Feasible Alternatives to Green Growth

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Climate change and increasing income inequality have emerged as twin threats to contemporary standards of living, peace and democracy. These two problems are usually tackled separately in the policy agenda. A new breed of radical proposals has been advanced to manage a fair low-carbon transition. In this spirit, we develop a dynamic macrosimulation model to investigate the long-run effects of three scenarios: Green Growth, Policies for Social Equity, and Degrowth. The Green Growth scenario, based on technological progress and environmental policies, achieves a significant reduction in greenhouse gas emissions at the cost of increasing income inequality and unemployment. The Policies for Social Equity scenario adds direct labour market interventions that result in an environmental performance similar to Green Growth while improving social conditions at the cost of increasing public deficit. The Degrowth scenario further adds a reduction in consumption and exports, and achieves a greater reduction in emissions and inequality with higher public deficit despite the introduction of a wealth tax. We argue that new radical social policies can combine social prosperity and low-carbon emissions and are economically and politically feasible.

The main responses to the global challenge posed by climate change are currently based on green growth policy proposals [1]. A combination of market-incentive tools – such as carbon taxes, cap and trade schemes, and subsidies to resource-efficient innovation – is widely seen by governments and international institutions as the viable way to foster economic growth while mitigating its environmental impact [2]. The promises of green growth also include its ability to promote income distribution and job creation, however concrete recommendations are generally limited to targeted compensation policies for low-income households and moderate employment protection[3].

Despite its prominent position in the policy agenda, several drawbacks to green growth have been put forward. Environmental scientists and interdisciplinary researchers question the ability of market mechanisms to reduce environmental damage [4], meet planetary boundaries [5,6] and avoid critical transitions [7,8]. Moreover, the evidence that new technologies reduce the correlation between growth and employment casts doubts on the capacity of green growth to create jobs [9].

Two alternatives to green growth have gained traction thanks to their emphasis on the promotion of social equity. First, the "Green New Deal", recently advanced in the US, recognizes the need to complement environmental policies with direct actions to reduce inequality and unemployment [10]. Notwithstanding its ambitious goals, there is an ongoing debate as to whether decarbonization can be achieved with economic growth[11,12].

A more radical argument in this debate comes from the degrowth literature. According to this second alternative, continuous economic growth and ecological sustainability are incompatible [13] and that the transition towards a sustainable society requires a downscale in consumption and production. Therefore, radical social policies – such as job guarantee programmes and working time reduction – become essential to sustain employment, reduce inequality and ensure prosperity[14–16].

We contribute to this debate by providing a dynamic macrosimulation model tailored to compare green growth and these two alternatives in terms of greenhouse gas (GHG) emissions and income distribution. The simulation results shed light on the following questions. Are the current measures advocated for green growth at risk of fostering inequality and unemployment? If so, is there room for social policies to offset such harmful outcome? Is a downscale in consumption necessary to meet environmental targets?

Our model relies on a post-Keynesian framework where production and employment dynamics are determined by effective demand owing to the fact that capital and labour are not fully utilized [17]. The model is also grounded in the ecological macroeconomics literature that aims to strengthen the ecological foundations of macroeconomics and shifts its focus to living well within planetary boundaries [18,19]. Compared to this stream of literature, we provide a more detailed specification of the social protection system by including multiple public revenues and expenditures to implement social and environmental policies. Furthermore, the distinction of the working age population by skill, the inclusion of wealth dynamics and financial incomes, and the heterogeneous industries modelled give a more accurate assessment of income distribution (see Figure 1).

The relation between environmental degradation and inequality is hardly new in the literature [20,21]. Although recent empirical studies have considered the effects of emissions and climate change on income distribution [22,23], we approach this issue from a different perspective and con-

