Article

A multi-model assessment of inequality and climate change

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Climate change and inequality are critical and interrelated issues. Despite growing empirical evidence on the distributional implications of climate policies and climate risks, mainstream model-based assessments are often silent on the interplay between climate change and economic inequality. Here we fill this gap through an ensemble of eight large-scale integrated assessment models that belong to different economic paradigms and feature income heterogeneity. We quantify the distributional implications of climate impacts and of the varying compensation schemes of climate policies compatible with the goals of the Paris Agreement. By 2100, climate impacts will increase inequality by 1.4 points of the Gini index on average. Maintaining global mean temperature below 1.5 °C reduces long-term inequality increase by two-thirds but increases it slightly in the short term. However, equal per-capita redistribution can offset the short-term effect, lowering the Gini index by almost two points. We quantify model uncertainty and find robust evidence that well-designed policies can help stabilize climate and promote economic inclusion.

Economic inequality between and within countries has become a major topic of debate. both in research and in society[1–3]. Inequality is interlinked with climate change mitigation and impacts, because of the regressive impacts of carbon taxes or higher energy prices[4,5] and of social repercussions and acceptability of climate policies. An increasing body of literature has explored the distributional effects of climate policies[6–8], poverty[9] and climate impacts between and within countries[10–12], suggesting that both climate policy and climate impacts affect more the lower end of income distribution. However, carbon revenues redistribution can address the adverse distributional implications of climate and energy policies[12–15].

Redistribution of carbon market revenues has been advocated to ensure that vulnerable households and businesses are sheltered

from higher energy expenditures due to carbon pricing, in the hope of increasing support for climate policy (for example, the European Association of Environmental and Resource Economists' statement signed by more than 1,700 economists: www.eaere.org/statement). The European Union recently approved a climate policy package that establishes a Social Climate Fund to be financed with emission trading scheme revenues. Even if the impact on policy support might not be as strong as theoretically predicted[16], 'climate dividends' or lump sum transfers could have major impacts on inequality and poverty alleviation[17,18] and become even more relevant as a result of the pandemic, the energy crisis and the ongoing inflationary period[19]. The empirical evidence on public opinion support for redistribution is mixed: equal per-capita (EPC), or targeted (on poor households),

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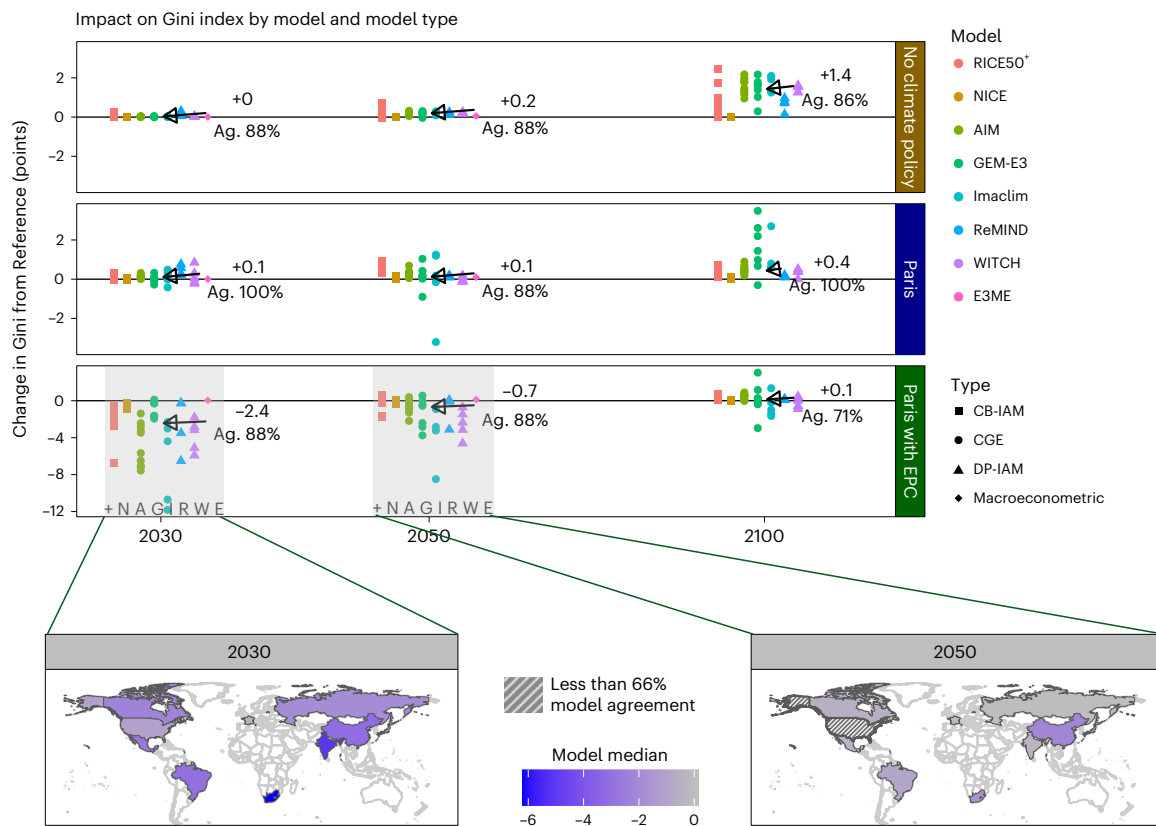
Fig. 1 | Change in Gini index from the Reference scenario without climate impacts. The top row shows the case of no climate policy, the middle row the Paris scenario and the bottom row shows the Paris scenario including EPC transfers. All individual countries are shown as points and all scenarios include climate impacts. Also included are the distributional consequences of climate damages. Models are categorized (colour and letter coded on the *x* axis using the first letter of each model ('+' for RICE50^{+})) and ordered and clustered by model type. Bottom, maps of the model median in 2030 and 2050. Numbers in black indicate median values pointing by the arrow to the median value. Note the different *y* axis scales across panels. Countries with less than two-thirds model agreement are shaded. Ag., agreement among models in terms of sign.

