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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 have been advanced to manage a fair low-carbon transition. In this spirit, we develop a dynamic macrosimulation model to investigate the long-term 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 sustainability challenges 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. Scholars question the ability of market mechanisms to reduce environmental damage[4,5], meet planetary boundaries[6–8] and avoid critical transitions[9,10]. Moreover, the evidence that new technologies reduce the correlation between growth and employment casts doubts on the capacity of green growth to create jobs[11].

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 United States, recognizes the need to complement environmental policies with direct actions to reduce inequality and unemployment[12]. Notwithstanding its ambitious goals, there is an ongoing debate as to whether decarbonization can be achieved with economic growth[13,14].

A more radical argument in this debate comes from the degrowth literature[15]. According to this second alternative, continuous economic growth and ecological sustainability are incompatible[16] and the transition towards a sustainable society requires a downscaling of 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[17–19].

We focus 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 a harmful outcome? Is a downscaling of consumption necessary to meet environmental targets? To address these questions, we develop a dynamic macrosimulation model, EUROGREEN, tailored to compare green growth and these two alternatives in terms of greenhouse gas (GHG) emissions and income distribution.

The need for a proper understanding of the interdependence between the macroeconomy and the natural environment together with the focus on social equity has led to the combined incorporation of post-Keynesian and ecological economics into ecological macroeconomics[20]. Following this perspective, we model an economy where the demand determines the dynamics of production and employment, and production factors (that is, capital and labour) are not fully utilized. Here, we provide a detailed specification of the welfare system and of the multiple income sources attributed to distinct groups of agents defined by working status, skill and age (see Fig. 1). These features allow us to understand how policies affect the income of each group differently and, thus, the evolution of inequality.

The relationship between environmental degradation and inequality is hardly new in the literature[21,22] and recent empirical studies have considered the effect of emissions and climate change on income distribution[23,24]. In contrast, this study considers how environmental and social policies mediate the nexus between emissions and inequality. In other words, we ponder whether overlooking this interconnection could lead to the implementation of policies that reduce emissions at the expense of income distribution or, conversely, to radical social policies that increase environmental pressure. Moreover, previous studies have often neglected the consequences of the joint implementation of multiple policies[25], focusing on the impacts of individual policies, such as carbon taxes[26], working time reduction[27] and job guarantee programmes[28]. The three policy-mix scenarios aim to fill this gap. Each scenario is defined by a set of individual policies and each individual policy is described in detail in the Methods.

Green growth 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 an increase in the share of electricity in final energy demand (energy mix). Green growth also extends the planned carbon tax for France and, additionally, levies an equivalent tax on imported goods according to their incorporated carbon emissions (border carbon adjustment).

Policies for social equity (PSEs) maintain the same policies as green growth, with the exception of incentives for labour-saving technology, and adds two radical social policies: a job guarantee programme and working time reduction.

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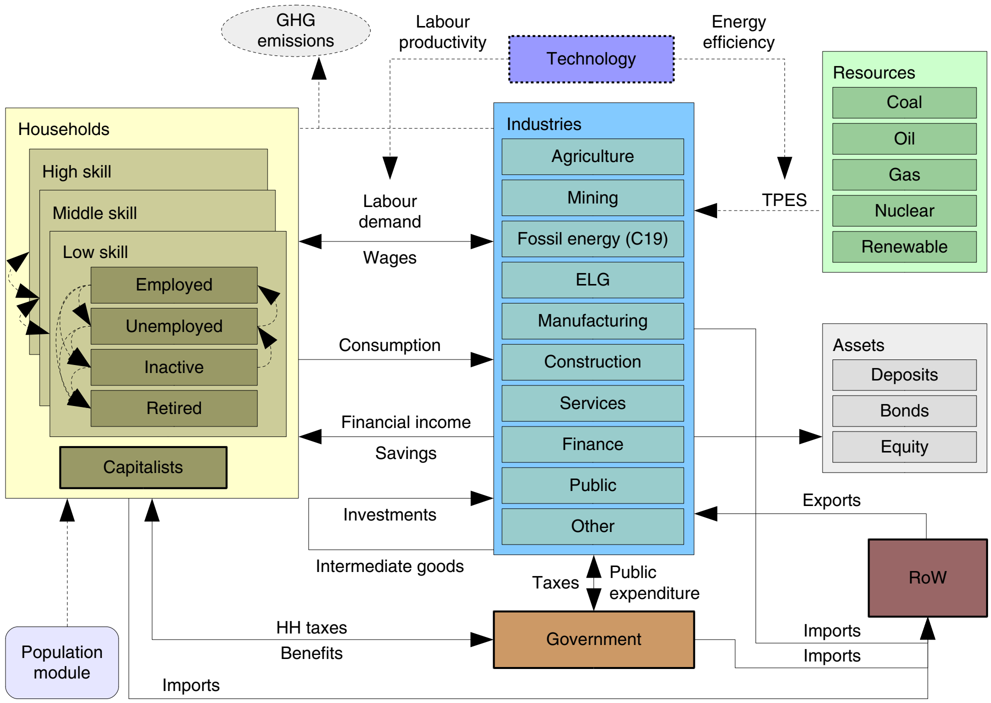

