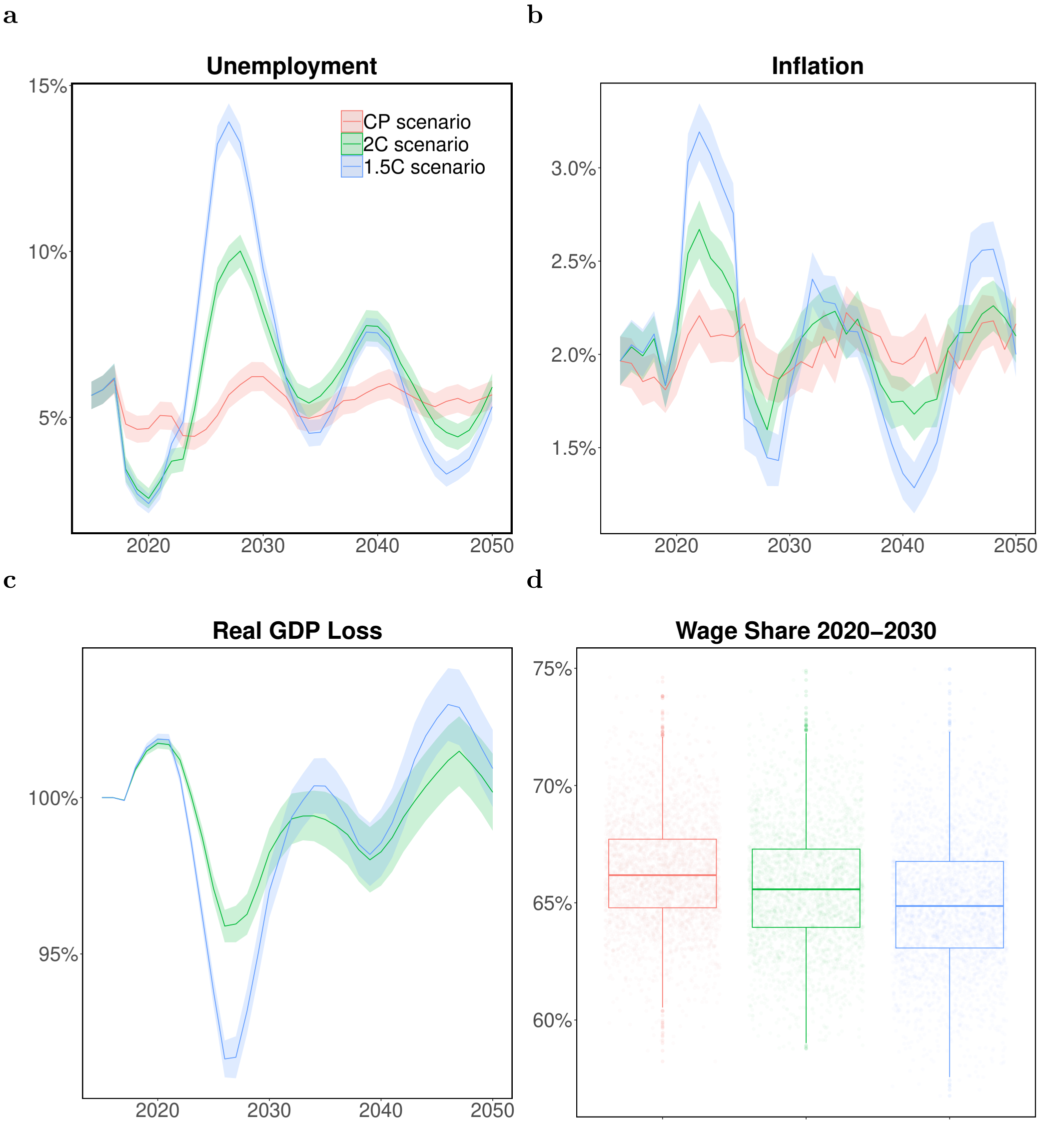
[4] Note that before 2020 in both the 1.5°C and 2C scenarios we observe a period of economic boom characterized by falling unemployment and high GDP. This occurs because, in WITCH, economic agents anticipate the future introduction of the carbon tax and begin investing in green energy technology. This investment stimulates economic activity before the carbon tax is implemented, resulting in a brief positive economic cycle.

Figure 3: Macroeconomic dynamics induced by different mitigation pathways. **a**-**c**, each line represents averages across 300 simulations, shaded areas are 95% confidence intervals, each colour is associated with a scenario; **c**, GDP loss relative to the CP scenario obtained using the ratio between real GDP in the 2C and 1.5°C scenarios relative to real GDP in the CP scenario; **d**, box-plot showing the distributions of wage shares in 300 simulations for of each scenario, period 2020-2030;



shift from labour income to dividend income, which is disproportionately saved rather than spent (Kaldor, 1955; Bhaduri and Marglin, 1990; Dynan et al., 2004; Dutt, 2017). The final effect is a lack of aggregate demand, leading to low employment and output.

As a result of cost pass-through,[5] an energy price surge induced by a rise in carbon prices is always inflationary on impact. In addition, nominal wage growth is pegged to the inflation rate (Equation 2 in SI). Higher inflation increases unit labour cost, which in turn feeds back into the general price level. However, wages also respond to labour market conditions, growing slower (faster) when unemployment is high (low). During a stagflationary period, inflation dynamics are hence dampened by weak labour market outcomes.

Figure 4b shows that inflation increases together with the energy price at first, but peaks while the latter is still growing and subsequently decreases before the energy price begins its downward trajectory driven by a rapidly growing share of renewables. Figure 5 shows the adjustments in the energy sector, which exhibits a strong increase in credit demand (Figure 5a). This is driven by the green sectors undertaking large investments (Figures 5b-5c) and by the fossil fuel sectors having to pay the carbon tax and sustain costly spare capacity (Figures 5d-5e). The consequent erosion of profitability affects financial stability, leading to an increase in defaults. Coal is especially affected, with default rates in this sector rising to 10-20% for 2°C and 1.5°C targets respectively (Figure 5f). Differently, oil and gas are only marginally impacted. This result confirms that rapid mitigation may generate imbalances harming the financial stability of high emitting sectors (e.g. Mercure et al., 2018), but these risks appear to be concentrated in specific areas (i.e. coal).

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[5] During the recent energy crisis due to the Russian invasion of Ukraine, firms have generally been able to fully pass energy price shocks (Lafrogne-Joussier et al., 2023) on to final output prices and possibly even increase their mark-ups in the process, giving rise to so-called *sellers' inflation* (e.g. Weber et al., 2024; Weber and Wasner, 2023). Our assumption of full pass-through with largely constant markups can therefore be seen as qualitatively in line with available empirical observations and possibly even somewhat conservative.

Figure 4: Macroeconomic and distributional effects along 1.5°C pathways. **a**, blue and red lines represent averages across 300 simulations of the 1.5°C scenario, the red line is the wage share (right), blue line is the unemployment rate (left); **b**, blue and red lines represent averages across 300 simulations of the 1.5°C scenario, red line is the energy price (right), blue line is the inflation rate (left); **c**, scatterplot of unemployment and logarithm of the energy price, results pooled across 300 simulations of each scenario, period from 2015 to 2050, red line is a non-linear interpolation; **d**, scatterplot of wage share and logarithm of the energy price, results pooled across 300 simulations of each scenario, period from 2015 to 2050, red line is a non-linear interpolation.

