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BRIEF COMMUNICATION

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Focusing on differences across scenarios could lead to bad adaptation policy advice

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As development and adaptation are closely intertwined, assessing the benefits of adaptation by focusing only on how it reduces climate impacts could lead to misleading policy advice. In some cases, trying to minimize climate impacts could lead to inferior outcomes. It is preferable to explore how policies influence the absolute level of metrics of interest in scenarios with climate change rather than to focus on how they influence incremental climate impacts.

Research on the evaluation of adaptation policies has traditionally been organized around the analysis of differences across scenarios. These scenarios represent uncertainties that pertain to future climate change[1] and socio-economic trends[2]. Climate change impacts are usually measured by comparing scenarios with and without (or between low and high) climate change[3–6] (for example, by the change in gross domestic product (GDP) between the scenario with and that without climate change (δGDP)); and the benefits of adaptation policies are measured by ΔGDP, that is, by how climate change impacts vary between a no interventions scenario and a scenario with interventions (Fig. 1). For example, one study evaluated the performance of alternative adaptation policies for Nigerien agriculture by comparing how changes in socio-economic indicators, which included GDP and poverty, varied with and without interventions[7]. Studies of flood risk management sometimes use a baseline no-policy no-climate change scenario to evaluate the impacts of alternative measures[8,9].

The approach that focuses on the deltas to measure the expected performance of a policy is paramount in many studies and official frameworks, and comes from a long tradition of project evaluation by marginal cost–benefit analysis[10–13]. One critical assumption behind this approach is that the policy under consideration affects only the vulnerability to climate change, but not the baseline trends—that is, socio-economic factors that influence society's welfare and adaptive capacity (in the 'baseline trends + policy' scenario in Fig. 1). Therefore, the approach assumes that only the perturbation due to the marginal change needs to be considered. In other words, it assumes that there is a separability of policy impacts across scenarios.

This assumption might hold in 'pure' climate adaptation interventions, that is, interventions that would not be implemented in the absence of climate change and have the unique objective to reduce climate change vulnerability, such as the heightening of dikes in a coastal city. However, many policy proposals to reduce climate change impacts are often not pure climate adaptation interventions, but rather a mix of adaptation and development (for example, to improve healthcare systems, rural accessibility and financial inclusion)[14]. These interventions affect not only people's vulnerability to climate change, but also their situation in the absence of climate change[14–16]. Therefore, to look only at the delta as a measure of benefits and disregard the impacts to the baseline outcomes could lead analysts to provide wrong advice as they miss the full picture of a policy's impacts on people's well-being. We illustrate this point by revisiting previously published simulations[14].

Using a microsimulation model to explore the implications of climate change for poverty, in 2017 we compared hundreds of socio-economic scenarios with climate change impacts and concluded that rapid development could reduce the number of people pushed into extreme poverty due to climate change by more than 100 million globally[14]. Without rapid and inclusive development, a newer study estimates that climate change impacts could push as many as 131.5 million into poverty[17]. In general, better baseline outcomes (such as improved health care systems, reduced poverty and well-functioning institutions) were found to reduce vulnerability to climate change. Therefore, there is a strong synergy between development policies and climate change adaptation, and what is good for one is good for the other. However, this is not the case for all development policies and all adaptation interventions in all contexts: when ranking policies in terms of their benefits for climate change adaptation, one has to be careful about how benefits are measured.

Going into the details of the hundreds of scenarios we ran at the country level (see Methods for details), we found that policies that minimized climate change impacts (measured by the delta, that is, the number of people falling into extreme poverty due to climate change) were not necessarily the most desirable from a development perspective. Similarly, some policies that deliver substantial development benefits may have negative implications for climate change vulnerability. For example, we found that in several countries, higher-income redistribution through universal cash transfers would increase the number of people who fall into poverty because of climate change. For instance, in Bolivia climate change would, on average, push 49,000 people to extreme poverty in the presence of a strong redistribution system, whereas with a low redistribution the number is only around 39,000. Policy design based on this delta indicator would lead countries like Bolivia to choose lower-income redistribution, as it reduces climate change impacts on poverty.