Fig. 1 | Macroview. Main causal relationships between heterogeneous household groups, industries, resources and assets in our model. Solid (dashed) arrows represent monetary (non-monetary) flows. Household consumption includes electricity and other energy products. The rest of the world (RoW) is included because the aggregate flows from (to) it are included as imports (exports), although the foreign sector is not defined in the model. HH, households; TPES, total primary energy supply.

Degrowth considers a reduction in consumption and exports, together with all of the PSEs. While this is certainly not a policy, it allows us to assess the environmental and economic consequences of a voluntary cut in consumption. Finally, degrowth also introduces a wealth tax to compensate for the rising government deficit-to-gross domestic product (GDP) ratio as a result of decreasing national product.

Results

We applied the simulation model to France over the period 2014–2050. We focused at the country scale since national governments are the main agents of environmental and labour market policies. Moreover, unique data on the distribution of wealth by skill and asset type are available for France[29].

Income distribution and GHG emissions. Figure 2 shows the two key indicators of environmental performance and income inequality: the GHG emissions level (index 1990 = 100) (Fig. 2a) and the Gini coefficient (Fig. 2b), which ranges from 0 (perfect equality) to 100% (perfect inequality). The Gini coefficient 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 Fig. 1.

The three policy-mix scenarios result in considerably greater GHG emission reductions than the baseline, for which emissions approach 45% of the 1990 level by 2050. Both green growth and PSEs reach very similar levels of emissions by 2050 (about 23% of the 1990 level), which are close to the EU Climate Action target[30]. The degrowth scenario results in an even stronger reduction (17.8% by 2050), due to the contraction of final consumption and energy demand. In contrast, the Gini coefficient diverges substantially among the scenarios. For the baseline, it increases by more than 1.5 points with respect to the initial year (from 32.7 to 34.3% by 2050). Under green growth, 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 onward. For the degrowth scenario, the reduction in income inequality reaches 23.9% by 2050.

The two alternative policy mixes considered herein are at least as effective as green growth in abating carbon emissions and achieve a long-lasting reduction in inequality. Moreover, the environmental and market-based incentives of green growth 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 the PSEs and the degrowth scenario can offset unintended social consequences of green growth strategies.

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

GDP growth rates under green growth and PSEs converge to the same long-term values of the baseline scenario (~1%). Under degrowth, they fall below 0% from the year 2035 onwards, reaching −0.7% by 2050. Figure 3b shows an increase in the unemployment rates under green growth and for the baseline, from an initial value of around 10% up to 13 and 11.4%, respectively. In contrast, unemployment rates fall sharply under PSEs and degrowth 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 (that is, the share of the working-age population either employed or in search of work).

