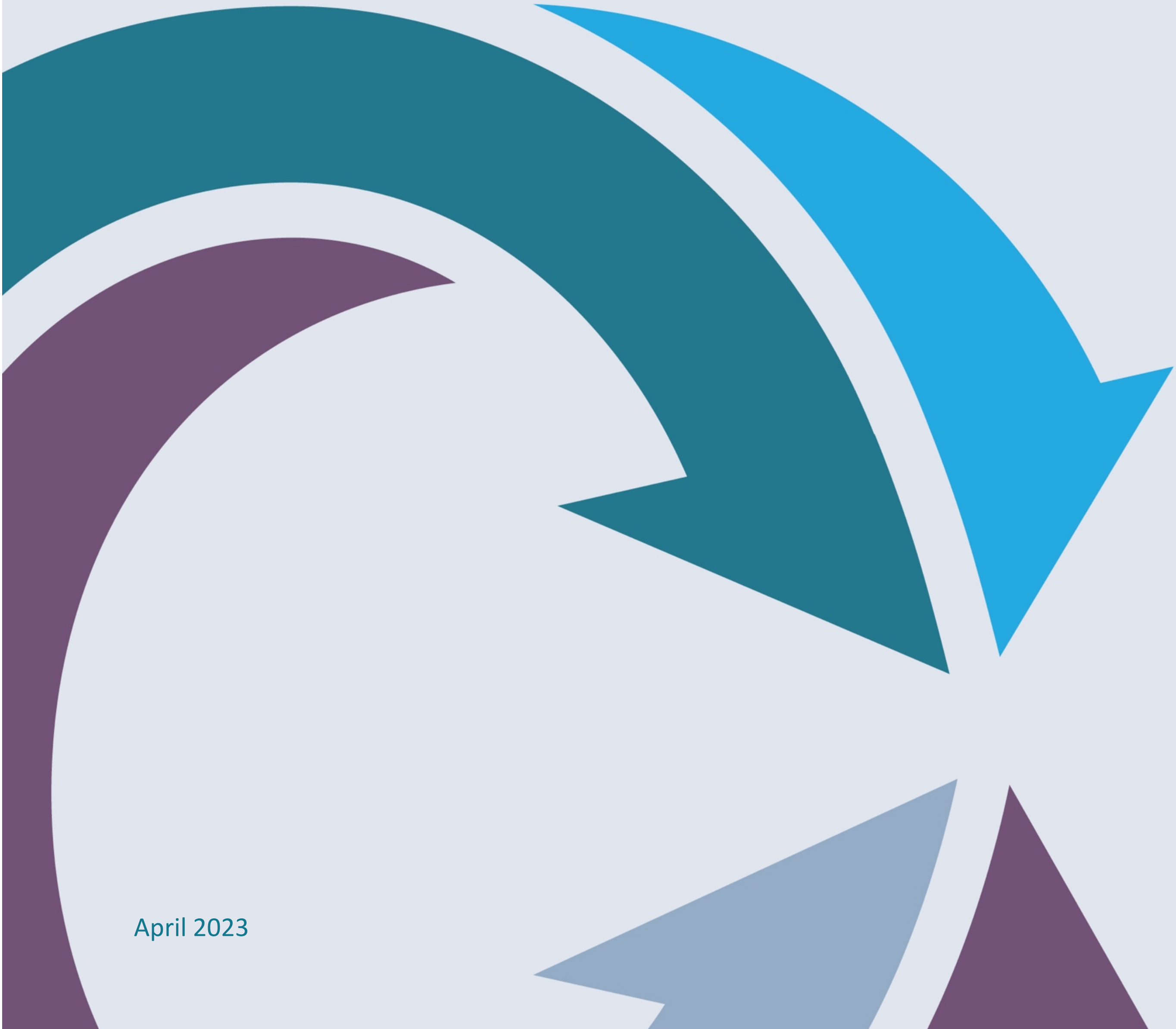
CHIPS
Climate Change Impacts and Policies
in Heterogeneous Societies

Integrated assessment of distributional effects of climate impacts and climate policies in the context of the SDGs

Deliverable 5.2 report



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Integrated assessment of distributional effects of climate impacts and climate policies in the context of the SDGs