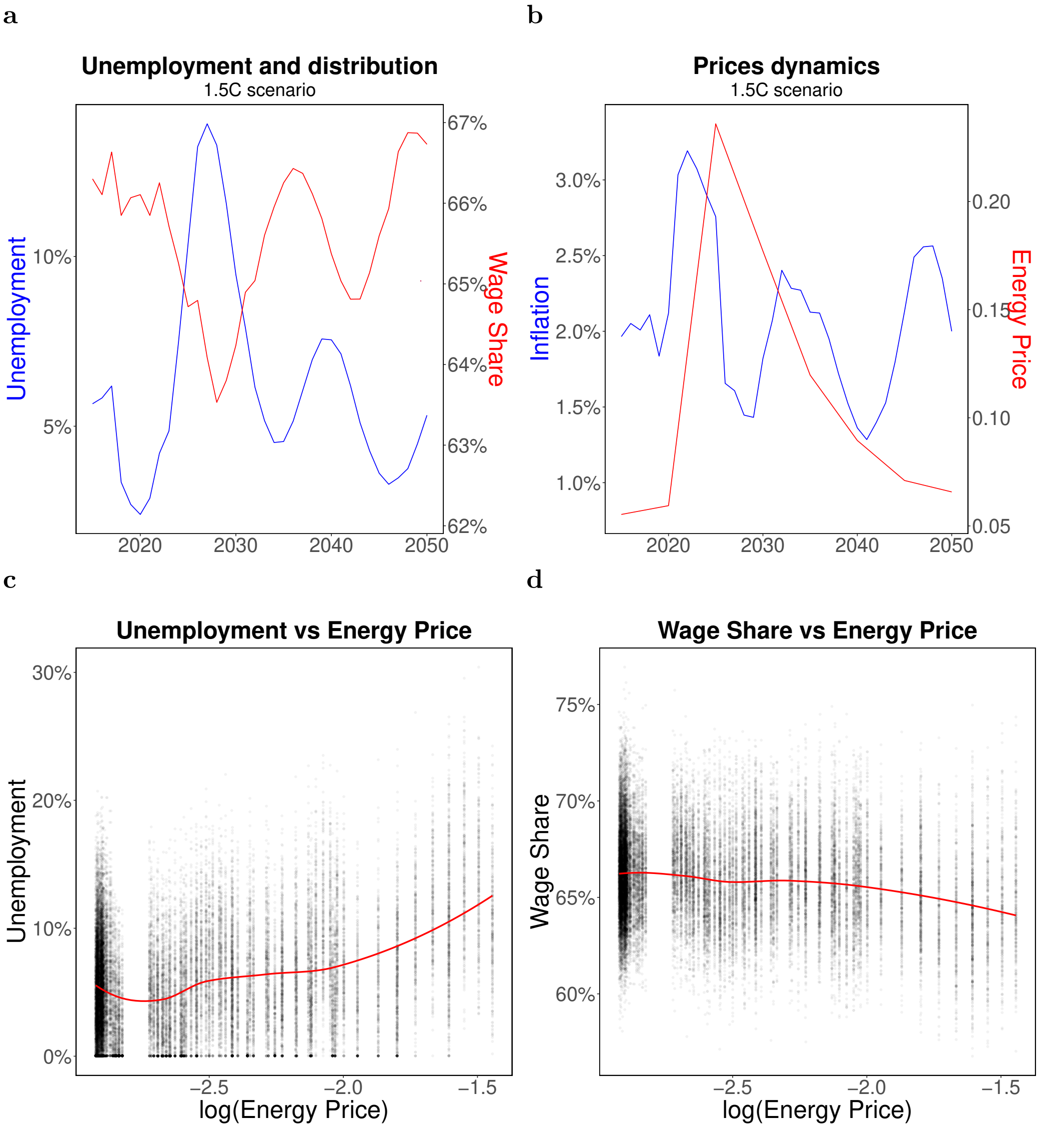
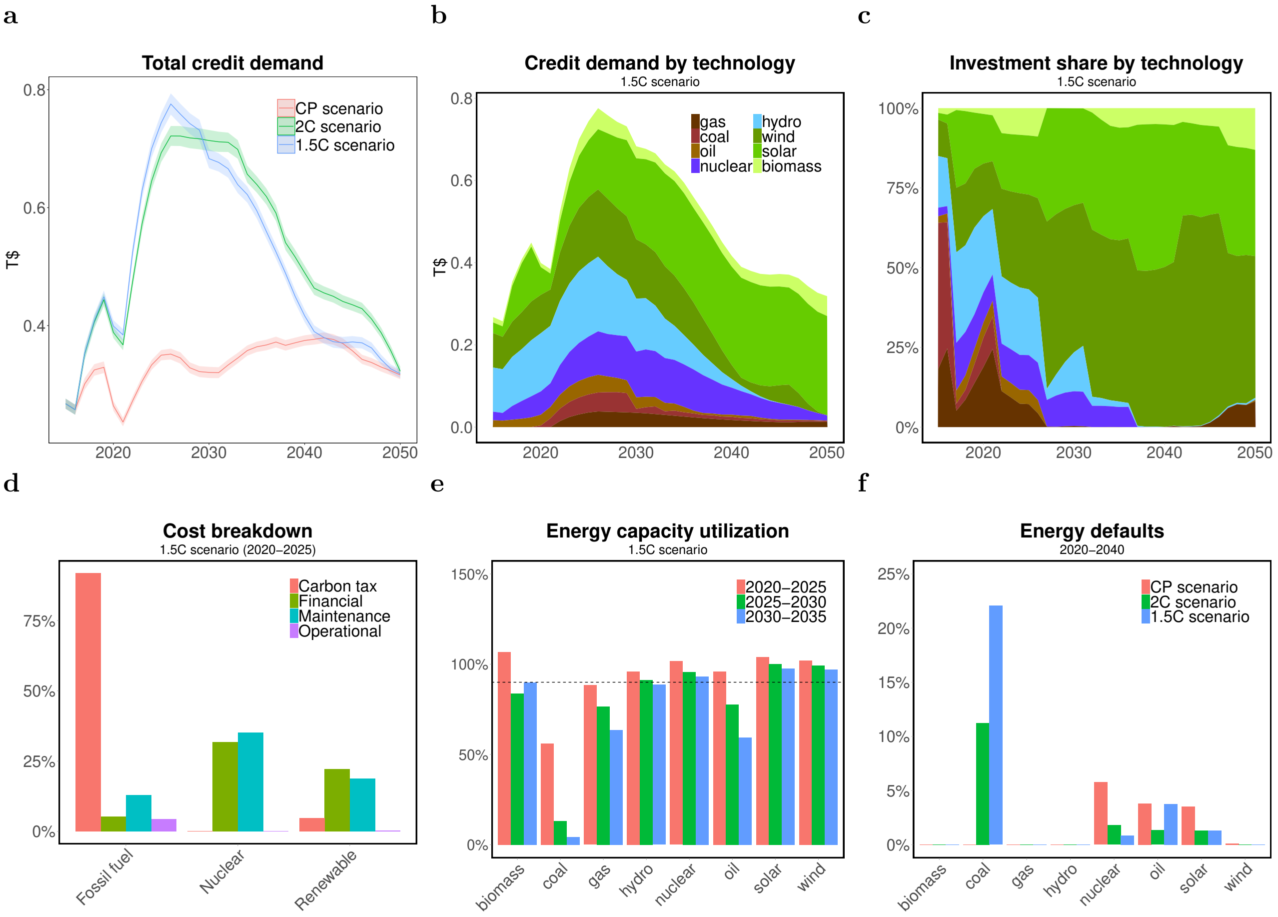