carbon tax redistribution has strong support in middle-income countries but lower support in high-income countries[20]. Redistribution of carbon revenues could also be combined with international between-country effort-sharing schemes[21], increasing the revenues available in developing countries.

Inequality is also affected by the uneven distribution of climate impacts and risks within and between countries. The advancements in estimation of impact functions of climate change with improved datasets and empirical methods[22–25], and highlight major regional discrepancies of climate risks, with potentially large implications of increasing inequalities across countries[26–28]. Recent empirical studies have found that climate impacts increase within-country inequality[11,29–33], in particular in low- or middle-income countries[34]. To date, however, assessments focus on the distributional effects of climate policies without considering the effect of climate impacts both within and between countries, with some exceptions[10,12,35].

Despite their relevance, climate–inequality interlinkages are not yet routinely included in mainstream climate–economy models, although individual modelling studies have explored policy incidence[36,37]: no scenario reported in the IPCC 6th assessment report database reports economic inequality indicators. One exception is a recent Energy Modelling Forum study[38], although this focused on international emission trading and is limited to computable general equilibrium models. Overall income deciles differ including in terms of in particular energy expenditures (Supplementary Fig. 1).

This Article provides a model comparison explicitly designed to investigate the link between climate change and inequality, quantifying the distributional implications of climate policies and

climate change impacts. We do so through a model ensemble of eight integrated assessment models (IAMs) covering four main modelling paradigms. The multi-model analysis addresses the following research questions: (1) how climate impacts will affect inequality within countries; (2) how climate policies will affect the distribution of income and consumption within countries; (3) what role redistributive policies can play; (4) how these three channels compare quantitatively; and (5) the robustness of findings across a diverse set of models and countries.

This multi-model study employs eight models (Supplementary Fig. 2) representing four theoretical approaches (notably computable general equilibrium (CGE) models, detailed process-based (DP-IAM) and cost-benefit (CB-IAM) integrated assessment models and one macroeconometric-Keynesian model) for the analysis of six scenarios, focusing on a Reference case and a scenario compatible with the goals of the Paris Agreement with a 650 GtCO$_2$ carbon budget. All models show persistent inequalities in the Reference scenario (Supplementary Fig. 3). The study implements a uniform carbon price across sectors and countries without international transfers and explores two revenue-redistribution methods: neutral recycling and EPC distribution. Inequality in climate risks is incorporated using various impact specifications. The analysis concentrates on ten large countries, allowing for uncertainty quantification through model agreement assessment. This diverse modelling approach adds value by addressing the varying results in the decarbonization economics literature and provides insights into the effectiveness of compensatory policies in mitigation of the distributional impacts of climate change and related policies.
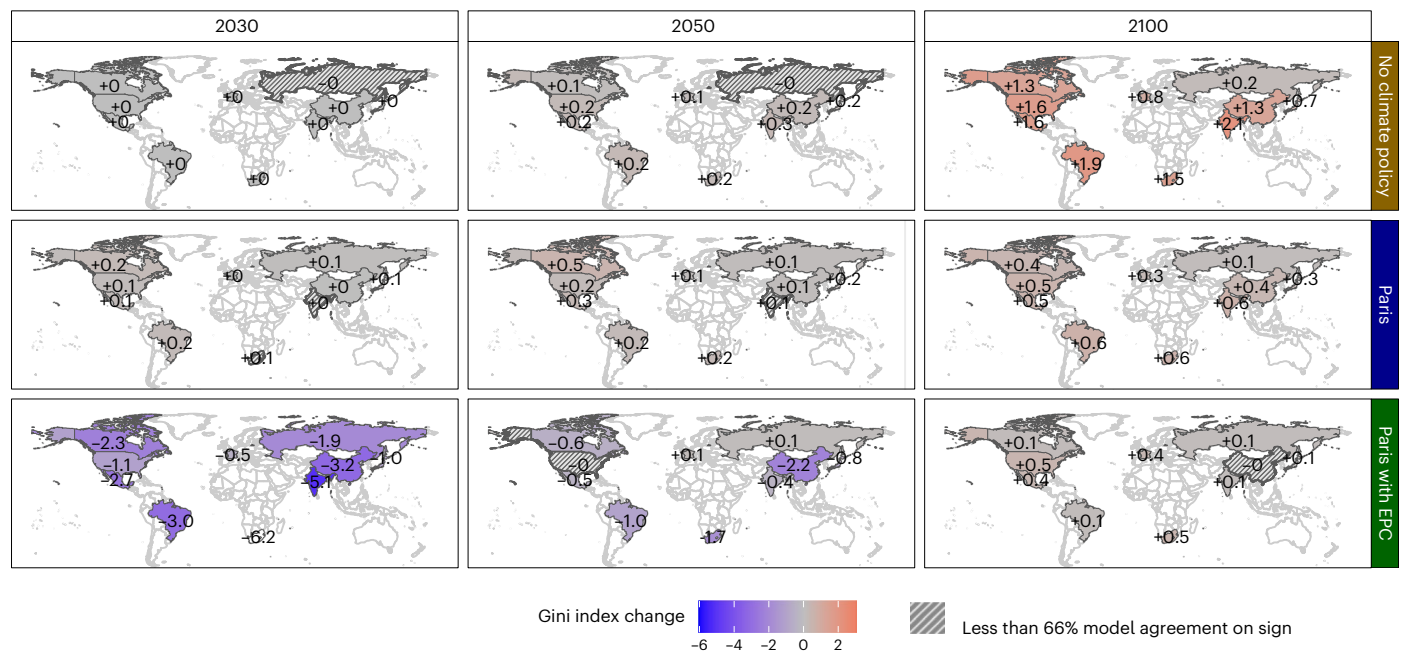
Impact on Gini index (model median)