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Abstract

Analyses of the distributional consequences of climate policy so far generally fail to acknowledge the reason why this policy is implemented, namely climate impacts with its own regressive effects. This report improves on that and applies the integrated assessment models REMIND and NICE to provide an integrated analysis of distributional consequences of mitigation and impacts under different climate scenarios, relying on the improvements of these models in the course of the CHIPS project. The analysis highlights the benefits of climate policy in terms of reduced long-term costs of impacts as well as negative distributional consequences of impacts. It analyzes different redistribution schemes (national and international) of carbon tax revenues to alleviate near-term increasing inequality due to the burden of climate policy and shows the great potential of these schemes to alleviate poverty. Beyond the global picture it also looks at regions and countries, as the consequences depend strongly on the vulnerability of a given country to climate damages, its reliance on fossil resources and its state of development. The role of other policies beyond pure carbon taxation is analyzed with the example of behavioral changes in the transport sector.

1. Introduction

During the course of the CHIPS project climate change impacts as well as rising tensions between ambitious climate policy and the need to address near-term crises like the COVID pandemic and the consequences of the Russian invasion in Ukraine have brought the challenges of existing inequity and further inequality through distributional consequences to the forefront of the political and societal debate. On the international level the loss-and-damage debate at the last COP brought about questions of quantifying climate change impacts for different countries and groups. National debates and protests around unequal burdens from rising energy prices and costs of living brought about questions of redistribution. It is clear that research is in high demand which quantifies the differential impacts of climate change and investigates equitable transformation pathways taking into account the need for ambitious climate policy to avoid long-term damages (and their distributional consequences) as well as addressing the need to alleviate near-term burdens from climate policy. The CHIPS project contributes to this need in multiple ways. Detailed analyses of policies on the national and regional level using microsimulation tools focus on carbon pricing as a climate policy instrument and redistribution options to alleviate distributional consequences (Labandeira et al. 2022, Feindt et al. 2021, see also Deliverables 3.1 and 3.2). This is complemented by the use of surveys to better understand the motivation and drivers of protest movements with the aim to understand how policies should be designed and communicated to receive stronger support (Ewald et al. 2022, see also Deliverable 3.3).

A large gap is the more robust quantification of the distributional impacts of climate change. A literature review currently still under way indicates the very scattered and mostly qualitative level of knowledge in this area (Méjean et al., in preparation). In particular, for integrated assessment modeling with a fairly high level of aggregation, there is currently no basis to quantify how aggregated climate change impacts on output should be distributed over different income groups, hampering robust policy advice. CHIPS developed two novel approaches to improve this quantitative basis (Deliverable 2.1).

This deliverable builds on these developments and improved understandings and focuses on integrating both the climate policy and the climate impact side with their distributional effects in the context of the analysis of future transformation pathways. It presents results from the application of two IAMs, the cost-benefit model NICE and the process-based model REMIND. The models and the modeling setup are introduced in Section 2. Section 3 presents results on transformation pathways including inequality, while Section 4 links to the broader framework of the Sustainable Development Goals. Finally, remaining challenges and avenues for future research are discussed in Section 5.

2. The models

The application of two complementary IAMs allows us to compare results from two different approaches to model inequality as well as harness each model's strength and focus. In the following we provide short overviews of each model, with key features summarized in Table 1. For further details in particular on the implementation of the distributional effects we also refer to Deliverable 4.2.

Feature	NICE	Remind
Type	Global cost-benefit IAM without sectoral detail	Global cost-benefit IAM without sectoral detail
Time Horizon	2000–2100, 1- to 5-year time steps	2005-2100, 5- to 10-year time steps
Regions	180 countries (newest version)	12, individual countries: USA, India, Japan, China, Russia)
Socioeconomic scenario	SSP2	SSP2
Discount rate	Endogenous	3%
Mitigation	Abatement cost curve relating cost of emission reduction to emissions control rate + backstop technology (emissions free, high cost) Emissions are driven by GDP	Carbon tax adjusted to achieve carbon budget constraint – drives changes in energy system (energy sources and technologies), allowing for friction in the adjustment, emission arise from the energy system
Damage	Aggregate output loss based on Nordhaus (2018)	Aggregate output loss based on Kalkuhl & Wenz (2020)
Climate	FAIR model as endogenous climate model	Soft-coupled to MAGICC, statistical downscaling of global mean temperature path to regional temperature change
Inequality	Consumption quintiles/deciles for each region, calibrated to match the SSP-based projections by Rao et al. (2019) and affected by mitigation costs, climate damages and redistribution of tax revenue	Log-normal distribution, matching the SSP-based projections by Rao et al. (2019) and affected by changes in energy expenditure, climate damages and redistribution of tax revenue