Figure 5: Energy sector-finance link, asset stranding and energy sector imbalances in 1.5°C pathways. **a**-**f**, averages across 300 simulations; **a**, total credit demand of the energy sector across scenarios, expressed in 2022 US T$[6]. Shaded areas represent 95% confidence intervals; **b**, energy sector credit demand disaggregated by sub-sectors, 1.5°C scenario, expressed in 2022 US T$[7];**c**, investment disaggregated by energy sub-sector, 1.5°C scenario, expressed as a share of total investment in the energy sector; **d**, energy sectors costs broken down by cost type and disaggregated by technology-groups. Costs are expressed in proportion to revenues and refer to the 1.5°C scenario for the time window 2020-2025; **e**, capacity utilization disaggregated by energy sub-sector, calculated as the ratio between actual production and the maximum potential production, the horizontal discontinuous line marks target capacity utilization, which is set to 90%[8]; **f**, defaults disaggregated by energy sub-sector expressed as the average ratio of defaulted debt to total debt across simulations, grouped by scenarios, period 2020-2040.



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[7] The model output is rescaled in order to obtain the credit demand figure in Trillion 2022 US$. We calculate the energy sector-wide nominal credit-investment ratio produced by the model for 2022 in the CP scenario. We then multiply that ratio by the empirically observed nominal "power sector investment", as reported by the IEA *World Energy Investment 2023* (IEA, 2023), to infer the equivalent nominal credit demand expressed in Trillion 2022 US$. Finally, we use this empirically inferred nominal credit demand for 2022 and its counterpart from the model to calculate a rescaling factor which is applied to the simulated time-series across all scenarios.

[8] Note that occasionally capacity utilization can slightly exceed 1. This is because the energy mix is an input taken from WITCH scenarios and, during the transition, some energy sub-sectors in DSK may not yet have obtained the entire capacity needed to satisfy the demand implied by the exogenous energy mix. Since such inconsistencies are small, we allow the respective sectors to exceed full capacity utilization and accommodate the demand implied by the energy mix taken from WITCH.

The role of monetary and fiscal policies

The simulations shown above point to disruptive business cycle fluctuations arising from the carbon pricing needed to stabilize global warming. So far, however, we did not consider potential monetary and fiscal policy responses. The central bank (CB hereafter) follows a single-mandate Taylor rule aimed purely at inflation stabilization (Section 1.1.6 in SI) and the government retains the entire carbon tax revenue.

To conduct a range of monetary and fiscal policy experiments, we relax these assumptions, allowing the CB to respond to unemployment and the government to redistribute carbon tax revenues. As was shown above, the dynamics generated by DSK in the 1.5°C and 2°C scenarios are qualitatively similar. We therefore conducted our policy analysis for the most stringent climate scenario (1.5°C). The alternative monetary policy rule modifies the single-mandate Taylor rule by adding an employment stabilization component that is activated when the unemployment rate exceeds a threshold, leading the central bank to lower its interest rate.[9] The central bank's reaction to unemployment is governed by an exogenous parameter, measuring the strength of the central bank's reactivity to high unemployment: the larger the CB's reactivity to unemployment, the lower the interest rate in case of high unemployment. The fiscal policy experiment involves the redistribution of the carbon tax revenue to households. We assume that a share of current carbon tax revenue is distributed to households as a lump sum transfer. Moreover, we assume that this transfer is treated as being equivalent to labour income, and hence that the same propensity to consume applies to it.

Results from our policy experiments are summarised in Figure 6. First of all, they suggest an important role for monetary-fiscal policy coordination to moderate the effects of the carbon tax. We focus on the most period, i.e. 2020-2040, which we split into two decades, and focus on unemployment and public debt-to-GDP ratios. In the first sub-period, fiscal policy is highly effective in reducing unemployment (Figure 6a). This is because, during this period, the carbon tax is high, resulting in large revenues to be redistributed. Monetary policy effects are instead negligible (Figure 6 in SI). This is because, in 2020-2030, the policy rate does not change much across different CB reactivity levels to unemployment (Figure 5 in SI). At the beginning of the transition phase, inflation rises faster than unemployment and hence dominates the Taylor rule. In 2030-2040, carbon tax revenues decline as emissions plummet, meaning that fiscal policy becomes less effective (Figure 7 in SI). However, we observe a stronger role for monetary policy during this period (Figure 6b). In 2030-2040, inflation recedes and so the employment stabilization effect dominates the Taylor rule, resulting in decreasing interest rates.[10]

We also find that inflation is not responsive to monetary policy during the transition, meaning that lowering the policy rate to fight unemployment does not produce additional inflationary pressure (Figure 6 in SI). This is because inflation during the transition is driven by the energy price, which is exogenous to the policy rate. In the case of cost-push shocks, the main channel through which monetary policy could stabilize inflation is through expectation anchoring. However strong such a