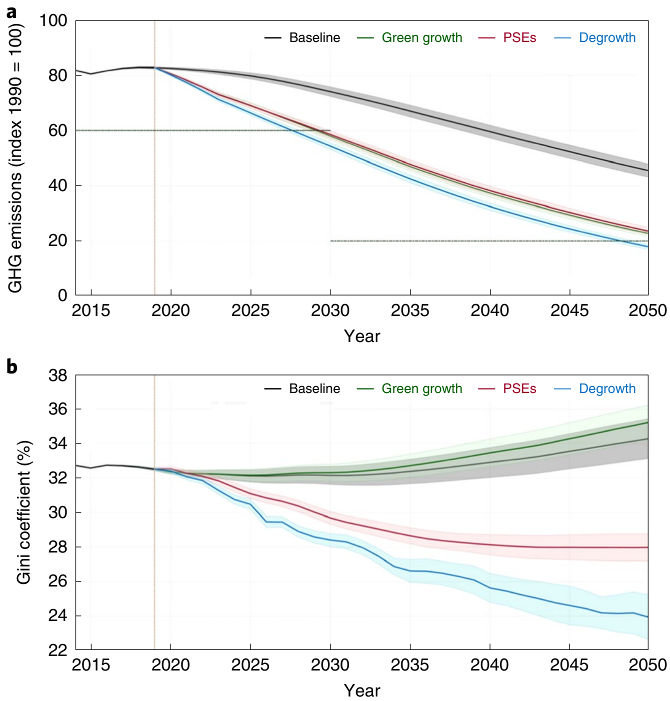

Fig. 2 | Scenario analysis: GHG emissions and income inequality. **a**,**b**, Comparison, from 2014–2050, of GHG emissions (**a**) and income inequality (**b**) under the baseline scenario (black) compared with the three policy mixes: green growth (green), PSEs (red) and degrowth (blue). The vertical dotted lines indicate introduction of the policies in the year 2019. The horizontal reference lines in **a** indicate the EU Climate Action targets for the reduction of GHG emissions by 2030 (−40%; left) and by 2050 (−80%; right) with respect to the 1990 level[50]. Solid lines and shaded areas indicate the means and 95% confidence intervals, respectively, of 500 simulations for each scenario, with different random processes for the extraction of new technologies.

Figure 3c compares the dynamics of the labour share, defined as the fraction of post-tax value added that is paid to employed workers as wages. Once again, the green growth scenario projects a trend close to that of the baseline, with declining paths that end up in the 60–65% range by 2050. PSEs and degrowth have a positive impact on the labour share, albeit with a delay of about 5 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 PSEs and degrowth, respectively, and then slightly decreases following an inverse U-shaped path.

Even though, in principle, lower unemployment should reduce inequality, in our simulations, the Gini coefficient falls more for degrowth than for PSEs. This apparent counterintuitive outcome can be explained by wage moderation under the degrowth scenario. For PSEs, 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, very 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 (Fig. 3d) projects the simulated deficit-to-GDP ratio (the public deficit is the difference between the current government's expenditures and revenues), which measures the fiscal cost of the active labour market policies introduced for PSEs and degrowth. All scenarios follow a decreasing trend until 2035. Green growth and the baseline continue on a declining path, reaching about 1.5 and 0.7% by 2050, respectively. In contrast, PSEs and degrowth 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 (that is, below the initial level of 3.9% for more than 30 years). For the degrowth scenario, the deficit-to-GDP ratio drastically increases after 2040. This trend is not due to a disproportionate amount of public expenditure, but rather to contraction of the GDP (Fig. 3a).

These simulations suggest that both green growth and PSEs are equally successful in terms of curbing GHG emissions, albeit through different mechanisms. In green growth, GHG emissions reductions follow directly from advances in energy efficiency, electrification and renewable energy, and indirectly from higher labour productivity resulting 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 degrowth 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.

Discussion

Interactions and feedback loops among economic, social and ecological dimensions constitute a complex system that can be analysed through computer-driven simulations. Even though this methodology might be received with certain scepticism, it is suitable for 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 multidimensional and interdisciplinary approach to question current policy priorities in terms of social justice, environmental care and economic performance[6,31].

The simulation results suggest that there are no win–win 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[14]. Indeed, in our analysis, only the degrowth scenario