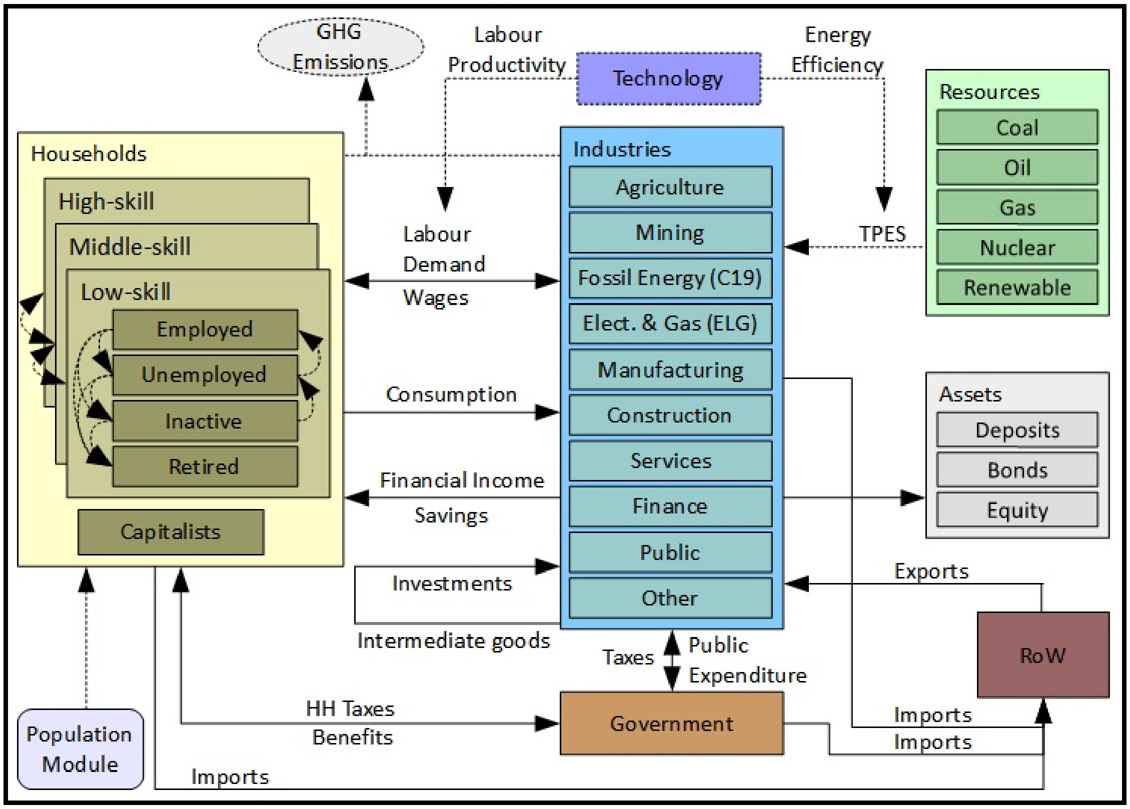


Figure 1: **Macroview.** Main causal relations between heterogeneous household groups, industries, resources and assets in the model. Solid (dashed) arrows represent monetary (non-monetary) flows. Household consumption includes electricity and other energy products.

GHG = greenhouse gas; *HH* = households; *RoW* = rest of the world. The RoW is included because the aggregate flows from (to) it are included as imports (exports), although the foreign sector is not defined in the model.

sider how policies shape the relationship between inequality and emissions. Moreover, previous studies have often neglected the consequences of the joint implementation of multiple policies [24], focusing on the impacts of individual policies such as carbon taxes [25], working time reduction [26] and job guarantee programmes [27]. The three policy-mix scenarios presented in the results aim to fill this gap.

Results

Our scenarios compare a baseline, without the introduction of any policy, with three policy mixes: Green Growth, Policies for Social Equity, and Degrowth. Additional information regarding each individual policy is presented in the Methods section. The simulations are based on data for France, over the period 2014-2050.

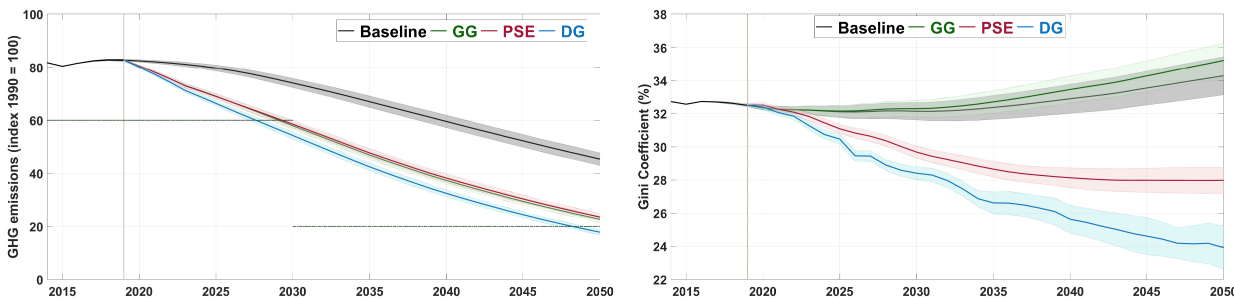
Green Growth (GG) is composed of energy policies and incentives for innovations that foster labour productivity and energy efficiency. It promotes an expansion of renewable energy sources in electricity production, and a more extensive use of electricity in final energy demand (i.e., electrification). GG also extends the current French carbon tax to imported goods, according to their incorporated carbon emissions, until €188 per ton of CO_2 in 2050.