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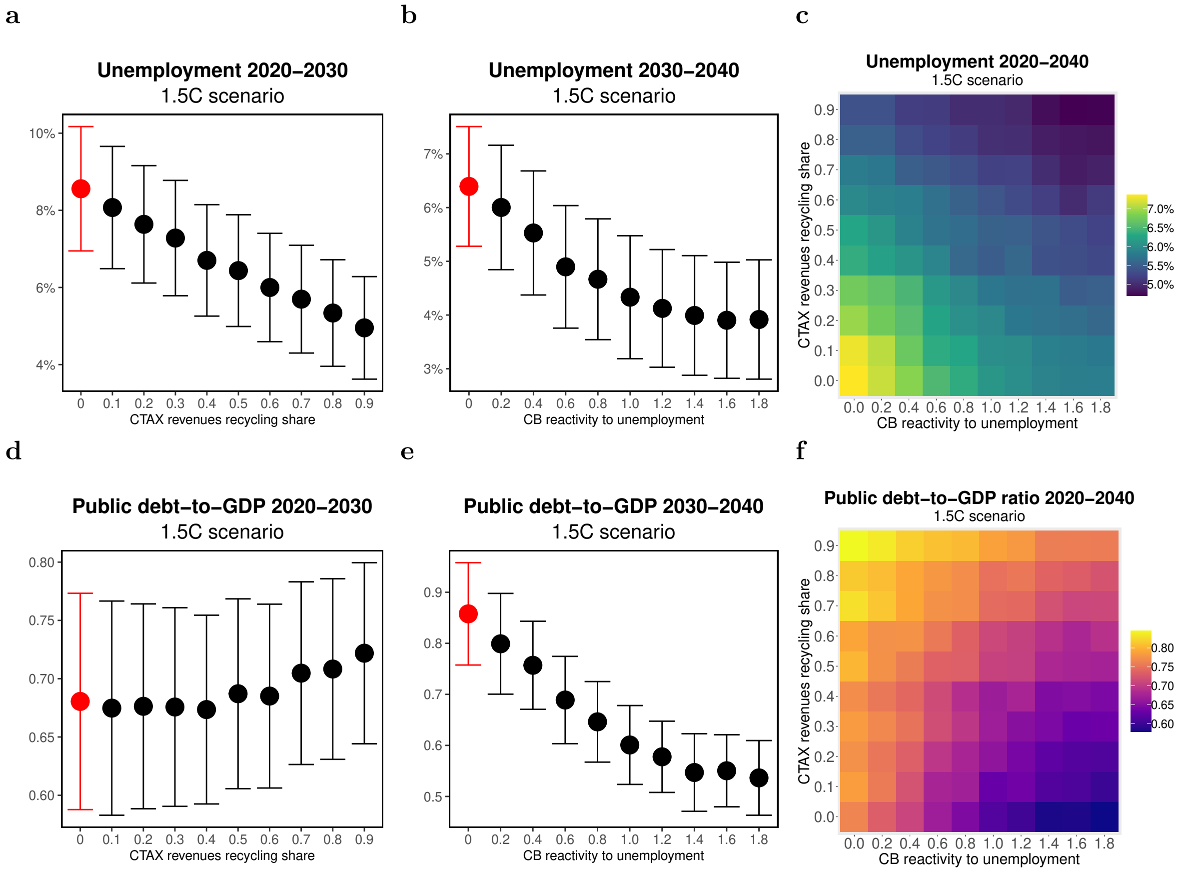
[9] Effectively, we assume a *recession avoidance preference* for the CB (cf. Cukierman and Muscatelli, 2008) with some degree of "recession tolerance", i.e. the policy rate response to unemployment is not asymmetrical around zero, but instead around a positive threshold level (cf. Bunzel and Enders, 2010). We set the threshold level at 10%, as this high unemployment rate can be considered an alarming indicator of a severe recession in most countries.

[10] Central banks typically avoid abrupt changes in the policy rate; instead, they gradually adjust the policy rate towards a specific target. This behaviour is captured by the implemented Taylor rule (Equations 57 and 76 in SI). As a result, the policy rate responds with a certain lag after unemployment reaches its safeguard level and remains relatively low even after unemployment drops below this level (Figure 6 in SI). These two effects together determine the efficacy of monetary policy in the second phase of the transition.

Figure 6: Monetary and fiscal policy to stabilize the transition in 1.5°C pathways. **a-b** and **d-e**, dots refer to averages across 50 simulations, with each dot representing a policy experiment, red dots refer to the baseline configuration, bars are 95% confidence intervals; **a**, average unemployment rate, 2020-2030, 1.5°C scenario, across fiscal policy experiments, i.e. different shares of redistributed carbon tax revenues; **b**, average unemployment rate, 2030-2040, 1.5°C scenario, across monetary policy experiments, i.e. different degrees of CB reactivity to unemployment; **d**, average public debt-to-GDP ratio, 2020-2030, 1.5°C scenario, across monetary policy experiments, normalized at 2015 value;**e**, average public debt-to-GDP ratio, 2030-2040, 1.5°C scenario, across monetary policy experiments, normalized at 2015 value; **c**, average unemployment rate, 2020-2040, 1.5°C scenario, across monetary and fiscal policy experiments; **f**, average public debt-to-GDP ratio, 2020-2040, 1.5°C scenario, across monetary and fiscal policy experiments, normalized at 2015 value.



channel might be in the real world, it is absent from our model, meaning that we may underestimate the inflationary costs of an expansionary monetary policy along the transition.

The complementarity between fiscal and monetary policy hence stems from the fact that they are effective at limiting unemployment during different phases of the transition. Figure 6c illustrates their complementarity by pooling simulation data across phases. It shows that the average unemployment rate for the full 2020-2040 period is lowest when fiscal policy redistributes a high share of carbon tax revenue and monetary policy is expansionary. In addition, monetary-fiscal policy coordination also has relevant effects on the public budget (Figures 6d, 6e, 6f). In particular, a lower policy rate will tend to lower the cost of servicing public debt in the latter phase of the simulation, hence creating fiscal space. Additionally, we observe that carbon tax revenue redistribution has a largely neutral effect on public debt. When carbon revenue is not redistributed, this represents an additional source of general revenue for the government. At the same time, however, declines in GDP and employment imply that other tax revenues will tend to decline, while outlays for unemployment benefits increase.

Discussion

Mitigation pathways, such as those reviewed in IPCC reports (IPCC, 2022), offer a detailed assessment of decarbonisation dynamics that all key sectors should undergo to meet certain climate targets. However, in their current status, they fail to provide an informative picture of the imbalances that such a process can create at the macro-financial level. Further, they are silent on the behaviour of macroeconomic aggregates at the time scale (e.g. quarterly or annual frequency) that is relevant for designing stabilisation policies accompanying climate ones. This study combined the strengths of two complementary modelling approaches, IAM and MABM, to shed light on the macroeconomic and financial implications of mitigation scenarios. Process-based IAMs generate transition pathways with high technological detail, while the strength of MABMs lies in the joint depiction of short and long-run out-of-equilibrium economic dynamics, distributional feedback effects, and real-financial interactions. This, combined with MABMs' capacity to handle a wide range of relevant economic variables, renders the IAM-MABM link a valuable instrument for refining the estimation of transition costs across various dimensions and transmission channels.

By simulating detailed transition scenarios generated by the WITCH IAM in the DSK MABM, we showed that ambitious mitigation trajectories guided by carbon pricing - as the vast majority of pathways in the literature - induce perils to macro-financial stability. Indeed, we showed that scenarios compatible with 2° and 1.5°C tend to generate high unemployment and high inflation, resembling dynamics typical of so-called "stag-flationary" episodes. The source of the instability lies in the rapid transformation of the energy sector and its connection to the financial system. Our results point to the emergence of costly physical stranded assets in the fossil fuel-intensive sectors (see also Mercure et al., 2018; Semieniuk et al., 2022), which contribute to an erosion of profitability of these sub-sectors during the transition. These decreases in profitability, in turn, result in an increased need for external finance as well as a higher rate of defaults. However, such risks concentrate in the coal sector, while gas and oil face much lower exposure.

Further, we showed that that an orderly (low unemployment) and just (low labour share losses) are not independent: they need to align. Indeed, the price of energy can be viewed as a distributional variable and shifts in functional income distribution resulting from climate policy can have undesired macroeconomic consequences. In particular, our results suggest that unless corrective policy action is taken, transition pathways guided by carbon prices are associated with temporary periods of high inflation and high unemployment. This volatility has detrimental consequences for the feasibility of decarbonization. These results point to the need (i) to account for ampler policy packages within mitigation pathways (e.g. Wieners et al., 2024), (ii) to report climate policy strength beyond carbon pricing.

Conducting a battery of fiscal and monetary policy experiments, we showed that redistribution of carbon tax revenue can play an important role in limiting the negative macroeconomic effects of carbon pricing during the early phase of the transition. Expansionary monetary policy, on the other hand, was found to be more effective during the later stages of the transition, suggesting a positive role for monetary-fiscal policy coordination.