Fig. 2 | Map of the median across models showing change in Gini index with respect to the Reference scenario without climate impacts. Top, Reference scenario; middle row, Paris scenario without redistribution; bottom, the Paris scenario with impacts and EPC redistribution (all quantified by points). All scenarios include climate change impacts. Countries with less than two-thirds model agreement in terms of the sign of the effect are shaded.

Results

The Reference scenario (without climate impacts) projects a continuation of secular trends of persisting within-country inequality. Within-country inequality varies by country, in line with the current range of 0.3–0.7 for the Gini index (Supplementary Fig. 4). Most models use baseline Gini projections from ref. 39 that project—in particular, in their Shared Socioeconomic Pathways 2 or 'middle of the road' scenario variant—a slight increase in within-country inequality for most countries. Notable exceptions include an increase in inequality in India and a faster decrease in China and Mexico (Supplementary Fig. 4). This allows good harmonization of inequality dynamics across models, despite important country specificities, with the top income decile representing up to 70% of total consumption in South Africa, followed by Brazil, India, the United States and Mexico. Canada, France and Japan show the lowest consumption dispersion, while Russia and China are in the middle of the regions analysed.

Climate impacts

We begin by quantifying the inequality arising from climate impacts in a world without ambitious climate policies. The Reference scenario foresees increasing temperatures reaching 2.75 (2.5–3.1) °C by 2100. With this temperature increase, climate impacts are expected to increase the Gini index by about 1.4 points (median across models) by 2100 (Fig. 1, top). For some regions/models, the inequality increase is as high as 2.5 points of the Gini index (Fig. 2). While in the short term the effect is marginal, by the end of this century almost all models find important effects, the exceptions being NICE, which found no effect (based on its assumption of proportional damages), and ReMIND, which showed relatively low effects. The models also largely agree on the sign of the effect. Overall, we estimate an effect of about 0.4 Gini points increase per degree of country-level temperature increase (Supplementary Table 2).

Climate policies without redistribution

In the senarios compatible with the goals of the Paris Agreement, the global carbon price leads to a modest and temporary increase in income inequality (Fig. 1): Gini index increases by 0.1 points in 2030, but the

inequality benefits of a lower global temperature have already materialized by mid-century. By 2100, Gini has increased by 0.4 points with respect to a world without either climate policies or climate impacts; this is one full Gini point below the scenario including climate damages, emphasizing the equality benefits of climate stabilization. Computable general equilibrium (CGE) models show a larger increase in inequality on average, because they capture the sectorial and structural costs of decarbonization to in greater detail but are also more rigid in terms of economic adjustments (for the 'Weak Paris' scenario based on a carbon budget of 1,150 GtCO$_2$ (Supplementary Fig. 5)). By 2100 the CGE models find the impact of the Paris agreement climate policy to be more than double the median value, and an increase in Gini index by up to 3.5 points in the case of the general equilibrium model for economy–energy–environment (GEM-E3). Detailed process-based IAMs on the other hand typically find a smaller impact with consistent increases of inequality due to climate policies. The macroeconometric model shows the smallest impact of all. In any case, model agreement is always above 70% (Fig. 1) for the sign of the effect.

These results partly confirm concerns about the regressivity of carbon taxes, notably due to changes in income and factor prices[36]. Countries with high carbon intensity (for example, South Africa) or high fossil extraction (for example, Canada and the United States) are most affected (see Fig. 2 and Supplementary Fig. 6 for country-level results). Only three cases of model–country combinations show a decrease in Gini index in the Paris scenario without redistribution, with Imaclim for India an improvement of about three points; this is because the much-reduced climate impacts obtained by stabilization of global temperature improve inequality more than the policy. Alternative inequality metrics, such as the share of the income of the richest 20% over the poorest 20% (D80:D20 ratio), lead to similar results (Supplementary Fig. 7).