Table 1: Overview of important model features

The REMIND model

The REMIND model is a global, process-based integrated assessment model, linking a detailed representation of the energy system with a macroeconomic model and a reduced form climate model. It covers 12 large world regions] , including 5 individual countries (China, India, Japan, USA, Russia) (see Figure 1). The main purpose of REMIND is the analysis of transformation pathways under different assumptions about future socioeconomic and technological development and different climate policy scenarios. The socioeconomic scenarios are taken from the Shared Socioeconomic Pathways (SSPs, Riahi et al. 2017), with SSP2 as the middle of the road scenario. Climate policy scenarios build on a budget for cumulative CO2 emissions from 2020 to 2100. A carbon price path is adjusted iteratively between REMIND iterations until the carbon budget is met. The carbon price is regionally differentiated (based on GDP per capita) and converges until 2050, after which it increases further linearly. Climate change damages are implemented as aggregate damage functions reducing regional GDP. The standard damage function is taken from Kalkuhl & Wenz (2020) and relates changes in GDP growth to annual changes in regional mean temperature. Damages are internalized in a soft-coupled approach via the social cost of carbon (Schultes et al. 2021) (see further details in Deliverable D2.2). Given the large uncertainties and gaps in the damage estimates, which likely lead to an underestimation of the damages in the standard damage functions (see Piontek et al. (2021) and Rising et al. (2022) for detailed discussions), REMIND is typically applied in a least-total cost approach, combining near term damages with a long-term climate target.

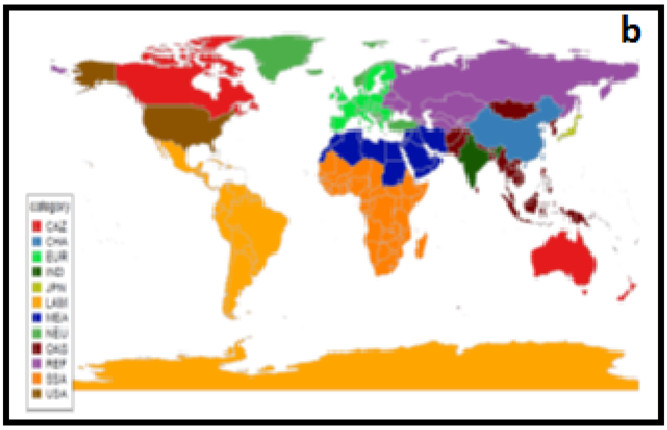

Figure 1: *Regions in the REMIND model.*

Further details on the REMIND model can be found in Baumstark et al. (2021). The model is open source and available at https://github.com/remindmodel/remind.

Its newly implemented inequality module is described in detail in Deliverable 4.2. It uses a log-normal assumption to describe subregional distribution of consumption, based on projections of the Gini index along the SSPs (Rao et al. 2019). This distribution changes due to three factors. The first are changes in energy expenditure under different climate policy scenarios, most important in the near term under stringent mitigation assumptions. Income elasticities of energy expenditures are estimated empirically as a function of income levels (Soergel et al. 2021a). The second factor affecting inequality are climate change damages. So far there is no robust quantification of their income elasticity available (though work is underway to estimate them based on empirical approaches, see Section 3 below), but it is most likely between 0 and 1 (Méjean et al., in prep.). We therefore use a value of 0.5 as our central estimate, but vary this in a sensitivity exercise. As damages increase with temperature they have a more long-term effect on inequality. Finally, carbon tax revenues are redistributed to households. In the least-total cost mode they consist of the components from the guardrail tax determined by the long-term climate target and the contribution by the social cost of carbon, which is increased by the assumption of inequality (Anthoff & Emmerling 2019). This can be redistributed distributionally neutral (proportional to income) or in a progressive way (equal per capita). As emissions are reduced over time, revenues are mostly available in the near term. Note that we limit redistribution to directly counteract negative effects of climate change mitigation and damages. Redistribution of carbon tax revenues cannot be used to improve inequality beyond the baseline level. This follows the philosophy that climate policy is not used to address other societal challenges.