Policies for Social Equity (PSE) maintains the same energy policies as GG, with the exception of incentives for labour-saving technology, and adds two radical social policies: a job guarantee programme and working time reduction. The first introduces a public initiative that hires up to $300,000$ workers per year and allocates them equally between public services and environmental work that improves households' energy efficiency. The second gradually reduces weekly working hours from the current 35 to 30 within 5 years.

Degrowth (DG) is the third policy mix and considers a reduction in consumption and exports together with all the PSE policies. While this is certainly not a policy, it allows us to assess the environmental and economic consequences of degrowth. For instance, this might reflect a change in citizens' behaviour due to increasing awareness of the environmental impacts required to sustain their standards of living [28]. Finally, DG also introduces a wealth tax to compensate for rising government deficit-to-GDP ratio as a result of decreasing national product.

Income distribution and GHG emissions. Figure 2 shows the two key indicators of environmental performance and income inequality: GHG emissions level (index 1990=100) (2a), and the Gini coefficient (2b) that ranges from 0 (perfect equality) to 100$\%$ (complete inequality). The latter is calculated on the basis of 13 heterogeneous population groups defined by the three skills and four occupational statuses of the households, plus the capitalists, as listed in Figure 1.

The three policy-mix scenarios result in considerably greater GHG emission reductions than the baseline whose emissions approach 45$\%$ of the 1990 level in 2050. Both GG and PSE reach very similar levels of emissions by 2050 (about 23% of the 1990 level) which are close to the EU Climate Action target [29]. The DG scenario results in an even stronger reduction, down to 17.8% in 2050, due to the contraction of final consumption and energy demand. In contrast, the Gini coefficient diverges substantially among the scenarios. In the baseline, it increases by more



(a) (b)

Figure 2: **Scenario analysis: GHG emissions and income inequality.** Comparison – from 2014 to 2050 – of the GHG emissions (2a) and income inequality (2b) under the baseline (black) compared with the three policy mixes: *GG* (green), *PSE* (red), and *DG* (blue). The vertical dotted line indicates the year 2019 when policies are introduced. The horizontal reference lines in panel (a) indicate the EU Climate Action targets for GHG emissions reduction in 2030 of -40% (left line) and in 2050 of -80% (right line) with respect to the 1990 level [29]. The solid lines and shaded areas around them indicate the means and 95% confidence intervals, respectively, of 500 simulations for each scenario with different random processes for the extraction of new technologies.

than 1.5 points with respect to the initial year, from 32.7% to 34.3% in 2050. Under GG it hikes 2.5 points in 30 years, ending up at 35.2%. When radical social policies are introduced, the Gini coefficient sharply declines until 2050, due to a reduction in income inequality among workers. Under the PSE scenario the Gini coefficient drops by more than 4.5 points and stabilizes around 28% from the year 2040 onwards. In DG the reduction in income inequality reaches 23.9% in 2050.

The two alternative policy mixes considered herein are at least as effective as GG in abating carbon emissions and achieve a long-lasting reduction in inequality. Moreover, the environmental and market-based incentives of GG worsen income distribution, through an increase in labour productivity that lessens the labour demand from industries. Thus, the simulation outcomes suggest that the social policies included in PSE and DG can offset unintended social consequences of green growth strategies.

Economic growth, employment, and public deficit. Figure 3 plots the main economic drivers behind these results: yearly GDP growth rates (3a), unemployment rates (3b), labour share on value-added (3c), and government deficit-to-GDP ratio (3d).

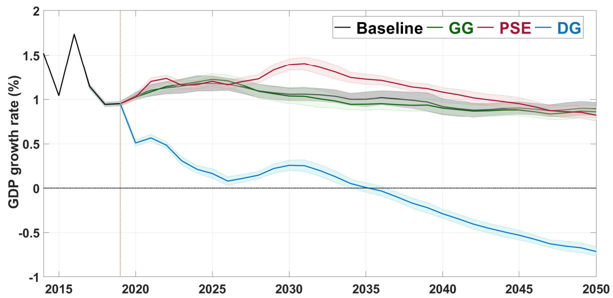
GDP growth rates in GG and PSE converge to the same long-term values of the baseline scenario ($\simeq 1\%$). Under DG they fall below 0% from the year 2035 onwards, reaching -0.7% in 2050. Panel 3b shows an increase in the unemployment rates in GG and in the baseline, from an initial value around 10% up to 13% and 11.4%, respectively. By contrast, unemployment rates fall sharply in PSE and DG due to the job guarantee programme and working time reduction. By the last simulated year, these scenarios project unemployment rates of 2% and 7%, respectively. The positive impact on income distribution is further amplified because the fall in unemployment is followed by an expansion of the labour force participation (i.e., the share of the working age population either employed or in search of work).