To summarize the regressivity of climate policies we estimate the income elasticity of the policy cost, running an ordinary least-squares regression for each country and decile over both time and models (Supplementary Table 3), and estimate the income elasticity of climate policy costs by country. Overall, we find that policy costs are close to
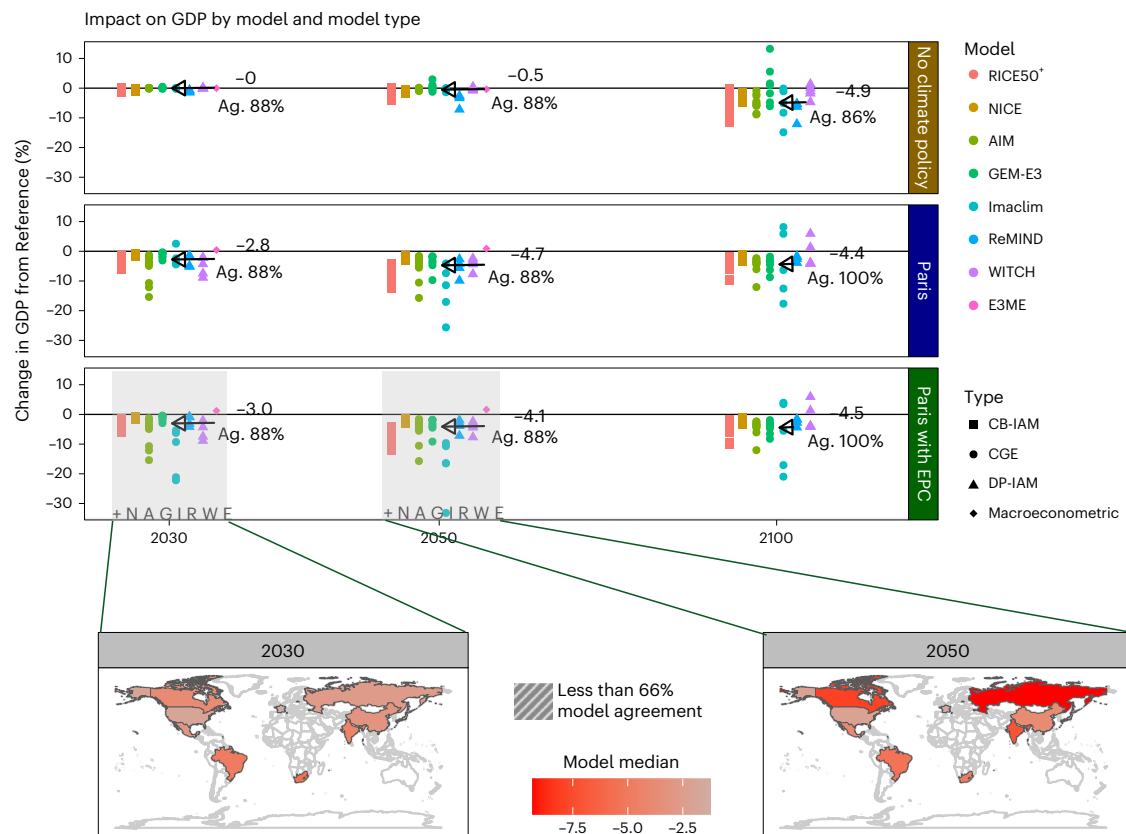
Fig. 3 | Policy cost in terms of GDP loss from the Reference scenario without climate impact. The top row shows the case of no climate policy, the middle row the Paris scenario and the bottom row shows the Paris scenario including EPC transfers. Individual countries are shown as points and all scenarios include climate impacts. Panels include the distributional consequences of climate damages. Models are categorized (colour and letter coded using the first letter or each model ('+' for RICE50+)), and ordered and clustered by model type. Bottom, maps of model median for 2030 and 2050. Numbers in black indicate median values pointing by the arrow to the median value. Countries with less than two-thirds model agreement are shaded.

proportional, with an estimated elasticity of 1.04 (note that a value of one would indicate equal relative policy costs and hence a neutral distribution). Across regions, the values in the ten countries lie between 0.75 and 1.05, with countries with higher gross domestic product (GDP) per capita typically exhibiting higher regressive policy costs (Supplementary Fig. 8). In contrast, poorer countries can even show progressive policy cost incidence, a finding in line with the meta-study of Budolfson et al.[12]. For assessment of model robustness, we also performed estimation for each model separately (Supplementary Table 4). Six of the eight models show this negative relationship with income (for three models it is statistically significant at the 10% level), and all models show on average a value of around one.

The role of carbon revenue recycling
The third building block of this analysis is carbon revenue recycling, which we implement across models with an EPC transfer within countries. Total carbon revenues by country are in most cases below US$1,000 per capita per year over the entire century (Supplementary Fig. 9), based on total emissions and carbon prices (Supplementary Fig. 10). When carbon revenues are redistributed equally as a climate dividend among citizens (Figs. 1 and 2), the combined effect of climate impacts, climate policy and redistribution becomes (with high agreement) inequality reducing, particularly in the short term. In 2030, on average across models, Gini decreases by 2.4 points compared with the Reference scenario (without climate impacts). The effect is higher in developing countries (Fig. 2 and Supplementary Fig. 6), and for model classes featuring higher economic resolution such as computable general equilibrium (Fig. 1). India and South Africa show the highest inequality reduction due to redistribution, given their lowest level

of income among the poorer deciles. Over time, as carbon revenues dry up due to marked reduction in emissions, the inequality benefits of revenue-recycling diminish. By mid-century, Gini remains lower than in the Reference without climate impacts (by 0.7 points) and is roughly equal by 2100. Note, however, the major inequality benefits of combining climate stabilization and redistribution compared with a Reference scenario with climate damages (gains of 2.4, 0.9 and 1.3 Gini points in 2030, 2050 and 2100, respectively).