The NICE model

The Nested Inequalities Climate Economy (NICE) model is a global but regionally disaggregated cost-benefit analysis integrated assessment model. It includes a macroeconomic component and a reduced form climate component that are linked. NICE is a modification of the Regional Integrated Climate Economy (RICE) model developed by Nordhaus (Nordhaus 2010).

The initial NICE model divided the world into 12 large world regions and it extended RICE by disaggregating regional consumption into five socio-economic groups with consumption levels reflecting the current distribution of consumption within the regions (Dennig et al. 2015). So as not to affect any of the aggregate economic variables (investment, capital, output, etc.), this was done by splitting average regional consumption into five quintiles after aggregate savings have been determined. NICE has recently been updated to divide the world into 180 countries that are themselves split into ten income groups or deciles.

The main purpose of NICE compared to RICE and similar models is to study the redistributive impacts of climate policy. In particular, it can be used to study the effects of redistributing the revenues of a carbon tax on inequality, poverty and optimal policy. A first step in that direction was Budolfson et al. (2021).

The NICE model is an optimizing cost-benefit analysis IAM that can be used to find optimal mitigation paths (under some constraints). In that case, it maximizes an inequality-sensitive intertemporal social welfare function (see Deliverable 5.1). But it can also be used as a simulation tool to explore the welfare consequences of specific policy scenarios. In our most recent versions, the NICE model has been taken to match a specific socioeconomic scenario, which is the “middle of the road” scenario (SSP2) taken from the Shared Socioeconomic Pathways (SSPs, Riahi et al. 2017). Country-level distributions of consumption are calibrated to match projections of the Gini index along the SSPs (Rao et al. 2019). Inequality and poverty are recomputed after redistribution of the carbon tax by assuming that consumption is distributed according to a log-normal distribution. Budolfson et al. (2021) considered a lump-sum redistribution at the regional level. Below, we explore other possibilities.

Climate damages are included using the most recent version of the standard damage function developed by Nordhaus (Nordhaus 2018). We however change the climate module of the DICE model by Nordhaus and use the FAIR model that better matches the results of more complex climate models (Leach et al. 2021). We obtain country-level temperature increases from GHG emissions.

Further details on the NICE model can be found in Dennig et al. (2015) and Budolfson et al. (2021). An open-source version of the model (with the 12 RICE regions) is available at https://github.com/Environment-Research/revenue_recycling.

Scenario design

As the focus of the analysis is on the distributional effects, the core set of policy scenarios is kept fairly small, guided by the Paris agreement:

- Baseline: a scenario without ambitious climate policy
    - REMIND: REMIND uses a scenario covering the currently already implemented climate policies, but no further ambitions, the resulting temperature pathway leads to about 3° global mean temperature increase above pre-industrial level. The baseline includes climate impacts.
    - NICE: The baseline is a scenario without any carbon tax.
- “Below 2°”: a scenario with an emission budget keeping warming below 2° above pre-industrial level
- “1.5°”: an emission budget leading to 1.5° warming by 2100, with an overshoot in the medium term.

Different variations of these scenarios are captured by the two models. Both capture redistribution of carbon tax revenues.

- REMIND differentiates between a neutral redistribution (proportional to income) and a progressive redistribution (equal per capita), limited to within-region redistribution.
- NICE focuses its analysis on this aspect and differentiates four cases:
    - within-region lump-sum redistribution (“Regional” scheme);
    - lump-sum redistribution at the global level (“Global” scheme);
    - Lump-sum, within region redistribution, but proportional to the damages faced by the region (“Proportional to damages” scheme);
    - Global lump-sum redistribution but only to poor regions (“Poor countries” scheme).