This reasoning, however, is misleading if we look at the absolute outcomes (that is, the absolute number of poor people) in scenarios with climate change that compare low and high redistribution cases. When climate change impacts are considered for Bolivia in 2030, on average around 695,000 people will live in extreme poverty when the redistribution is low, whereas the number is only around 156,000 in high redistribution scenarios (in spite of the larger impacts of climate change). The same policy advice holds true with other indicators. For instance, the average income of Bolivians in the bottom 20% of the economy will be around 48 and 70 US dollars per month under the low and high redistribution scenarios, respectively. Therefore, a high redistribution leads to a much better outcome with 77% fewer poor people and a 46% increase in income of

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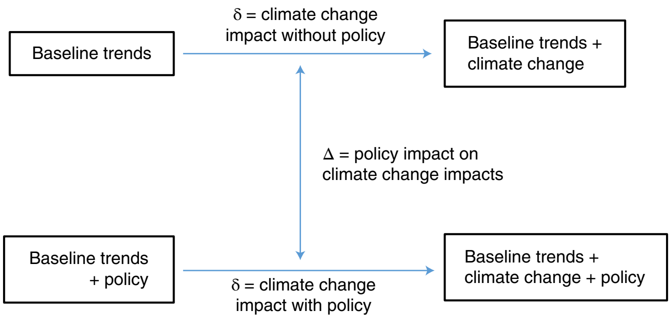

Fig. 1 | Schematic representation of how scenarios are involved to assess the impact of a climate adaptation policy. Each box represents the absolute value of various metrics, such as GDP or poverty or welfare, under the corresponding scenario.

the bottom 20%, even though it increases Bolivia's poverty vulnerability to climate change by 33% (as measured by the delta of poor people). The explanation behind this is that income redistribution moves a lot of people out of extreme poverty, but some people are only lifted just above the poverty line, so that when climate change hits, a larger number of people fall back into poverty. In an extreme case, a policy that would put the entire population in poverty would ensure that nobody falls in poverty due to climate change.

Using a global perspective, we found that the development policies in many countries could have opposing impacts with better baseline outcomes but worsen climate vulnerability (Fig. 2). The opposing impacts of redistribution policies to poverty eradication and climate change adaptation (when measured by the delta of people falling in extreme poverty due to climate change) are observed in 43 countries in our scenarios (Fig. 2a). We found similar opposing impacts in 19, 10 and 25 countries for policies that lead to higher productivity growth in the agriculture (Fig. 2b), manufacturing (Fig. 2c) and service sectors (Fig. 2d), respectively. These results demonstrate that vulnerability to climate change should not be assessed separately from broader development indicators (usually 'hidden' in the baseline).

In sum, to compare the scenario of interest (with climate change and policies) with a counterfactual no or low climate change scenario is misleading as soon as development and adaptation are influenced by the same policies and instruments. As many adaptation policies can have as much impact on the no-climate-change counterfactual (for example, 'baseline' scenarios) as on the impacts of climate change[14,18,19], reducing the impacts of climate change can have a net negative effect when the full response is taken into account.

Such misleading results can be found not only in the modelling world[6–8], but also in multiple qualitative case studies. In many coastal areas and small islands, resettlement would certainly minimize exposure and vulnerability to sea level rise, but it could also lead to many adverse outcomes for 'baseline' variables, such as unemployment, food insecurity and social marginalization[20]. Drought adaptation strategies in Afar, Ethiopia, which mainly focused on reducing climate vulnerability through investment in irrigation and transition to non-pastoral livelihood, also worsened the 'baseline' outcomes as people responded by migrating to other areas[21]. Such unintended consequences exemplify the phenomena of negative externalities and decreased adaptive capacity incurred by adaptation policies, both of which are symptoms of maladaptation[22].

The lack of separability across scenarios was well noted when the SSP–SPA (SSP, shared socio-economic pathways; SPA, shared climate policy assumptions) framework was created[23], but with little discussion on how the resulting scenarios would be used for