Panel 3c compares the dynamics of the *labour share*, defined as the fraction of post-tax value added paid to employed workers as wages. Once again, the GG scenario projects a trend close to that of the baseline, with declining paths that end up in the 60-65% range by 2050. PSE and DG have a positive impact on the labour share, albeit with a delay of about five years from the beginning of their implementation. In both cases, the wage share first increases until 2035, reaching a maximum of about 75.7% and 77.6% under PSE and DG, respectively, and then slightly decreases following an inverse U-shaped path.

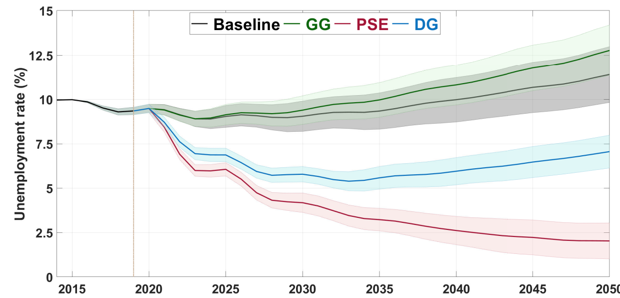
Note that there seems to be a contradiction in comparing inequality and unemployment in PSE and DG which deserves an explanation. The wage moderation in the DG scenario improves income distribution when compared to PSE. In PSE, labour demand accelerates high-skill hourly wage gains with respect to middle- and low-skill wages due to the lower supply of high-skill workers. Therefore, although employment policies can pair higher wages with an increase in employment, partly absorbing individuals out of the labour force, low unemployment rates might lead to an increase in wage inequality among workers of different skills (with a premium for high-skill workers).

The last panel (3d) projects the simulated deficit-to-GDP ratio – the public deficit is the difference between the current government's expenditures and revenues – that measures the fiscal cost of the active labour market policies introduced in PSE and DG. All scenarios follow a decreasing trend until 2035. GG and the baseline continue on a declining path, reaching about 1.5% and 0.7% in 2050, respectively. In contrast, PSE and DG result in deficit-to-GDP ratios above the European Union's 3% limit, due to the cost of the job guarantee programme. In both of these scenarios, the ratio stays below 3% until 2040, hence below the initial level of 3.9% for more than 30 years. In DG the deficit-to-GDP ratio drastically increases after 2040. This trend is not due to a disproportionate amount of public expenditure, but rather to the contraction of the GDP (3a).

The simulations suggest that both GG and PSE are equally successful in terms of curbing GHG emissions, albeit through different mechanisms. In GG, GHG emissions reductions follow directly from advances in energy efficiency, electrification and renewable energy; and indirectly from higher labour productivity that results in larger unemployment which, in turn, curtails aggregate demand and production. Under the PSE scenario, the improvement in labour market conditions leads to an increase in consumption and production. The consequent increase in emissions that should follow from this mechanism is partially offset by the increment in households' energy efficiency owing to the environmental activities of the job guarantee programme. Finally, the DG scenario curtails emissions and inequality even further through a contraction of economic activity, suggesting that decreasing economic growth does not necessarily entail catastrophic social consequences if employment and redistribution policies are in place.



(a)



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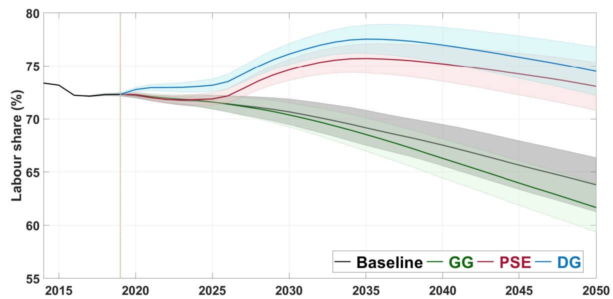

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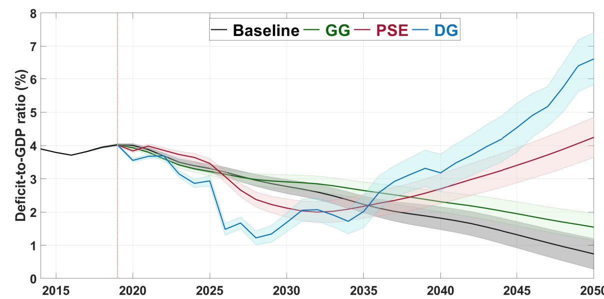