REMIND additionally includes two variations of the policy scenarios:

- Carbon price implementation: the default assumption is a regionally differentiated carbon price, but a globally uniform carbon price scenario is also analyzed
- Behavioral variation: an optimistic scenario of behavioral change flanking policy (carbon price) driven transformation is analyzed, e.g. assuming shifts towards more public transport (with implicit benefits for inequality)

Elasticities

The key modeling tools to describe the distributive impacts of climate policy and climate impacts are elasticities that are described in detail in Deliverable 4.2. Those elasticities relate an increase in income and an increase in a certain quantity. For instance, an elasticity of 1 for climate damages means that an increase of 1% in income yields an increase of 1% in climate damages suffered by the household. Changing those elasticities makes impacts more or less progressive. There are two key elasticity parameters used by both models: for climate damages and for mitigation costs (for REMIND these are energy expenditures; for NICE these also apply to the amount of carbon tax paid). We discuss here briefly their quantification as they are key variables for the analysis of distributional effects in integrated assessment. (see also Dennig et al. 2015, Budolfson et al. 2021 and Deliverable 4.2).

The income elasticity of damages

As mentioned in the introduction, there is very little quantitative research on how climate impacts affect different income groups, therefore currently we are lacking a robust basis to quantify this parameter. Empirical research of the effect of temperature change on different income groups, as conducted in CHIPS and described in Deliverable 2.1, can pave the way towards deriving the elasticities directly. However, there is clear evidence that it is below 1, i.e. that impacts fall more heavily on the poor (e.g. Mendelsohn et al. 2012, Hallegatte & Rozenberg 2017, Tol 2021). Therefore, we assume a value of 0.5 in the REMIND application and conduct a sensitivity analysis with values of 0 and 1 to check the results.

The income elasticity of mitigation costs

Regarding the elasticity of mitigation costs, the literature, and also results from microsimulation within the CHIPS project, shows that carbon pricing and related energy expenditure increases generally have a regressive effect if there is no redistribution. Based on that, both models use existing data to estimate the elasticity empirically. In the following we describe both approaches.

The approach in NICE

The current approach in NICE is the one obtained in Budolfson et al. (2021). The elasticity of mitigation costs is based on a review of existing studies. For each country reported in the studies, an elasticity is computed. Then we regress the elasticity on the log of per capita GDP, so that we obtain the following equation:

$$\omega_k = \alpha + \beta \, log(y_k)$$

Then we obtain an endogenous elasticity of mitigation costs. We find that the elasticity is larger than 1 for poorer countries (which means that mitigation has a progressive impact: it falls more on richer people), but that it is decreasing with average per capita GDP so that mitigation is regressive (elasticity lower than 1) for richer countries.

Figure 2 below is taken from Budolfson et al. (2021) and shows this relation.

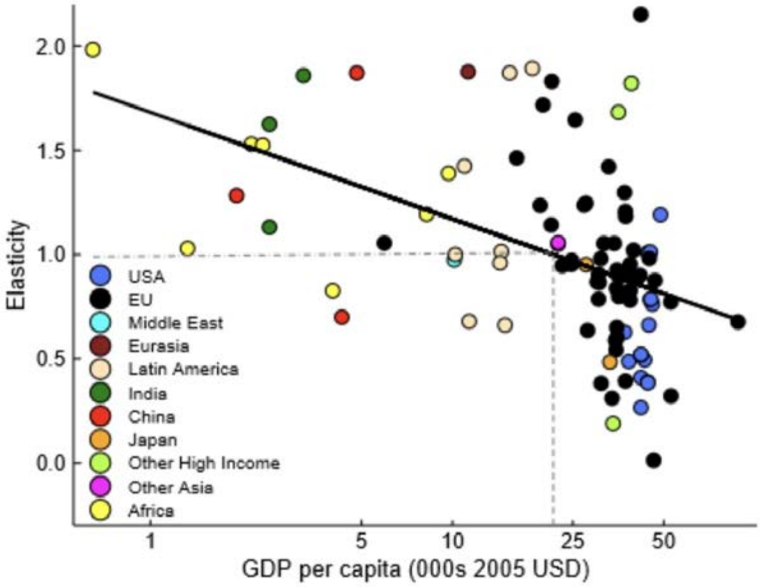

Figure 2: *Taken from Budolfson et al. (2021) (their Figure 1). Estimates from the literature on the distribution of the initial burden of a carbon or gasoline tax, and the resulting relationship with per capita GDP (black line).*

To project elasticities for each region and period in the model, we compute the predicted elasticities according to the regression above for the model GDP per capita, of each region in a certain period.