In regard to the amount of carbon dividend, overall we find a significant and robust reduction of around 0.6 points decrease in Gini index for each US$1,000 per capita of revenue redistribution (Supplementary Table 5). The highest reduction in Gini index is found for South Africa, India and Brazil (all with a reduction of about three points of Gini index ceteris paribus, while inequality in the Reference case is also highest in these countries). In contrast, the impact in Organisation for Economic Co-operation and Development countries is lower, with a reduction of 1.0–1.5 points. However, we also find some model differences, including some due to variation in the carbon prices required to implement the Paris scenario: notably, the CGE model Imaclim shows greater reduction due to higher carbon prices. The overall positive impact of revenue recycling with an EPC climate dividend is in line with single-model studies[8,12,40].

Macroeconomic and welfare impacts
In addition to income and consumption distribution within countries, the models also provide insight into macroeconomic dynamics (here measured as GDP loss compared with the Reference scenario without climate impacts, measured using purchasing power parities). When considering climate impacts, GDP losses reach on average 4.9%
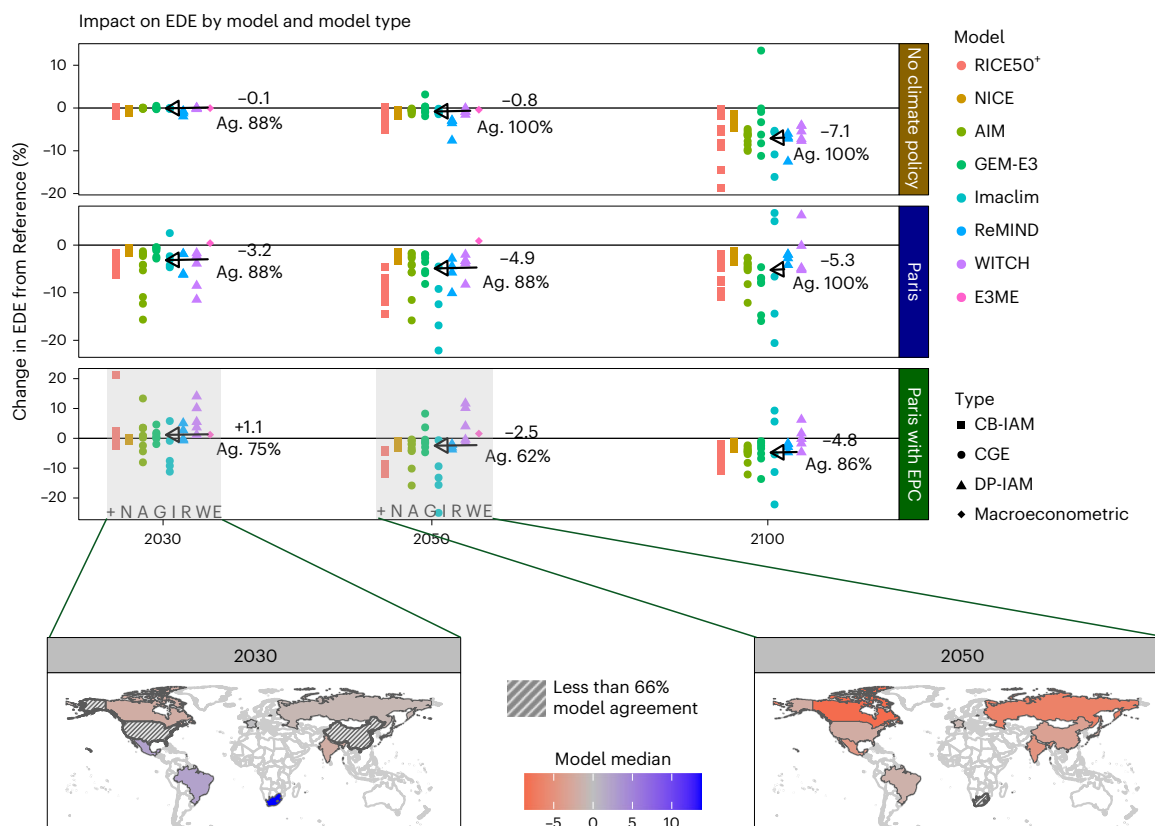
Fig. 4 | Welfare impact based on the EDE welfare measure. The top row shows the case of no climate policy, the middle row the Paris scenario and the bottom row shows the Paris scenario including EPC transfers. All individual countries are shown as points and all scenarios include climate impacts. Panels include the distributional consequences of climate damages. Models are categorized (colour and letter coded using the first letter or each model ('+' for RICE50⁺)) and ordered and clustered by model type. Bottom, map of the model median in 2030 and 2050. Numbers in black indicate median values pointing by the arrow to the median value. Countries with less than two-thirds model agreement are shaded.