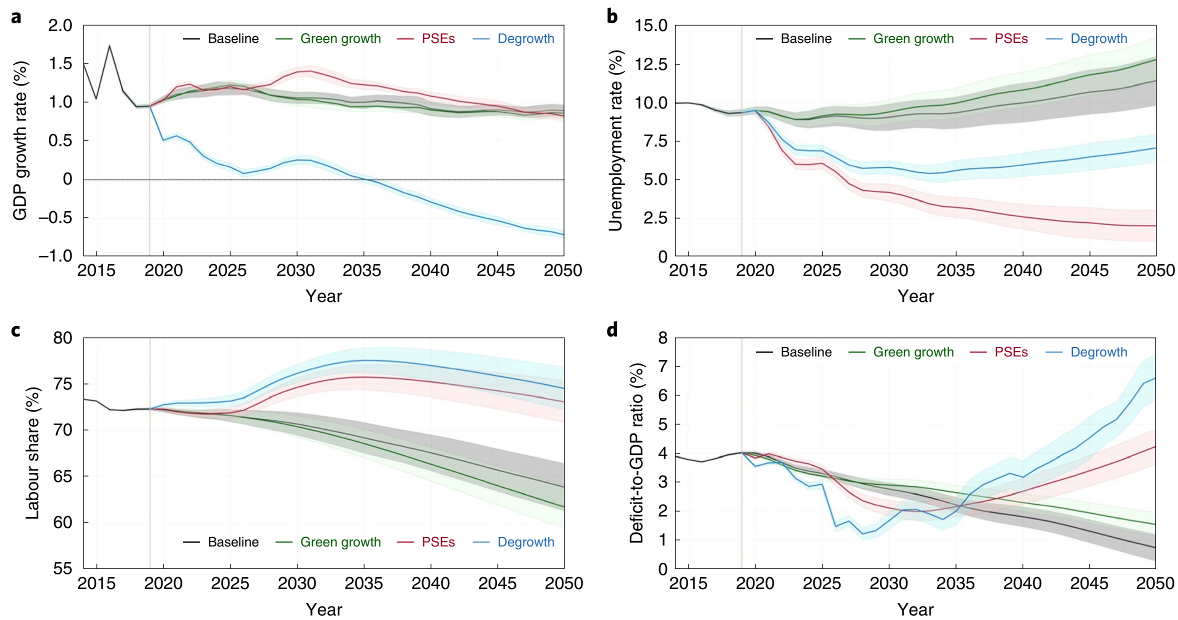

Fig. 3 | Scenario analysis: socioeconomic indicators. a–d, Comparison, from 2014–2050, of the GDP growth rate (**a**), unemployment rate (**b**), labour share (**c**) and public deficit-to-GDP ratio (**d**) under the baseline scenario (black) compared with the three policy mixes: green growth (green), PSEs (red) and degrowth (blue). The vertical dotted lines indicate introduction of the policies in the year 2019. Solid lines and shaded areas indicate the means and 95% confidence intervals, respectively, of 500 simulations for each scenario, with different random processes for the extraction of new technologies.

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.

Methods

Theoretical background. The 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 provide a realistic and consistent basis for understanding the feasibility of the policy mixes proposed. Supplementary Table 21 shows a comparison of the forecasts from the baseline scenario as simulated in the EUROGREEN model and in the European Union official reports. 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, we do not include it in the transaction flow matrix (see Supplementary 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 used to calibrate the initial conditions, for the French economy in the year 2014, are: Eurostat, EU KLEMS, the World Input–Output Database, the Organisation for Economic Co-operation and Development, the International Energy Agency and the National Institute of Statistics and Economic Studies. Given the stochastic nature of the innovation process, as described below, we ran 500 simulations for each scenario, to ensure robust results. Below, we describe the main building blocks exposed in Fig. 1, while the Supplementary Information provides a 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 or high. The working-age population (aged 15–64 years) is further divided among employed, unemployed and inactive people. Individuals aged 65 years or more are assumed to all be pensioners. A small percentage (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 matrix, which is composed of ten macro-industries: agriculture, mining, manufacturing, the manufacture of coke and refined petroleum products (C19), electricity and gas (ELG), construction, services, finance, the public sector and 'other'. The input–output 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 Statistical Classification of Economic Activities in the European Community (NACE) classification (revision 2) as presented in the World Input–Output Database[36].

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. The EUROGREEN model 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. This study models 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[37].

Technological progress. The mechanism behind the innovation process comprises three steps (see Supplementary Fig. 5): (1) the possible emergence of new available technologies; (2) the most minimizing technology choice among those available; and (3) implementation. We define a technology (γ) as combinations of labour productivity (λ; that is, output per worked hour) and energy efficiency (η; that is, 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 (Supplementary 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 (that is, λ increases) but energy augmenting (that is, 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 on the impact of relative input prices (of energy and labour in our case) as drivers of research and development investment decisions[38]. It is assumed that the ratio between the growth rates of labour and energy costs affects the probability of new technologies emerging. For instance, a relative increase in labour with respect to energy costs results in a higher probability of γ_2 becoming 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 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 values 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. Electricity 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 and the associated GHG emissions, in CO_2 equivalents. The model considers a carbon tax starting from €7 per tonne of CO_2 in 2014, as recently was introduced in France. The tax increases by about €8 per tonne of CO_2 per year until 2020, reaching €56, and by €4.4 per year afterwards to achieve the planned €100 per tonne in 2030. The carbon tax is not applied to those industries participating in the European Union's Emissions Trading System, which accounted for about one-third of total French GHG emissions in 2014 (145 out of 435 million tonnes of oil equivalent).

Labour market. Workers are differentiated by three skills and allocated among ten industries. The level of employment is determined by labour productivity, working hours and the level of output, which, in turn, depends on the final demand. 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[39,40].

Labour force supply and its skill composition are endogenous and follow unemployment rates. Inactive individuals enter the labour force whenever unemployment rates fall[41]. 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 around, 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[42]. Moreover, increases in labour productivity are only partially converted into hourly wages, to reflect empirical evidence of a decoupling between median wages and productivity[43].