(d)

Figure 3: **Scenario analysis: socio-economic indicators.** Comparison – from 2014 to 2050 – of the GDP growth rate (3a), unemployment rate (3b), labour-share (3c), and public deficit-to-GDP ratio (3d) under the baseline (black) compared with the three policy mixes: *G.G.* (green), *P.S.E.* (red), and *D.G.* (blue). The vertical dotted line indicates the year 2019 when the policies are introduced. The solid lines and shaded areas around them indicate the means and 95% confidence intervals, respectively, of 500 simulations for each scenario with different random processes for the extraction of new technologies.

Discussion

Interactions and feedback loops among economic, social and ecological dimensions constitute a complex system that can be properly analysed through computer-driven simulations. Even though this methodology might be received with certain scepticism, it is suitable for the analysis of the evolution of this system under alternative narratives. In this study, the use of simulations makes it possible to evaluate the impacts of the simultaneous implementation of multiple policies. The current analysis supports a multi-dimensional and inter-disciplinary approach to question current policy priorities in terms of social justice, environmental care and economic performance [30,31].

The simulation results suggest that there are no winwin solutions. Each policy mix generates trade-offs. On the one hand, under the green growth scenario, the technological progress that improves environmental performance also undermines social equity. On the other hand, the policies that allow the PSE and degrowth scenarios to attain social equity with low-carbon emissions require substantial levels of public expenditure, thus leading to an increase in the deficit-to-GDP ratio. Therefore, equivalent reductions in emissions can result in radically different consequences in terms of income distribution and employment. Importantly, the green growth scenario does not improve economic performance compared with the baseline, since green investments are offset by the loss of aggregate demand due to high unemployment rates. Thus, a green growth paradox emerges: the effectiveness of GHG reductions depends on the failure to promote GDP growth.

Under the PSE scenario, the boost in aggregate demand from higher employment is partially offset by the lower per-capita annual labour income due to working time reduction, resulting in a relatively low growth rate. Hence, if stronger social policies accelerated economic growth, they would limit the capacity of the system to reach environmental goals (for example, unconditional basic income). Furthermore, despite the presence of mitigating factors that limit GDP growth under the green growth and PSE scenarios, they are not able to reach the desired emissions reduction, since they only rely on energy efficiency and environmental policies for decarbonization. This supports the thesis that economic policies ought to go beyond the stimuli for technological solutions and move away from the growth imperative to achieve large-scale reductions in emissions [12]. Indeed, in our analysis, only the degrowth scenario achieves carbon emissions goals thanks to the assumed contraction in consumption and production.

Finally, both simulated social policies (that is, the job guarantee programme and working time reduction) bring about improvements in employment and distribution that are independent of growth. These interventions allow for a controlled contraction of aggregate demand, avoiding harmful socioeconomic consequences. Growing inequality, unemployment and non-standard forms of labour have led to the emergence of populism and environmental scepticism within Western countries[32] that might undermine the governance of the low-carbon transition. Although radical social policies have a detrimental effect on public deficit in the long term, it is a cost our societies may need to pay in order to avoid social unrest. The case of the gilets jaunes protests demonstrates that additional leeway for expenditure in social policies should be considered to promote a fair low-carbon transition.

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Methods

Theoretical background. Our EUROGREEN model develops a simulation framework to assess the direct and indirect consequences of policy interventions on income distribution, unemployment, economic growth, energy demand, GHG emissions and government budget. The empirical calibration of the parameters and initial values for the French economy provides a realistic and consistent basis to understand the feasibility of the policy mixes proposed. To ensure logical consistency in macroeconomic accounting, the model was built following stock-flow consistency principles [33,34]. Accordingly, it allocates monetary stocks and flows, within the French national economy, coherently among agents. However, given that the EUROGREEN model addresses an open economy without modelling the rest of the world, the latter is not included in the transaction flow matrix (see SI tables 17 and 18).

The scenarios are simulated by applying a system dynamics methodology that has proved to be suitable for policy analysis to evaluate low-carbon transition and social equity [35]. The main data sources considered to calibrate the initial conditions, for the French economy in the year 2014, are: Eurostat, EU-Klems, WIOD, OECD, IEA, and INSEE. Given the stochastic nature of the innovation process, as described below, we ran 500 simulations for each scenario to ensure robust results. In what follows we describe the main building blocks exposed in Figure 1 of the main text, while the Supplementary Information (chapter 1) provides the detailed description of the mathematical framework.