Overall, our study emphasizes the importance of incorporating a macro-financial dimension into the analysis of mitigation pathways. This addition is essential for a more comprehensive assessment of the viability of decarbonization trajectories and the effectiveness of underlying climate policies. We demonstrate that integrating macroeconomic models with integrated assessment models is a promising approach, although several limitations must be addressed in future research. Specifically, adopting a more disaggregated perspective at the country or macro-regional level is essential to offer clearer insights into practical policymaking.

Online Methods

This study integrates an agent-based macroeconomic model and a process-based integrated assessment model to assess the materiality of transition risks along ambitious (deep) mitigation pathways. Detailed descriptions of the two models can be found in Reissl et al. (2024) (DSK) and Emmerling et al. (2016) (WITCH). Additionally, a thorough discussion of key model features, including necessary extensions to the DSK framework for coupling with WITCH, is provided in Section 1 of the SI. In this section, we outline the main model features relevant to our analysis.

The economic core of the DSK model is formed by two vertically integrated agent-based firm sectors, namely consumption good firms and capital good firms (C-Firms and K-Firms hereafter). K-Firms produce machines characterised by heterogeneous labour productivities, energy efficiencies and emission intensities. To produce them, K-Firms use production techniques which are also heterogeneous in terms of labour productivity, energy efficiency and emission intensity. New capital goods and production techniques are the product of K-Firms' R&D, which determines long-term growth.

C-Firms use machines, labour, and energy to produce a homogeneous consumption good. C-Firms buy machines to match expected demand. Firms' activities are financed through retained earnings and, in the case of C-Firms, loans from a banking sector. Households consume and receive income in the form of wages for supplied labour, interest on deposits, dividends from firms, banks and the energy sector, as well as unemployment benefits and occasional government transfers (like redistributed carbon tax revenues). The government collects taxes and spends on unemployment benefits, transfers, and the bailout of failing banks, while the central bank sets the policy rate. The DSK model also includes an energy sector which supplies the firm sector with the energy needed for production, invests in physical capital and finances its activities using internal funds and bank credit.

The consumption and capital goods sectors, as well as the banking sector, consist of multiple and heterogeneous agents. We leverage the MABM framework to agentify the WITCH energy sector into eight macro-agents, each representing a distinct energy technology. Households are modelled as an aggregate entity. Table 2 in SI shows the transaction flow matrix of the model, summarising the transactions between sectors and how these are financed.

The balance sheet and transaction flow matrices (Section 1, Tables 1-2 in SI) can be used to derive the accounting identities that must be satisfied for the model to be formally stock-flow consistent. To ensure stock-flow consistency during simulations of the model, all transaction flows and balance sheet items are explicitly tracked. At the end of each simulation period, the model performs a series of checks at the agent, sectoral and aggregate levels to ensure that no accounting identities have been violated during the period.

The WITCH (World Induced Technical Change Hybrid) model is an integrated modelling framework that captures the interactions among climate change, energy systems, and economic growth. It combines a macroeconomic model with a detailed energy system. The macroeconomic (top-down) aspect uses an intertemporal optimization strategy that incorporates macroeconomic relationships and dynamics over time. Simultaneously, the energy system (bottom-up) component details the technology options available in the energy sector. This dual approach facilitates the cost-effective optimization of strategies to minimize global costs associated with achieving specific climate and energy targets, taking into account investment, operational costs, the repercussions of climate change, and policy instruments such as carbon pricing.

The model divides the world into distinct global regions and generates optimal mitigation pathways up to 2100. These pathways are obtained through a welfare maximization process that accounts for regional interactions and the strategic dynamics spawned by global externalities, employing an iterative method to achieve a non-cooperative Nash equilibrium.

WITCH is distinguished by its dynamic representation of R&D diffusion and innovation in energy efficiency and low-carbon technologies. It encapsulates the broad spectrum of externalities in climate and innovation policy, including the global sharing of knowledge and technology spillovers, which influence each country's adoption of low-carbon technologies and energy productivity. This is based on regional energy research and development, capital stocks, and the global cumulative installed technology capacity.

From an economic point of view, the model simulates a single-sector economy, where output may be influenced by climate impacts (climate change impacts are not activated in this study), and costs related to fossil fuel use and greenhouse gas mitigation are accounted for. It employs a social planner perspective to optimize regional utility, including risk aversion to future consumption levels. A CES function represents the production of goods using capital, labour, and energy services.

The energy sector within the WITCH model covers a broad spectrum of primary energy sources, conversion technologies, and consumption sectors. It includes diverse energy carriers, from fossil fuels to renewables, and technologies, from power generation to transportation, representing technological advancements and energy efficiency gains over time.

The scenarios generated for this study follow standard policy designs. The Current Policy scenario implements current national climate policies and extrapolates the same effort level across the century using regional carbon prices. Regulations and emission constraints are maintained throughout the century. The climate policies '2C' and '1.5°C' aim for global net-zero emissions, following the design presented in Rogelj et al. (2019). Starting from 2020, a global carbon tax is implemented to reduce CO2 emissions. Once CO2 emissions reach net zero, global emissions are maintained at this level until the end of the time horizon. Until the net-zero year, the carbon price is set to limit cumulative emissions to 1000 GtCO2 for the '2C' scenario and 500 GtCO2 for the '1.5°C' scenario. Thereafter, the carbon price is adjusted to equal the emission market price to stabilize emissions at zero globally. More details about these two scenarios can be found in Drouet et al. (2021) and Riahi et al. (2021).

To couple the two models, we establish a one-way link from WITCH to DSK. Specifically, technology and cost-related variables for the energy sector, along with energy and carbon prices from transition scenarios generated by WITCH, are fed into DSK (see Figure 1). We chose these variables to partially replace the DSK energy sector with that of WITCH. The resulting energy-level variables — such as production, investment, and credit demand — emerge from the interaction between the two models. This interaction combines the microeconomic variables from WITCH (e.g., operation and maintenance costs, energy mix) with the macroeconomic variables from DSK (e.g., aggregated energy demand, financial conditions). Table 1 illustrates how the variables from WITCH and DSK are combined, along with the resulting outputs. For more detailed information, please refer to the SI.

WITCH produces scenarios up to 2100. For the current exercise, we only examine their effect on DSK dynamics up to 2050, which is the phase during which the transition takes place in decarbonization scenarios. Since DSK is a single-region model, global-level variables from WITCH are used as

WITCH-DSK coupling

Coupling output	**WITCH**	**DSK**	**Coupling output**
Coupled energy price	Energy price	Inflation	
Energy production	Energy mix	Aggregate energy demand	
Energy expenditures		Aggregate energy demand	Coupled energy price
Coupled carbon tax	Carbon tax	Inflation	
Capacity expansion		Target capacity utilisation	Energy production
Capacity	Capital depreciation		Capacity expansion
Nominal investment	$\frac{\text{Unit costs of investment}}{\text{Capacity factor}}$		Capacity expansion
Fixed costs	Maintenance costs		Capacity
Operating costs	Production costs		Energy production
Emissions	Emission intensities		Energy production
Carbon tax payments			Emissions Coupled carbon tax
Credit demand		$\frac{\text{Loan refinancing}}{\text{Deposits}}$	Operating costs Fixed costs Nominal investment Carbon tax payments

Table 1: The first column lists the variables that result from combining WITCH inputs with endogenously produced variables from DSK. The second and third columns indicate which variables from WITCH and DSK are used to produce a particular coupling output variable. The last column indicates that some coupling outputs are recombined with WITCH and/or DSK variables to produce additional coupling outputs.

inputs.Section 1.4 in the SI discusses the calibration and the empirical validation of the modelling framework used in this work.