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 modelled 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 of 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. High-skill households pay dividends from company profits. Households pay a progressive income tax, a flat tax that combines social security contributions (that is, *contribution sociale généralisée* and *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 (that is, 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 the Jevons paradox[44], 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 at least a minimum 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 (if the demand does not increase enough), 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 Results.

Technological incentives. To assess at an aggregate scale the effects of the strategies to boost technological progress, we introduce two types of incentives. The first stimulates labour productivity and the second stimulates high energy efficiency. We set increased probabilities of emergence for new labour- (γ_2) and energy-saving (γ_3) technologies under high labour productivity and high energy efficiency, respectively. The sum of these two incentives composes the single policy termed next production revolution[45] presented in the Supplementary Results. Next production revolution allows for faster technological progress, to assess its impact on employment, emissions and income distribution.

Energy mix. First, this policy considers a change in the mix of energy sources in electricity power generation. It gradually substitutes renewable sources for brown and nuclear ones in the energy-supplying sectors. Second, energy mix imposes the phase-out of coal by 2050, with constant annual reductions, from its initial share of about 3%. Third, it defines an electrification process that substitutes electricity 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, from an initial value of about 53% of the total primary energy supply in 2014 to 71% by 2050.

Border carbon adjustment. The border carbon adjustment extends the currently planned carbon tax to imports, according to their incorporated GHG content. Moreover, the tax rates continue to increase by €4.4 per year from 2030–2050, reaching €188 per tonne of CO_2 for both domestic and imported goods. Note that under the baseline scenario, the carbon tax increases only until 2030 and then remains constant.

Working time reduction. This social policy consists of a curtailment of weekly working hours, from the current 35-h week to a 30-h working week within 5 years[46]. In the past decade, working time reduction has been considered a multiple-dividend policy[47] capable of improving income distribution and reducing emissions due to scale and composition effects[48]. Workers earn and consume less (scale effect), while time availability allows them to choose less energy-intensive consumption baskets (composition effect). 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 the working hours of those initially employed. Since consumption baskets are fixed in our model, the simulated working time reduction policy captures only the scale effect.

Job guarantee. With the job guarantee 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 environment-related work (which increases the households' energy efficiency). The maximum amount corresponds to about 10% of the unemployed workers in 2014 (that is, a large public hiring policy).

Consumption reduction plus export reduction plus wealth tax. We consider a strategy for controlled degrowth of the economy via a reduction of the marginal propensities to consume (consumption reduction), together with a fall in the growth rate of exports. These changes induce a reduction in the marginal propensities of about 11.7% and a reduction in the export growth rate of about 0.1% per year. Moreover, a wealth tax is introduced. This increases in proportion to the increase in the average propensity to save due to the fall in private consumption that results from consumption reduction. This tax rate reaches a maximum of about 1.5% per year and contains an increase in the government's deficit-to-GDP ratio due to a significant reduction in GDP.

Methodological remarks. The distinctive features and novelties proposed by the EUROGREEN model are summarized as follows:

(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) A mesoscale approach. Although EUROGREEN rests on a macroeconomic 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 enables us to investigate the possibility (and necessity) of tackling inequality, unemployment and emissions together.

Limitations. First, even though we introduce endogenous technological progress that changes the technical coefficients associated with 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[49]—might ignore other spillover effects of technological progress that change the demand of intermediate commodities.

Second, the assumed policies for enhancing labour productivity and energy efficiency are a simplified representation of manifold interventions to promote automation and energy efficiency. However, this framework allows us to capture the aggregate scale effects of these policies (as though they were effective) in terms of social justice and environmental sustainability.

From a methodological perspective, compared with general (or partial) equilibrium models, we do not include specific technologies for renewable energy generation and storage. Hence, this study is not suitable for determining whether the environmental goals simulated with energy mix 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. Thus, 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 behaviour of global emissions. Moreover, our national model does not properly consider binding institutional constraints defined by the European Union, nor financial interconnections between France and other European Union 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.

Data availability

The initial data and the simulation outcomes of the model that support the findings of this study are available from Zenodo at https://doi.org/10.5281/zenodo.3549756. Source Data for Figs. 2 and 3 are provided as Source Data files.

Code availability

The EUROGREEN model was developed in Vensim DSS. The code for the model can be viewed at https://doi.org/10.5281/zenodo.3624944.

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Author contributions
S.D. and K.D. initiated this project and developed an initial version of the model. S.D., A.C. and T.D. developed 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 Fig. 1 and T.D. created Figs. 2 and 3. All authors contributed to the Supplementary Information.

Competing interests
The authors declare no competing interests.

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