Population We consider four age groups: $0-14$, $15-44$, $45-64$, and $65+$ years with fertility and mortality rates fixed and exogenous to the economic conditions simulated. The adult population is stratified into three skill levels according to their maximum educational attainment: low, middle, and high. The working-age population (aged 15-64) is further divided among the employed, unemployed, and inactive people. Individuals aged 65 or more are assumed to be all pensioners. A 0.1% of the adult population corresponds to capitalists whose income depends entirely on financial gains and profits.

Supply-side Production is defined by an input-output (IO) matrix composed by 10 macro-industries: agriculture, mining, manufacturing, manufacture of coke and refined petroleum products ($C19$), electricity and gas (ELG), construction, services, finance, public sector and other. The IO matrix reports the monetary flows ($Z_{i,j}$) from one industry i to another j, domestic or foreign, and is calculated for 2014 following the NACE classification (Rev. 2) as presented in WIOD.

The amount of material inputs required per unit of output (measured in basic prices) in each industry is represented in the matrix of 'technical coefficients' (**A**) whose entries ($a_{i,j}$) are calculated as: $a_{i,j} = Z_{i,j}/y_j$, where y_j is the output of the buying sector. Most of the studies that rely on an IO approach keep these coefficients constant even in long-run analyses [?]. The EUROGREEN model, on the contrary, considers the effects of new technologies on the technical coefficients of the two energy-supplying industries: $C19$ and ELG. If more energy-efficient technologies are adopted, buying industries decrease the relative demand for goods produced by $C19$ and ELG. To the best of our knowledge, this study is the first to model *endogenous* change in technical coefficients in the ecological macroeconomics literature. Moreover, prices in each industry are set as a *mark-up* over the cost per unit of output, given by the sum of labour and intermediate goods demanded for production [17].

Technological progress The mechanism behind the innovation process comprises three steps (SI Figure 5): *step 1.* possible emergence of new available technologies, *step 2.* choice of the cost-minimizing technology among those available, and *step 3.* implementation. We define a technology (γ) as combinations of labour productivity (λ, i.e. output per worked hour) and energy efficiency (η, i.e. energy per unit of output) in each industry.

In each period industry-specific innovations might emerge (*step 1.*) affecting either λ or η, or both. Hence, there are four possible alternative new technologies (SI table 8). γ_1 corresponds to the previous-period (old) technology that keeps λ and η unchanged. It is always available for all industries. Technology γ_2 is labour-saving (i.e., λ increases) but energy-augmenting (i.e., η decreases), while γ_3 has the opposite effect: λ decreases and η increases. Finally, γ_4 improves both labour productivity and energy efficiency and is always chosen if available. We consider recent evidence about the impact of relative input prices - of energy and labour in our case - as drivers of R&D investment decisions [36]. It is assumed that the ratio between the growth rates of labour and energy costs affects the probability of emergence of new technologies. For instance, a relative increase in labour with respect to energy costs results in a higher probability of γ_2 that becomes available more often than γ_3.

In *step 2* each industry chooses the cost-minimizing technology among those available after *step 1*. This choice is endogenous because it depends on the growth rates of labour and energy costs of an industry, and on the industry's relative demand for labour and energy. An increasing trend in labour with respect to the energy costs will lead the industry to opt for labour-saving technologies more often, when available. The pace of the implementation of new technologies in *step 3* depends on investments. The values of labour productivity (λ) and energy efficiency (η) are given by a weighted average of the λ and η from new and old technologies. The weights are investments and capital stock after depreciation, respectively. Hence, new technologies are implemented in proportion to the renovation of fixed capital.

Energy and Emissions Energy demand from industries and households is distributed among four energy sources: gas, oil, coal and electricity. The latter is produced by a mix of fossil fuels, renewable sources and nuclear power. Given the total demand for energy, by source, we recover the Total Primary Energy Supply ($TPES$) and the associated GHG emissions, in CO_2 equivalents. The model considers a carbon tax as recently introduced in France, starting from €7 per ton of CO_2 in 2014. The tax increases by about €8 per ton of CO_2 per year until 2020, reaching €56, and by €4.4 per year afterwards to achieve the planned €100 per ton in 2030. The carbon tax is not applied to those industries participating in the European Emissions Trading System, which accounted for about a third of total French GHG emissions in 2014 (145Mtoe out of 435Mtoe).

Labour Market Workers are differentiated by three skills and allocated among ten industries. The level of employment is determined by the level of output – which, in turn, depends on the final demand –, labour productivity, and working hours. Moreover, following the contemporary literature on labour economics, we reproduce a “job polarization” process in which technological progress substitutes routine more standardized easier-to-automate occupations, leading to higher demand for high- and low-skill jobs at the expense of middle-skill jobs [37,38].