Macroeconomic policies and climate policies run together in the coupled model. Climate policy is implemented into WITCH, while fiscal and monetary policies are set in DSK. Section 1 of the SI provides additional insights into the policy rules adopted. Section 2 in the SI discusses the transmission of the climate policy shocks at the macroeconomic level (see Section 2.1) and provides additional results on the stabilizing effects of monetary and fiscal interventions (see Sections 2.2 and 2.3, respectively).

References

Aleluia Reis, L., Vrontisi, Z., Verdolini, E., Fragkiadakis, K., Tavoni, M., 2023. A research and development investment strategy to achieve the paris climate agreement. Nature Communications 14, 3581. https://doi.org/10.1038/s41467-023-38620-4.

Allan, G., Lecca, P., McGregor, P., Swales, K., 2014. The economic and environmental impact of a carbon tax for Scotland: A computable general equilibrium analysis. Ecological Economics 100, 40–50. https://doi.org/10.1016/j.ecolecon.2014.01.012.

Allen, T., Dees, S., Caicedo Graciano, C., Chouard, V., Clerc, L., de Gaye, A., Devulder, A., Diot, S., Lisack, N., Pegoraro, F., Rabaté, M., Svartzman, R., Vernet, L., 2020. Climate-related scenarios for financial stability assessment: an application to france. Banque de France Working Paper 774. https://publications.banque-france.fr/sites/default/files/medias/documents/wp774.pdf.

Annicchiarico, B., Carattini, S., Fischer, C., Heutel, G., 2021. Business cycles and environmental policy: Literature review and policy implications. NBER Working Paper 29032. https://doi.org/10.3386/w29032.

Annicchiarico, B., Di Dio, F., 2015. Environmental policy and macroeconomic dynamics in a new keynesian model. Journal of Environmental Economics and Management 69, 1–21. https://doi.org/10.1016/j.jeem.2014.10.002.

Auclert, A., Monnery, H., Rognlie, M., Straub, L., 2023. Managing an energy shock: Fiscal and monetary policy. NBER Working Paper 31543. https://doi.org/10.3386/w31543.

Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., Visentin, G., 2017. A climate stress-test of the financial system. Nature Climate Change 7, 283–288. https://doi.org/10.1038/nclimate3255.

Battiston, S., Monasterolo, I., Riahi, K., van Ruijven, B., 2021. Accounting for finance is key for climate mitigation pathways. Science 372, 918–920. https://doi.org/10.1126/science.abf3877.

Bhaduri, A., Marglin, S., 1990. Unemployment and the real wage: the economic basis for contesting political ideologies. Cambridge Journal of Economics 14, 375–393. https://doi.org/10.1093/oxfordjournals.cje.a035141.

Bodenstein, M., Erceg, C., Guerrieri, L., 2008. Optimal monetary policy with distinct core and headline inflation rates. Journal of Monetary Economics 55, S18–S33. https://doi.org/10.1016/j.jmoneco.2008.07.010.

Bosetti, V., Carraro, C., Galeotti, M., Massetti, E., Tavoni, M., 2006. WITCH - a world induced technical change hybrid model. The Energy Journal 27, 13–37. https://doi.org/10.5547/ISSN0195-6574-EJ-VolSI2006-NoSI2-2.

Brenner, M., Riddle, M., Boyce, J., 2007. A chinese sky trust? Distributional impacts of carbon charges and revenue recycling in China. Energy Policy 35, 1771–1784. https://doi.org/10.1016/j.enpol.2006.04.016.

Bunzel, H., Enders, W., 2010. The Taylor rule and “opportunistic” monetary policy. Journal of Money, Credit and Banking 42, 931–949. https://doi.org/10.1111/j.1538-4616.2010.00313.x.

Cahen-Fourot, L., Campiglio, E., Godin, A., Kemp-Benedict, E., Trsek, S., 2021. Capital stranding cascades: The impact of decarbonisation on productive asset utilisation. Energy Economics 103, 105581. https://doi.org/10.1016/j.eneco.2021.105581.

Caiani, A., Godin, A., Caverzasi, E., Gallegati, M., Kinsella, S., Stiglitz, J., 2016. Agent based-stock flow consistent macroeconomics: Towards a benchmark model. Journal of Economic Dynamics and Control 69, 375–408. https://doi.org/10.1016/j.jedc.2016.06.001.

Caiani, A., Russo, A., Gallegati, M., 2019. Does inequality hamper innovation and growth? an AB-SFC analysis. Journal of Evolutionary Economics 29, 177–228. https://doi.org/10.1007/s00191-018-0554-8.

Callan, T., Lyons, S., Scott, S., Tol, R., Verde, S., 2009. The distributional implications of a carbon tax in Ireland. Energy Policy 37, 407–412. https://doi.org/10.1016/j.enpol.2008.08.034.

Campiglio, E., Lamperti, F., Terranova, R., 2024. Believe me when i say green! heterogeneous expectations and climate policy uncertainty. Journal of Economic Dynamics and Control , 104900https://doi.org/10.1016/j.jedc.2024.104900.

Carattini, S., Heutel, G., Melkadze, G., 2023. Climate policy, financial frictions, and transition risk. Review of Economic Dynamics 51, 778–794. https://doi.org/10.1016/j.red.2023.08.003.

Castro, J., Drews, S., Exadaktylos, F., Foramitti, J., Klein, F., Konc, T., Savin, I., van Den Bergh, J., 2020. A review of agent-based modeling of climate-energy policy. Wiley Interdisciplinary Reviews: Climate Change 11, e647. https://doi.org/10.1002/wcc.647.

Comerford, D., Spiganti, A., 2023. The carbon bubble: climate policy in a fire-sale model of deleveraging. The Scandinavian Journal of Economics 125, 655–687. https://doi.org/10.1111/sjoe.12519.

Conefrey, T., Fitz Gerald, J., Valeri, L., Tol, R., 2013. The impact of a carbon tax on economic growth and carbon dioxide emissions in Ireland. Journal of Environmental Planning and Management 56, 934–952. https://doi.org/10.1080/09640568.2012.709467.

Cukierman, A., Muscatelli, A., 2008. Nonlinear Taylor rules and asymmetric preferences in central banking: Evidence from the United Kingdom and the United States. The BE Journal of Macroeconomics 8. https://doi.org/10.2202/1935-1690.1488.

Dafermos, Y., Nikolaidi, M., Galanis, G., 2018. Climate change, financial stability and monetary policy. Ecological Economics 152, 219–234. https://doi.org/10.1016/j.ecolecon.2018.05.011.

Dawid, H., Delli Gatti, D., 2018. Agent-based macroeconomics, in: Hommes, C., LeBaron, B. (Eds.), Handbook of Computational Economics, Vol. 4. Elsevier/North-Holland, London, pp. 63–156.