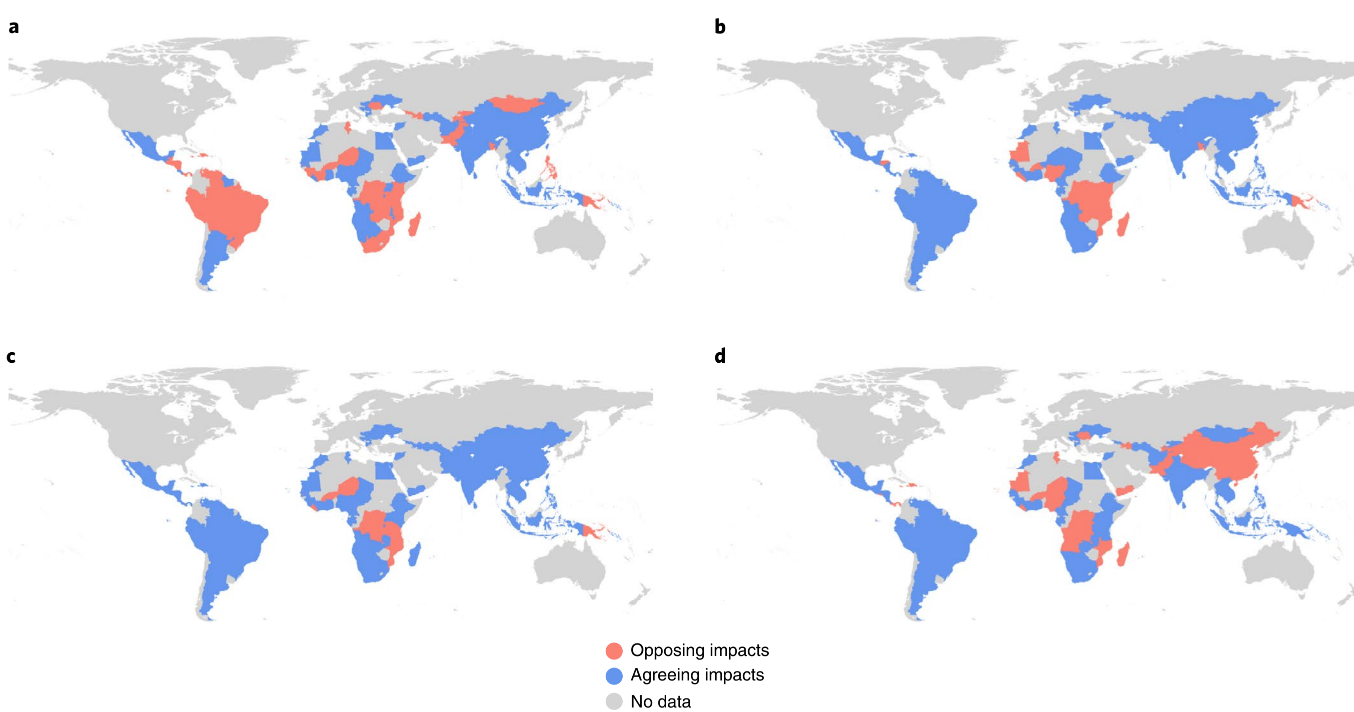

Fig. 2 | Agreeing and opposing impacts of various development variables. Agreeing impacts imply that progress for the corresponding development variable leads to better baseline outcomes (measured by the absolute number of poor people) and lower vulnerability (measured by the delta of poor people), whereas opposing impacts imply that progress leads to better baseline outcomes, but higher vulnerability. **a–d**, The development variables are income redistribution (**a**), agriculture productivity growth (**b**), manufacturing productivity growth (**c**) and service sector productivity growth (**d**).

adaptation policy advice. What is the solution to assessing adaptation policies? Policies should be analysed by considering only the outcome when climate change is accounted for (right boxes in Fig. 1). Coming back to our Bolivia example, this means focusing on the absolute number of people living in poverty in scenarios with climate change, the main uncertainties that pertain to these numbers and the policies that can reduce them (be they adaptation or development policies). A scenario without climate change or looking at differences across climate scenarios plays no role in such an analysis. Put differently, the solution is to carefully select an appropriate objective and to focus on this objective across various realistic scenarios[24], taking into account climate change but without considering climate impacts in isolation (one may call this 'mainstreaming climate change in development study').

It is well-known that mainstreaming climate change in development policies is needed because poorly designed development can be bad for climate vulnerability[14,18,19], for example, through a rapid urbanization in flood zones or an increase in non-sustainable use of resources. Here we emphasize another reason to mainstream climate change into development policies: the risk that poorly designed adaptation could be bad for development and that silos within governments—with one agency solely in charge of climate change adaptation, for instance—make it impossible to capture the synergies between resilience and development. The rationale for mainstreaming becomes even more important as and where efforts for (and funding towards) climate change adaptation increase and become large enough to become transformational and influence development pathways.

Online content

Any methods, additional references, Nature Research 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/s41558-021-01030-9.

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Methods

Microsimulation. Our analysis builds on the microsimulation model originally reported in Hallegatte and Rozenberg[14], which looks at climate change impacts on poverty. The population in each country is represented by a set of representative households with information on labour participation in different sectors (agriculture, manufacture and service), education, household income and representative 'weights' to indicate the representativeness of each household in the economy.

The model operates in two stages. In the first stage, for each country we generated 1,200 'baseline' 2030 scenarios using Latin hypercube sampling in which we combined different values for various drivers of socio-economic changes, which included demographic (population growth, age structure and education attainment) and economic (sectoral share of employment) structures. To model the distribution of future households, we adjusted their representative weights to match future demographic and structural projections. Then, we adjusted each household's income in accordance with the sectoral productivity growth and skill premium. The macrolevel changes in socio-economic characteristics were calibrated based on the SSPs for demographic changes[2,25], and a range of historical changes for other drivers.