Labour force supply and its skill composition are endogenous and follow unemployment rates. Inactive individuals enter the labour force whenever unemployment rates fall [39]. Although the model does not consider the impact of education on skill, we attempt to model it indirectly through the effects of skill-specific unemployment rates on the transitions of workers across skills. We assume that the transitions from lower- to higher-skills are less frequent than the other way round to reflect the significant investments of resources and time required to access more specialized jobs.

Hourly wages are an increasing function of the employment growth rate, by skill and industry, and labour productivity. Setting wages as a function of skill-industry employment, instead of skill or overall unemployment rates, reflects a higher degree of stratification among occupations which plays a significant role in the determination of wage inequality [40]. Moreover, increases in labour productivity are only partially converted into hourly wages to reflect empirical evidence of a decoupling between median wages and productivity [41].

Consumption Households’ sources of income are wages, pensions, unemployment benefits, and other social protection transfers for sickness and disability, social exclusion (revenu de solidarité active), and family and children. The social security transfers are modeled in accordance with the current French welfare system and their simulated dynamics follow variations in average skill-specific wages and inflation.

Additionally, households hold stocks of different assets and receive a financial income from interest, dividends and asset price variations. Low-skill households hold all their assets in deposits, which pay no interest. Middle-skill ones hold deposits and government bonds that pay interest, while high-skill households and capitalists distribute their savings among deposits, bonds and equities. The latter pay dividends from company profits. Households pay a progressive income tax, a flat tax which combines social security contributions (i.e., *contribution sociale généralisée* with the *contribution au remboursement de la dette sociale*), and a 30% tax levied on financial income.

Consumption depends directly on disposable income and wealth multiplied by fixed, skill-specific, marginal propensities to consume out-of-income and out-of-wealth. The composition of the consumption bundle is given by fixed shares, calculated from final consumption spent in each industry in France in 2014. An exception to these fixed shares is introduced in energy consumption which falls, in monetary terms, whenever households become more energy-efficient. In other words, household expenditure for energy services – such as illumination or transportation – falls if new technologies increase energy efficiency (i.e., γ_3 and γ_4). The subsequent savings are allocated to the remaining industries. This mechanism reproduces an energy-related rebound effect, also known as Jevon's paradox [42], in which the direct effects of energy efficiency may be offset by an increase in demand for energy-intensive goods and services.

Investments Capacity utilization, profit rates, and fixed capital depreciation determine the level of desired investments which, in turn, is constrained by the industry's capacity to finance itself. Financing capacity depends on net profits that must cover a fixed share of investments, while the remaining portion is financed by new loans. Investments expand the assets, fixed capital and liabilities (debt and equity) of an industry's balance sheet. Even though current investments contribute to aggregate demand and growth, they also increase productive capacity and reduce capacity utilization in the future, thus reducing desired investments in the following periods.

Public Sector The Government's balance sheet comprises its main sources of expenditure (benefits, wages, investments and interest payments) and revenues (taxes paid by households and industries). The fiscal feasibility of the proposed radical social policies is reflected in the deficit-to-GDP ratio, given by the difference between public expenditure and revenue over GDP.

Individual Policies

This subsection briefly describes the individual policies that compose the policy mixes simulated in the main text. Simulation results for each individual policy are presented in the Supplementary Information (chapter 2).

New Production Revolution In order to assess at an aggregate scale the effects of the strategies to boost technological progress, we introduce a policy here termed 'New Production Revolution' (NPR) [43]. It is composed by incentives to automation or *high labour productivity* (HLP) and to *high energy efficiency* ($HEEF$). We set increased probabilities of emergence for new labour- (γ_2) and energy-saving (γ_3) technologies under HLP and $HEEF$, respectively. Thus, NPR allows for faster technological progress to assess its impact on employment, emissions and income distribution.

Emission reduction First, we consider a change in the *Energy Mix* (EnM) of electricity power generation that gradually substitutes renewable sources for brown and nuclear ones in the energy-supply sectors. Finally, EnM imposes the phase-out of coal by 2050 with constant annual reductions, from its initial share of about 3%.

Second, we define an *electrification* process that substitutes renewable sources for polluting energy products (with a yearly rate of 0.5% in industries‘ and households‘ electricity demand). Promoting the *electrification* of energy demand results in a considerable increase in energy supply from electric power generation, which goes from an initial value of about 53% of the $TPES$, in 2014, to 71% in 2050. The combination of the EnM with *electrification* results in a gradual and substantial substitution of nuclear energy for renewable sources in the $TPES$.