of GDP by the end of the century, albeit with regional variation and some higher-latitude countries even showing gains (Supplementary Fig. 11). Under the Paris scenario, policy costs are added while impacts are reduced. The second row in Fig. 3 shows the policy costs in terms of GDP loss. Meeting the Paris agreement reduces global GDP by 2–5% of GDP on average per year until 2050. By 2100, the total GDP impact is lower than in the Reference scenario, reducing overall GDP losses by around one-third. Nevertheless, there is substantial model and regional variation (higher values in poorer and more carbon-intensive (and fossil fuel-exporting) countries). Some models find costs of up to 20%—in particular CGEs—and, in some cases, also indicate GDP gains (macroeconometric or CGE models in some cases). These results are coherent with those of the sixth assessment report of the IPCC. Redistribution of carbon revenues to households has almost no macroeconomic impact in almost all countries and models, except for the CGE model Imaclim. Here, in the standard Paris scenario by default, tax revenues are recycled by reduction of pre-existing labour taxes affecting GDP. Moreover, there is feedback on emissions, with increased economic activity from redistribution tending to increase emissions, resulting in slightly higher carbon tax trajectories needed to reach the same carbon budget. Regarding model uncertainty, the GDP impact has an even higher model agreement rate of no less than 86%, and only the Keynesian model E3ME shows potential positive GDP impacts of the Paris scenario.

Ultimately, what matters from a societal viewpoint is welfare. We compute a welfare measure that accounts for both aggregate GDP impacts and inequality. Specifically, we compute the equally distributed equivalent level of consumption (EDE)[41], which is the amount of consumption per capita that, if perfectly equally distributed, would yield the same welfare as the actual distribution[41]. It is based on an

isoelastic welfare function (where we use a parameter of inequality aversion of one, or that utility is logarithmic. With inequality, EDE is lowered and a higher aggregate GDP level would be required to achieve the same level of welfare. It is, therefore, a broader measure than GDP alone and combines the equity and efficiency implications of a policy. Figure 4 shows the welfare impact (in percentages) compared with the Reference scenario.

In Fig. 4, the top row shows the impact of climate damages on welfare in the Reference scenario. Welfare losses accrue over time unanimously across models, reaching 7.1% by the end of century as climate risks reduce economic growth and increase inequality. In the Paris scenario without transfers (second row), welfare decreases early on due to higher policy costs and a small increase in inequality, stabilizing around 5% by mid- and end-century. Although significant, this welfare loss is about one-quarter lower than in the Reference scenario without climate policy.

With compensatory transfers on an EPC basis (third row), welfare increases by 1.1% on average in the short term (2030). That is, the redistribution effect overcompensates for GDP loss from a welfare perspective; this shows the crucial welfare benefits of compensatory policies. As shown above, the benefits of compensatory measures vanish in the longer term, notably after 2050, when carbon revenues dry up due to emissions reaching net zero, while mitigation costs remain substantial. Nonetheless, welfare loss due to the climate policy is approximately halved by 2050, at about 2.5% loss, while in the long term the welfare gains from maintaining global warming <2 °C are still dominant. The results also vary by country (Supplementary Figs. 11–13). Model agreement is high, although somewhat less than in the previous scenarios because additional policy provisions compound uncertainties.

Discussion

The intergenerational implications of climate change have received great attention and, more recently, the distributional consequences of climate policies within countries have gained traction while long-term climate impacts are also becoming better understood. As the ambition and implementation gap in climate policies persists, their public acceptability and feasibility have become more important. We use a large and diverse ensemble of coupled climate–economy models to analyse the short- and long-term economic and distributional effects of climate impacts (Supplementary Fig. 14), climate policies and redistribution options. Among the eight models employed, we also find some model differences; overall, however, the model agreement on the sign of the effects is, in most country, scenario and year combinations, above 70%.

We find that stringent climate policies can generate important welfare benefits, because climate benefits pay off in terms of higher GDP and lower inequality. Moreover, we find substantial inequality reductions and welfare gains in the short term due to carbon revenue redistribution. These results and methods highlight the potential of coupled climate–energy–economy models to complement the standard assessment of transition pathways by adding the equity dimension within countries towards welfare-enhancing policy design. The relative robustness of the direction and order of magnitude of results across modelling paradigms provides a sound basis for policy recommendations towards effective, just and acceptable climate policies.

However, we identify mid-century as a potentially critical period: carbon revenues dry up, negative emissions technologies need to be financed and the climate benefits do not yet overcompensate for policy costs in most countries and models. This points to the need for the implementation of new welfare-enhancing policies that are designed for net-zero times and societally disruptive technologies such as negative emissions—beyond traditional instruments such as carbon pricing with transfers[42]. The need for adaptation and related investments would also increase this challenge, in particular for lower-income households, even though a precise quantification is still missing.

Several additional dimensions of equity are still missing in the modelling analysis and will play a potentially important role in future policy design and research. Notably, the distribution of wealth alongside income appears to be becoming ever more relevant[1]. The interaction of economic growth and income disparities could also lead to mutual aggravation of economic development and inequalities[43]. Global redistribution schemes, as well as wealth and capital taxation proposals. could help to alleviate these dynamics[44].

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-024-02151-7.