In the second stage, we modelled climate change impacts on households through five channels: increase in food prices, impact on farmers' income, increase in disease prevalence, decrease in labour productivity and intensification of natural disasters. The impact was modelled directly through the decrease of future households' income. We then calculated aggregate macroeconomic indicators, such as poverty headcount (number of people with income below 1.90 US dollars per day), average income growth and income growth of the bottom 40%.

Identification of opposing and agreeing impacts. Using the simulation results from Hallegatte and Rozenberg[14], we assessed how different drivers—those accounted in the first stage of the model—affect extreme poverty in the baseline scenarios (that is, scenarios without climate change) and climate change vulnerability (that is, additional people pushed into extreme poverty due to climate change). We look at four drivers of development: redistribution through universal cash transfers and productivity growth in three economic sectors. We performed the analysis for each country independently.

Our analysis aimed to identifying the (dis)agreement of the direction of impacts of good development to baseline outcomes and climate vulnerability. For each development variable, we split the 1,200 scenarios into two groups: those in which the level of the development variable is higher than the median of the entire range of that variable ('good' development scenarios), and those in which the level is lower than the median ('bad' development scenarios). We then compared the distribution of the baseline outcome and climate vulnerability between the two groups of scenarios. We record whether the impacts of good development to baseline outcomes and climate vulnerability are in agreement or in opposition. Agreeing impacts imply that good development scenarios lead to better baseline outcomes and lower vulnerability, whereas opposing impacts imply that progress leads to better baseline outcomes but higher vulnerability. We ensured the statistical significance by calculating Student's *t*-test. We record only countries and development variables for which the difference in outcomes from good and bad development scenarios are statistically significant ($P < 0.05$).

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

Data availability

The simulation results data that support the analysis in and findings of this study can be accessed at https://github.com/bramkaarga/poverty_analysis. Source data are provided with this paper.

Code availability

The code behind the analysis and the code to generate Fig. 2 can be accessed at https://github.com/bramkaarga/poverty_analysis.

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Author contributions

S.H. conceived the study and designed it with B.A.J. and J.R. jointly. J.R. conducted the simulation experimentation. B.A.J. performed the analysis and wrote an initial draft of the manuscript. All the authors contributed to the further writing and editing of the manuscript as well as responding to referees.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41558-021-01030-9.

Correspondence and requests for materials should be addressed to B.A.J.

Peer review information *Nature Climate Change* thanks Francis Dennig and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

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Research sample	N/A
Sampling strategy	N/A
Data collection	The study makes use of simulation results from an article published in Nature Climate Change (doi.org/10.1038/nclimate3253).
Timing and spatial scale	N/A
Data exclusions	N/A
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☐	☐	Any other significant area

Experiments of concern

Does the work involve any of these experiments of concern:

No	Yes	
☐	☐	Demonstrate how to render a vaccine ineffective
☐	☐	Confer resistance to therapeutically useful antibiotics or antiviral agents
☐	☐	Enhance the virulence of a pathogen or render a nonpathogen virulent
☐	☐	Increase transmissibility of a pathogen
☐	☐	Alter the host range of a pathogen
☐	☐	Enable evasion of diagnostic/detection modalities
☐	☐	Enable the weaponization of a biological agent or toxin
☐	☐	Any other potentially harmful combination of experiments and agents

ChIP-seq

Data deposition

☐ Confirm that both raw and final processed data have been deposited in a public database such as GEO

☐ Confirm that you have deposited or provided access to graph files (e.g. BED files) for the called peaks.

Data access links *May remain private before publication.*	*For "Initial submission" or "Revised version" documents, provide reviewer access links. For your "Final submission" document, provide a link to the deposited data.*
Files in database submission	*Provide a list of all files available in the database submission.*
Genome browser session (e.g. UCSC	*Provide a link to an anonymized genome browser session for "Initial submission" and "Revised version" documents only, to enable peer review. Write "no longer applicable" for "Final submission" documents.*

Methodology

Replicates	*Describe the experimental replicates, specifying number, type and replicate agreement.*
Sequencing depth	*Describe the sequencing depth for each experiment, providing the total number of reads, uniquely mapped reads, length of reads and whether they were paired- or single-end.*
Antibodies	*Describe the antibodies used for the ChIP-seq experiments; as applicable, provide supplier name, catalog number, clone name, and lot number.*
Peak calling parameters	*Specify the command line program and parameters used for read mapping and peak calling, including the ChIP, control and index files used.*
Data quality	*Describe the methods used to ensure data quality in full detail, including how many peaks are at FDR 5% and above 5-fold enrichment.*
Software	*Describe the software used to collect and analyze the ChIP-seq data. For custom code that has been deposited into a community repository, provide accession details.*

Flow Cytometry

Plots

Confirm that:

☐ The axis labels state the marker and fluorochrome used (e.g. CD4-FITC).