Border Carbon Adjustment Following a proposal by the French President Emmanuel Macron during the COP21 held in Paris in 2015, a policy termed *Border Carbon Adjustment* (BCA) imposes the same carbon tax rates described above upon imports, according to their incorporated GHG content. Moreover, the tax rates continue to increase by €4.4 per year from 2030 to 2050, reaching €188 per ton of CO_2 for both domestic and imported goods.

Working Time Reduction This social policy consists in a curtailment of weekly working hours, from the current 35 [44] to a 30-hour working week within five years. In the last decade, working time reduction has been considered "a multiple dividend policy" [45] capable of improving income distribution and reducing emissions due to scale and composition effects [46]. Workers earn and consume less (scale), while time availability allows them to choose less energy-intensive consumption baskets (composition). Nevertheless, at the macroeconomic level, in an economy with idle resources, newly hired workers earn and consume more which could offset the environmental benefits of reducing working hours of those initially employed. Since consumption baskets are fixed in our model, the simulated WTR policy captures only the scale effect.

Job Guarantee With this programme the government hires unemployed workers at the minimum wage, thereby absorbing up to a maximum of $300,000$ workers per year. These workers are then evenly allocated into two productive activities: services, substituting part of private services, and environmentally related work which increases the households' energy efficiency.

Wealth tax We consider a strategy for a controlled degrowth of the economy via a joint reduction of the average propensities to consume and exports, together with the introduction of a *wealth tax* ($WTax$) proportional to the increase in the average propensity to save. This tax offsets the possible increase of the government's deficit- and debt-to-GDP ratios due to a significant reduction in GDP growth, and provides public revenues needed to sustain social transfers and benefits.

Methodological remarks

The distinctive features and novelties proposed by the EUROGREEN model are hereby summarised:

1. *endogenous* determination of technological progress and of the key macroeconomic variables such as economic growth, emissions, and income distribution;

2. *detailed welfare accounting*: available macroeconomic models typically treat public expenditure as a single aggregate and consider a limited number of income sources for households. We overcome this shortcoming by including the main sources of public revenues and expenditures, associated with the specific groups of agents, to better assess the economic viability of radical social policies and their effects on income distribution;

3. *meso-scale* approach: although EUROGREEN rests on a macro-economic framework, it goes one step further, differentiating 13 household groups, by skill and occupational status, and ten productive industries;

4. *policy mix*: the joint introduction of multiple policies evaluates the possibility (and necessity) of tackling inequality, unemployment, and emissions together.

Limitations First, even though we introduce an endogenous technological progress that changes the technical coefficients associated to the energy-supplying industries, the rest of matrix **A** is kept constant. This rigidity – although partly justified by the evidence that technical coefficients are fairly stable over time [47] – might lead to understate other spillover effects from technological progress.

Second, the definition of the change in labour productivity (HLP) and energy efficiency ($HEEF$) is a simplified representation of manifold interventions to promote automation and energy efficiency. However, this framework allows us to capture the aggregate scale effects of the policies ("as if" they were effective) in terms of social justice and environmental sustainability.

From a methodological perspective, in comparison to the general (or partial) equilibrium models, we do not include specific technologies for renewable energy generation and storage. Hence, this study is not suitable to determine whether the environmental goals simulated with EnM and *Electrification* are technically feasible. Yet it captures the impact that these policies have on economic variables, thus allowing the model to assess their social and distributive effects.

We have opted for the development of a country-scale model since national governments are the main agents of environmental and labour market policies. Hence, unlike global-scale integrated assessment models, our approach does not consider negative feedback effects from climate change on the economy. Considering these in EUROGREEN would require *ad-hoc* assumptions on the behavior of global emissions. Moreover, our national model does not properly consider binding institutional constraints defined by the EU and financial interconnections between France and other EU members. At most, these limitations could constitute further constraints to the implementation of radical social policies but would not change the direction of their effects

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Competing Interests The authors declare no competing interests.

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Data Availability The EUROGREEN model was developed in Vensim DSS. The code for the model, simulation output data used for the figures and the complete list of equations are available in Zenodo with the identifier https://doi.org/10.5281/zenodo.3549756

Author Contribution S.D. and K.D. initiated this project and developed an initial version of the model. S.D., A.C. and T.D. develop the final version of the model, selected and programmed the individual policies and policy mixes, performed the simulation and wrote the manuscript. A.C. created Figure 1 and T.D. Figures 2 and 3. All authors contributed to the Supplementary Information.