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Methods

This study consists of a six-scenario protocol, run by eight models that represent four different theoretical paradigms (Methods): detailed process-based IAMs (two models), cost–benefit IAMs (CB-IAMS; two models), CGE models (two models) and one macroeconometric model. The diversity in representing economic processes, in the solution concept and in technological, sectoral and regional resolution, is a primary added value of this modelling exercise, given the widely differing results available in the literature on the economics of decarbonization[45–47]. The representation of economic inequality varies across model type and characteristics: from parametric assumptions such as log-normal consumption in ReMIND, through income and consumption deciles and disaggregated consumption patterns in CGE models, to elasticity-based approaches based on deciles in CB-IAMs (see Supplementary Information A for a detailed description of participating models). A dataset collected for this study, which includes energy expenditures for housing and transportation by household deciles, is used by several participating models (Supplementary Information B).

Participating IAM

A total of eight state-of-the-art IAMs have been used in this study, with the notable focus of adding the distributional consideration of mitigation costs, potential redistribution of carbon revenues and climate impacts. This section shows the main characteristics of the models used and their key features in terms of the modelling of within-country inequalities.

While most of the models considered have a global focus, regional disaggregation varies. Moreover, when aggregating several countries to macroregions, income distribution becomes a mixture of distribution across and within countries. Because wage distributions, net consumer prices, income taxes and transfer schemes are designed at the country level, aggregation of income distributions is challenging. Notably, within-country distributional impacts could be dwarfed by between-country variations through economic growth, convergence or potential transfers between countries. Because here we wanted to isolate the within-country dimension of climate change and policy, we chose to focus on single countries that have been modelled in at least three IAMs, which resulted in a set of ten large countries (Brazil, Canada, China, France, India, Japan, Mexico, Russia, South Africa and the United States). All models have a time horizon of at least 2100, except for E3ME, which runs until 2050.

Scenario protocol

The scenario protocol includes a reference scenario (Reference) without new climate policies and a scenario compatible with the goals of the Paris Agreement (Paris), modelled through a constraint on cumulative CO_2 emissions (from 2020 to 2100) of 650 $GtCO_2$, consistent with the Paris goal of staying well below 2 °C (1.5 °C with one-third probability, or 1.7 °C with more than two-thirds probability, according to IPCC Sixth Assessment Group Working Group 1 (AR6 WG1). For robustness, we also explore a carbon budget of 1,150 $GtCO_2$ consistent with 2 °C of warming.

The carbon budget is reached using a uniform carbon price across sectors and countries, with no overshoot. The carbon price is also applied to non-CO_2 greenhouse gases when represented in the models. As a consequence, we consider neither regionally differentiated carbon pricing nor transfers (implicit or explicit) and trade of carbon permits[48]. Therefore, these scenarios serve as a benchmark in the absence of international transfers that could, however, greatly increase the redistributive power in developing countries. While politically unrealistic, this allows for the separation of within-country distribution from the discussion of between-country transfers, which might interact with within-country redistribution[15].

Orthogonal to the climate policy dimension, the models implemented two redistributive policies to the revenues generated by carbon price: climate dividends are recycled within each country neutrally or distributed back to households on an EPC basis. The resulting scenario matrix allows quantification of both the within-country distributional implications of carbon pricing and the effectiveness of compensatory policies. To isolate the within-country dimension of climate change and policy, we focus on the ten large countries mentioned above that are represented in at least three models in the ensemble. Finally, we exploit the large-model ensemble for uncertainty quantification: we quantify an index of model agreement as the share of models that concurs regarding the sign of the policy response.

Main scenario details. *Reference*. This is a counterfactual scenario with lenient or absent climate policies. Each model is left free to choose a business-as-usual policy or to implement current policies until the year 2030[49]. Your model's default Reference scenario (after 2020, no (further) climate policies: this can be a business-as-usual scenario if you don't implement current policies, or current policies until 2020 without further strengthening (preferred).

Paris. Until 2020, fixed to Reference. After 2020, implement a global uniform carbon price, with time profile at the discretion of models (for example, Hotelling rule growing at social discount rate or, if not available, fixed at 5% per annum). Target: peak carbon budget (2020–2100) of 650 $GtCO_2$ for CO_2 emissions, including both fossil fuel and industry and land use. The carbon budgets cannot be overshot—that is, no net-negative emissions are allowed. This design is consistent with the most recent practices in the modelling community[49,50]. Non-CO_2 gases are prices at the same CO_2 price using the global warming potential from AR6 WG1 (www.ercevolution.energy/ipcc-sixth-assessment-report/) or, alternatively, model default global warming potential if not available.

Paris with EPC. Same as Paris. Now, all domestic carbon revenues are redistributed to households on an EPC basis. Note that, in some cases, (small) negative emissions might imply negative transfers with resulting increases in inequality. We preclude this and set transfers in these years to zero.

Moreover, for robustness, we also implemented two scenarios based on a 1,150 $GtCO_2$ carbon budget (Weak Paris). That is, we have a total of five different policy scenarios. Moreover, we have a set of these five runs without climate impacts, and (where models do implement climate impacts) also with climate impacts, for a total of ten scenarios (Supplementary Fig. 2).

One important distinction of inequality measurement is income versus consumption or expenditure inequality. All teams were asked to focus on consumption inequality, where available, because inequality data in expenditures or overall consumption are more reliable than income inequality, notably in surveys from developing countries. This seems justifiable in the assessment of climate policy incidence because carbon pricing in particular affects energy and food expenditures. Nevertheless, impacts on factor prices, including wages, can lead to additional impacts across income distribution[36,51], which are considered in particular in the Macroeconometric/post-Keynesian and CGE models (E3ME, GEM-E3 and Imaclim).