☐ The axis scales are clearly visible. Include numbers along axes only for bottom left plot of group (a 'group' is an analysis of identical markers).

☐ All plots are contour plots with outliers or pseudocolor plots.

☐ A numerical value for number of cells or percentage (with statistics) is provided.

Methodology

Sample preparation	*Describe the sample preparation, detailing the biological source of the cells and any tissue processing steps used.*
Instrument	*Identify the instrument used for data collection, specifying make and model number.*

Software	*Describe the software used to collect and analyze the flow cytometry data. For custom code that has been deposited into a community repository, provide accession details.*
Cell population abundance	*Describe the abundance of the relevant cell populations within post-sort fractions, providing details on the purity of the samples and how it was determined.*
Gating strategy	*Describe the gating strategy used for all relevant experiments, specifying the preliminary FSC/SSC gates of the starting cell population, indicating where boundaries between "positive" and "negative" staining cell populations are defined.*

☐ Tick this box to confirm that a figure exemplifying the gating strategy is provided in the Supplementary Information.

Magnetic resonance imaging

Experimental design

Design type	*Indicate task or resting state; event-related or block design.*
Design specifications	*Specify the number of blocks, trials or experimental units per session and/or subject, and specify the length of each trial or block (if trials are blocked) and interval between trials.*
Behavioral performance measures	*State number and/or type of variables recorded (e.g. correct button press, response time) and what statistics were used to establish that the subjects were performing the task as expected (e.g. mean, range, and/or standard deviation across subjects).*

Acquisition

Imaging type(s)	*Specify: functional, structural, diffusion, perfusion.*
Field strength	*Specify in Tesla*
Sequence & imaging parameters	*Specify the pulse sequence type (gradient echo, spin echo, etc.), imaging type (EPI, spiral, etc.), field of view, matrix size, slice thickness, orientation and TE/TR/flip angle.*
Area of acquisition	*State whether a whole brain scan was used OR define the area of acquisition, describing how the region was determined.*

Diffusion MRI ☐ Used ☐ Not used

Preprocessing

Preprocessing software	*Provide detail on software version and revision number and on specific parameters (model/functions, brain extraction, segmentation, smoothing kernel size, etc.).*
Normalization	*If data were normalized/standardized, describe the approach(es): specify linear or non-linear and define image types used for transformation OR indicate that data were not normalized and explain rationale for lack of normalization.*
Normalization template	*Describe the template used for normalization/transformation, specifying subject space or group standardized space (e.g. original Talairach, MNI305, ICBM152) OR indicate that the data were not normalized.*
Noise and artifact removal	*Describe your procedure(s) for artifact and structured noise removal, specifying motion parameters, tissue signals and physiological signals (heart rate, respiration).*
Volume censoring	*Define your software and/or method and criteria for volume censoring, and state the extent of such censoring.*

Statistical modeling & inference

Model type and settings	*Specify type (mass univariate, multivariate, RSA, predictive, etc.) and describe essential details of the model at the first and second levels (e.g. fixed, random or mixed effects; drift or auto-correlation).*
Effect(s) tested	*Define precise effect in terms of the task or stimulus conditions instead of psychological concepts and indicate whether ANOVA or factorial designs were used.*

Specify type of analysis: ☐ Whole brain ☐ ROI-based ☐ Both

Statistic type for inference (See Eklund et al. 2016	*Specify voxel-wise or cluster-wise and report all relevant parameters for cluster-wise methods.*
Correction	*Describe the type of correction and how it is obtained for multiple comparisons (e.g. FWE, FDR, permutation or Monte Carlo).*

Models & analysis

n/a	Involved in the study
☐	☐ Functional and/or effective connectivity
☐	☐ Graph analysis
☐	☐ Multivariate modeling or predictive analysis

Functional and/or effective connectivity	*Report the measures of dependence used and the model details (e.g. Pearson correlation, partial correlation, mutual information).*
Graph analysis	*Report the dependent variable and connectivity measure, specifying weighted graph or binarized graph, subject- or group-level, and the global and/or node summaries used (e.g. clustering coefficient, efficiency, etc.).*
Multivariate modeling and predictive analysis	*Specify independent variables, features extraction and dimension reduction, model, training and evaluation metrics.*