Delli Gatti, D., Gallegati, M., Greenwald, B., Russo, A., Stiglitz, J., 2010. The financial accelerator in an evolving credit network. Journal of Economic Dynamics and Control 34, 1627–1650. https://doi.org/10.1016/j.jedc.2010.06.019.

Diluiso, F., Annicchiarico, B., Kalkuhl, M., Minx, J.C., 2020. Climate actions and stranded assets: The role of financial regulation and monetary policy. CESifo working paper 8486. https://www.cesifo.org/DocDL/cesifo1_wp8486.pdf.

Dosi, G., Fagiolo, G., Napoletano, M., Roventini, A., 2013. Income distribution, credit and fiscal policies in an agent-based Keynesian model. Journal of Economic Dynamics and Control 37, 1598–1625. https://doi.org/10.1016/j.jedc.2012.11.008.

Dosi, G., Fagiolo, G., Roventini, A., 2010. Schumpeter meeting Keynes: A policy-friendly model of endogenous growth and business cycles. Journal of Economic Dynamics and Control 34, 1748–1767. https://doi.org/10.1016/j.jedc.2010.06.018.

Dosi, G., Napoletano, M., Roventini, A., Treibich, T., 2017. Micro and macro policies in the keynes+ schumpeter evolutionary models. Journal of Evolutionary Economics 27, 63–90. https://doi.org/10.1007/s00191-016-0466-.

Dosi, G., Pereira, M., Roventini, A., Virgillito, M., 2018. The effects of labour market reforms upon unemployment and income inequalities: an agent-based model. Socio-Economic Review 16, 687–720. https://doi.org/10.1093/ser/mwx054.

Drouet, L., Bosetti, V., Padoan, S., Aleluia Reis, L., Bertram, C., Dalla Longa, F., Després, J., Emmerling, J., Fosse, F., Fragkiadakis, K., et al., 2021. Net zero-emission pathways reduce the physical and economic risks of climate change. Nature Climate Change 11, 1070–1076. https://doi.org/10.1038/s41558-021-01218-z.

Dutt, A.K., 2017. Heterodox theories of economic growth and income distribution: a partial survey. Journal of Economic Surveys 31, 1240–1271. https://doi.org/10.1111/joes.12243.

Dynan, K., Skinner, J., Zeldes, S., 2004. Do the rich save more? Journal of Political Economy 112, 397–444. https://doi.org/10.1086/381475.

Emmerling, J., Drouet, L., Reis, L., Bevione, M., Berger, L., Bosetti, V., Carrara, S., De Cian, E., De Maere D'Aertrycke, G., Longden, T., et al., 2016. The WITCH 2016 model - documentation and implementation of the shared socioeconomic pathways. FEEM Working Paper 42.2016. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2800970.

Fagiolo, G., Roventini, A., 2017. Macroeconomic policy in dsge and agent-based models redux: New developments and challenges ahead. Journal of Artificial Societies and Social Simulation 20. https://doi.org/10.18564/jasss.3280.

Farrell, N., 2017. What factors drive inequalities in carbon tax incidence? Decomposing socioeconomic inequalities in carbon tax incidence in Ireland. Ecological Economics 142, 31–45. https://doi.org/10.1016/j.ecolecon.2017.04.004.

Fierro, L., Giri, F., Russo, A., 2023. Inequality-constrained monetary policy in a financialized economy. Journal of Economic Behavior & Organization 216, 366–385. https://doi.org/10.1016/j.jebo.2023.10.031.

Fremstad, A., Paul, M., 2019. The impact of a carbon tax on inequality. Ecological Economics 163, 88–97. https://doi.org/10.1016/j.ecolecon.2019.04.016.

Gualdi, S., Mandel, A., 2019. Endogenous growth in production networks. Journal of Evolutionary Economics 29, 91–117. https://doi.org/10.1007/s00191-018-0552-x.

Hötte, K., 2020. How to accelerate green technology diffusion? Directed technological change in the presence of coevolving absorptive capacity. Energy Economics 85, 104565. https://doi.org/10.1016/j.eneco.2019.104565.

IEA, 2023. World Energy Investment 2023. IEA, Paris. https://www.iea.org/reports/world-energy-investment-2023, accessed 16/05/2024.

IPCC, 2022. Climate Change 2022: Mitigation of Climate Change - Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY. https://doi.org/10.1017/9781009157926.

Jiang, Z., Shao, S., 2014. Distributional effects of a carbon tax on Chinese households: A case of Shanghai. Energy Policy 73, 269–277. https://doi.org/10.1016/j.enpol.2014.06.005.

Kaldor, N., 1955. Alternative theories of distribution. The Review of Economic Studies 23, 83–100. https://doi.org/10.2307/2296292.

Känzig, D., 2021. The macroeconomic effects of oil supply news: Evidence from OPEC announcements. American Economic Review 111, 1092–1125. https://doi.org/10.1257/aer.20190964.

Känzig, D., 2023. The unequal economic consequences of carbon pricing. NBER Working Paper 31221. https://doi.org/10.3386/w31221.

Lafrogne-Joussier, R., Martin, J., Mejean, I., 2023. Cost pass-through and the rise of inflation. Conseil d'Analyse Economique, Focus 094-2023. https://www.cae-eco.fr/staticfiles/pdf/focus-94-inflation-en-230509.pdf.

Lamperti, F., Bosetti, V., Roventini, A., Tavoni, M., 2019. The public costs of climate-induced financial instability. Nature Climate Change 9, 829–833. https://doi.org/10.1038/s41558-019-0607-5.

Lamperti, F., Bosetti, V., Roventini, A., Tavoni, M., Treibich, T., 2021. Three green financial policies to address climate risks. Journal of Financial Stability 54, 100875. https://doi.org/10.1016/j.jfs.2021.100875.

Lamperti, F., Dosi, G., Napoletano, M., Roventini, A., Sapio, A., 2018. Faraway, so close: coupled climate and economic dynamics in an agent-based integrated assessment model. Ecological Economics 150, 315–339. https://doi.org/10.1016/j.ecolecon.2018.03.023.

Mercure, J.F., Pollitt, H., Viñuales, J.E., Edwards, N.R., Holden, P.B., Chewpreecha, U., Salas, P., Sognnaes, I., Lam, A., Knobloch, F., 2018. Macroeconomic impact of stranded fossil fuel assets. Nature Climate Change 8, 588–593. https://doi.org/10.1038/s41558-018-0182-1.

Metcalf, G., 2019. On the economics of a carbon tax for the united states. Brookings Papers on Economic Activity 2019, 405–484. https://doi.org/10.1353/eca.2019.0005.

Metcalf, G., Stock, J., 2023. The macroeconomic impact of europe's carbon taxes. American Economic Journal: Macroeconomics 15, 265–286. https://doi.org/10.1257/mac.20210052.

Monasterolo, I., Raberto, M., 2019. The impact of phasing out fossil fuel subsidies on the low-carbon transition. Energy Policy 124, 355–370. https://doi.org/10.1016/j.enpol.2018.08.051.

Newell, P., Mulvaney, D., 2013. The political economy of the 'just transition'. The Geographical Journal 179, 132–140. https://doi.org/10.1111/geoj.12008.