Climate impact post-processing for models without climate impacts

In addition to the distributional effects of climate policies, the models feature inequality in climate risks. While three of the models in this study have their own distributional impact implementations (NICE, RICE50⁺ and ReMIND), for the other models we apply the impact function at the income decile level estimated in recent empirical work[32]. The damage function is based on the country-level degree of warming, taking into account heterogeneity across countries, and implies an income elasticity of damages of 0.6 on average. This damage function

suggests that damages are less than proportional to income, indicating modestly regressive impacts within countries.

We focus on the impacts of future temperature changes, controlling for precipitation, on decile income growth by estimating the following equations via ordinary least squares:

$$\Delta y_{iqt} = \Delta y_{iqt-1} + \beta_1^q \text{Temp}_{it} + \beta_2^q \text{Temp}_{it}^2$$
$$+ \gamma_1^q \text{Temp}_{it} y_{it-1} + \gamma_2^q \text{Temp}_{it}^2 y_{it-1}$$
$$+ \pi \mathbf{P}'_{it} + \alpha_i + \lambda_t + \vartheta_i t + \varepsilon_{iqt}$$

where y_{iqt} is the logarithm of income of decile $q = 1, ..., 10$ in country i in year t; Temp is average annual temperature; y_{it-1} is the log of per-capita GDP of country i over the sample period; $\mathbf{P}'_{it}$ is a vector of cumulative annual precipitation variables (linear and quadratic, and respective interactions with y_{it-1}, as for temperature); α_i are country fixed effects; λ_t are common time fixed effects; ϑ_i is a linear time–trends by country; and ε_{iqt} is an error term assumed to be orthogonal to temperature conditional on the controls. We thus estimate separate sets of coefficients for each income decile. The damage function is then defined by a change in decile-level income, specified as

$$\delta_{iqt} = f_q\left(\text{Temp}_{it}, y_{it-1}^{impacts}\right) - f_q\left(\text{Temp}_0, y_{it-1}^{Reference}\right)$$

where f_q is the estimated function defined above, and y_{it-1}^s is GDP per capita in country i either under the Reference scenario without climate impacts (Reference) or under Reference with impacts ($s = impacts$). This specification follows from the equation above, with climate impacts depending on the country's GDP which is, in turn, also impacted over time by the realized temperature changes.

The income of decile q in year t thus evolves according to

$$y_{iqt} = (1 + g_{iqt} + \delta_{iqt})y_{iqt-1}$$

where g_{iqt} is the counterfactual growth rate under no climate impacts, which is taken from the submitted GDP and deciles computed by the different IAMs. To obtain country-level projections of future temperatures given an emission path, we first compute the global average surface temperature anomaly as a function of cumulative emissions.

We convert cumulative emissions to global temperature increase using the estimated transient climate response to cumulative emissions of carbon dioxide of 0.44 °C per 1,000 GtCO$_2$. We then downscale global average surface temperature to the country level according to the linear downscaling procedure based on the CMIP6 database[32] (Supplementary Fig. 14).

Reporting summary
Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability
All scenario data and figure data are available via GitHub at https://github.com/JohannesEmm/navigate_inequality_mip.

Code availability
All code is available via GitHub at https://github.com/JohannesEmm/navigate_inequality_mip.

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Author contributions
J.E. and M.T. designed the research with all coauthors. J.E. carried out analysis of the modelling results, created figures and wrote the draft of the paper. S.D., S. Feindt, C. Grottera and D.M. compiled the national decile-based detailed datasets based on household surveys. M.G. implemented the climate impact post-processing tool. S.Z. and S. Fujimori provided AIM data. P.A. provided RICE50$^+$ data. I.C., D.F. and P.F. provided GEM-E3 data. A.M. and C. Guivarch provided Imaclim data. F.P., N.T. and B.S. provided ReMIND data. Y.S. and F.N. provided E3ME data. G.M., Y.Z. and J.E. provided WITCH data. F.D., S. Feindt, U.K., A.M. and M.Y.-B. provided NICE data. S. Feindt, C. Grottera, E.K., A.M., D.M., F.P., B.S., M.T., T.V., M.Y.-B. and S.Z. provided extensive contributions to the development of the narrative. All authors contributed to the discussion and interpretation of results.

Competing interests
The authors declare no competing interests.

Additional information
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Software and code

Policy information about availability of computer code

Data collection	The data was generated by eight IAM teams.
Data analysis	The data was analyzed in R 4.2.0.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

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All raw data and analysis code will be made available at the date of the publication in a zenodo repository.

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Reporting on sex and gender	no gender aspects were in the data.
Population characteristics	no human participants were involved.
Recruitment	n/a.
Ethics oversight	n/a.

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Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	IAM model runs were analyzed in several scenarios with respect to their inequality implications.
Research sample	IAM model runs.
Sampling strategy	All data was used.
Data collection	The data was generated by eight IAM teams.
Timing and spatial scale	n.a.
Data exclusions	n.a.
Reproducibility	All tables and figures can be reproduced using a public repository containing all data and code.
Randomization	n.a.
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Methods

n/a	Involved in the study
☒ ☐	ChIP-seq
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