NGFS, 2023. Monetary policy and climate change: Key takeaways from the membership survey and areas for further analysis. Technical document https://www.ngfs.net/sites/default/files/medias/documents/monetary_policy_and_climate_change_-_key_takeaways_from_the_membership_survey.pdf, accessed 16/05/2024.

Niamir, L., Mastrucci, A., van Ruijven, B., 2024. Energizing building renovation: Unraveling the dynamic interplay of building stock evolution, individual behaviour, and social norms. Energy Research & Social Science 110, 103445. https://doi.org/10.1016/j.erss.2024.103445.

Ponta, L., Raberto, M., Teglio, A., Cincotti, S., 2018. An agent-based stock-flow consistent model of the sustainable transition in the energy sector. Ecological Economics 145, 274–300. https://doi.org/10.1016/j.ecolecon.2017.08.022.

Reissl, S., Fierro, L., Lamperti, F., Roventini, A., 2024. The dsk-sfc stock-flow consistent agent-based integrated assessment model. LEM Working Paper 2024/09. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4766122.

Rengs, B., Scholz-Wäckerle, M., van den Bergh, J., 2020. Evolutionary macroeconomic assessment of employment and innovation impacts of climate policy packages. Journal of Economic Behavior & Organization 169, 332–368. https://doi.org/10.1016/j.jebo.2019.11.025.

Riahi, K., Bertram, C., Huppmann, D., Rogelj, J., Bosetti, V., Cabardos, A., Deppermann, A., Drouet, L., Frank, S., Fricko, O., et al., 2021. Cost and attainability of meeting stringent climate targets without overshoot. Nature Climate Change 11, 1063–1069. https://doi.org/10.1038/s41558-021-01215-2.

Rivera, G., Reynès, F., Cortes, I., Bellocq, F.X., Grazi, F., 2016. Towards a low carbon growth in Mexico: Is a double dividend possible? A dynamic general equilibrium assessment. Energy Policy 96, 314–327. https://doi.org/10.1016/j.enpol.2016.06.012.

Rogelj, J., Huppmann, D., Krey, V., Riahi, K., Clarke, L., Gidden, M., Nicholls, Z., Meinshausen, M., 2019. A new scenario logic for the Paris Agreement long-term temperature goal. Nature 573, 357–363. https://doi.org/10.1038/s41586-019-1541-4.

Roncoroni, A., Battiston, S., Escobar-Farfán, L., Martinez-Jaramillo, S., 2021. Climate risk and financial stability in the network of banks and investment funds. Journal of Financial Stability 54, 100870. https://doi.org/10.1016/j.jfs.2021.100870.

Safarzyńska, K., van den Bergh, J.C., 2017. Integrated crisis-energy policy: Macro-evolutionary modelling of technology, finance and energy interactions. Technological Forecasting and Social Change 114, 119–137. https://doi.org/10.1016/j.techfore.2016.07.033.

Sanders, M., Serebriakova, A., Fragkos, P., Polzin, F., Egli, F., Steffen, B., 2022. Representation of financial markets in macro-economic transition models — a review and suggestions for extensions. Environmental Research Letters 17, 083001. https://doi.org/10.1088/1748-9326/ac7f48.

Semieniuk, G., Campiglio, E., Mercure, J.F., Volz, U., Edwards, N., 2021. Low-carbon transition risks for finance. Wiley Interdisciplinary Reviews: Climate Change 12, e678. https://doi.org/10.1002/wcc.678.

Semieniuk, G., Holden, P., Mercure, J.F., Salas, P., Pollitt, H., Jobson, K., Vercoulen, P., Chewpreecha, U., Edwards, N., Viñuales, J., 2022. Stranded fossil-fuel assets translate to major losses for investors in advanced economies. Nature Climate Change 12, 532–538. https://doi.org/10.1038/s41558-022-01356-y.

Stangl, J., Borsos, A., Diem, C., Reisch, T., Thurner, S., 2024. Firm-level supply chains to minimize unemployment and economic losses in rapid decarbonization scenarios. Nature Sustainability , 1–9https://doi.org/10.1038/s41893-024-01321-x.

TCFD, 2023. Task force on climate-related financial disclosures - 2023 status report. TCFD status reports https://assets.bbhub.io/company/sites/60/2023/09/2023-Status-Report.pdf, accessed 16/05/2024.

Terranova, R., Turco, E., 2022. Concentration, stagnation and inequality: An agent-based approach. Journal of Economic Behavior & Organization 193, 569–595. https://doi.org/10.1016/j.jebo.2021.11.002.

Turco, E., Bazzana, D., Rizzati, M., Ciola, E., Vergalli, S., 2023. Energy price shocks and stabilization policies in the MATRIX model. Energy Policy 177, 113567. https://doi.org/10.1016/j.enpol.2023.113567.

van der Hoog, S., Deissenberg, C., 2011. Energy shocks and macroeconomic stabilization policies in an agent-based macro model, in: Dawid, H., Semmler, W. (Eds.), Computational Methods in Economic Dynamics. Springer, Berlin, pp. 159–181.

van der Ploeg, F., Rezai, A., 2020. Stranded assets in the transition to a carbon-free economy. Annual Review of Resource Economics 12, 281–298. https://doi.org/10.1146/annurev-resource-110519-040938.

Vermeulen, R., Schets, E., Lohuis, M., Kolbl, B., Jansen, D.J., Heeringa, W., 2018. An energy transition risk stress test for the financial system of the netherlands. De Nederlandsche Bank Occasional Studies 16-7. https://www.dnb.nl/media/pdnpdalc/201810_nr-_7_-2018-_an_energy_transition_risk_stress_test_for_the_financial_system_of_the_netherlands.pdf.

Wang, X., Lo, K., 2021. Just transition: A conceptual review. Energy Research & Social Science 82, 102291. https://doi.org/10.1016/j.erss.2021.102291.

Weber, I., Jauregui, J., Teixeira, L., Nassif Pires, L., 2024. Inflation in times of overlapping emergencies: systemically significant prices from an input-output perspective. Industrial and Corporate Change 33, 297–341. https://doi.org/10.1093/icc/dtad080.

Weber, I., Wasner, E., 2023. Sellers' inflation, profits and conflict: why can large firms hike prices in an emergency? Review of Keynesian Economics 11, 183–213. https://doi.org/10.4337/roke.2023.02.05.

Weyant, J., 2017. Some contributions of integrated assessment models of global climate change. Review of Environmental Economics and Policy 11, 115–137. https://doi.org/10.1093/reep/rew018.

Wieners, C., Lamperti, F., Dosi, G., Roventini, A., 2024. Macroeconomic policies for rapid decarbonization,steady economic transition and employment creation. Available at Research Square https://doi.org/10.21203/rs.3.rs-4637209/v1.

Wildauer, R., Kohler, K., Aboobaker, A., Guschanski, A., 2023. Energy price shocks, conflict inflation, and income distribution in a three-sector model. Energy Economics 127, 106982. https://doi.org/10.1016/j.eneco.2023.106982.

Yilmaz, D., Sawsen, B.N., Mantes, A., Nihed, B.K., Daghari, I., 2023. Climate change, loss of agricultural output and the macro-economy: The case of tunisia. AFD Research Paper 286. https://www.afd.fr/en/ressources/climate-change-loss-agricultural-output-and-macro-economy-case-tunisia.

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