The approach in REMIND

The approach we use is also described in Soergel et al. (2021a). We build on the empirical finding that energy expenditure shares increase with growing income in low-income countries (making energy price increases somewhat progressive), but decrease in high-income countries. Therefore we estimate the elasticity by relating final energy expenditure shares to income. This is done empirically using country-level data on energy, food and total expenditures for four consumption groups from Dorband et al. (2019), compiled from the Global Consumption Database from the World Bank. Figure 3 shows the result with a number of different fits. We use the loglog quadratic model results as it performs best. The elasticity parameter is then given by α_{FE}-1=1.64-2*0.097*log(y) and can be calculated at the level of REMIND regions, dependent on time and regional income (Figure 3, right panel). The turnover point for which energy expenditure increase becomes regressive is at 4800$ per year.

Differences to the results described in the previous section arise from different underlying data (here a single data set of expenditures, in the NICE analysis a set of elasticities estimated in different studies put into a meta-regression) as well as a different income ranges these data capture in detail (lower here, higher in the NICE approach). A more detailed intercomparison of the approaches is beyond the scope of this report.

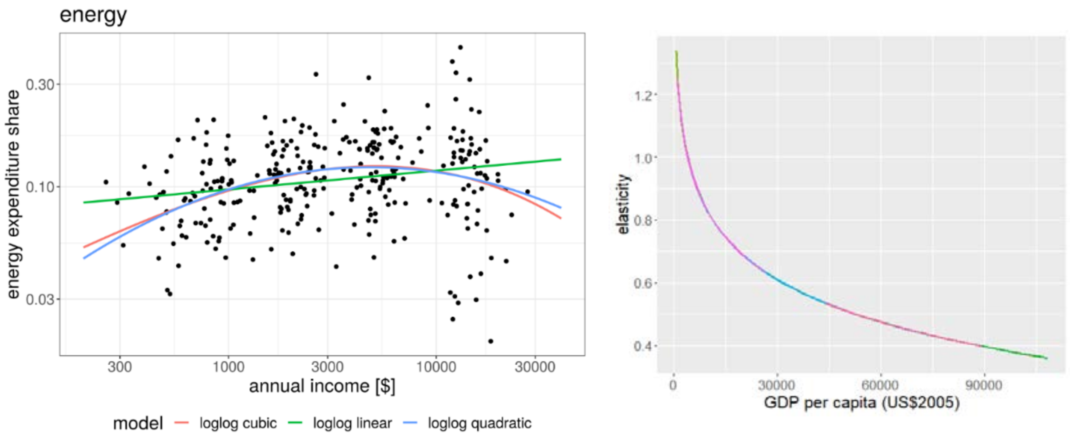

Figure 3: *Left panel: Taken from Soergel et al. (2021a) (their Supplementary Figure 4=. Data points are country data from Dorband et al. The caption reads "We show our estimation of the final energy expenditure share as a function of income, which we use to derive the income elasticity used in the distributional analysis. The inverse U-shape relationship between expenditure share and income indicates that energy price increases are progressive in low-income countries, and regressive in middle/higher-income countries. The scatter in expenditure share at fixed income is partially caused by country-specific conditions (e.g. climate zone, culture), which are absorbed by the country fixed effects in our regression specification. For the model lines shown in this figure, the mean of all country fixed effects was used." (Soergel et al. 2021a, Supplementary Material, p. 10)*
Right panel: Resulting values for income elasticity of energy expenditure as used in the REMIND model.

3. Future transformation pathways and distributional consequences

Approaches for redistributing carbon tax revenues - a NICE application

In the following, we apply the NICE model to study inequality and poverty under different climate policy pathways and tax revenue redistribution schemes. In particular, we highlight a new form of redistribution, which is proportional to the climate damages faced by a country. This form of redistribution can be seen as a way of implementing the recent discussions of "loss and damages" at the UN. Some countries have promoted the use of a global carbon tax as a way of funding payments for loss and damage suffered by the developing world. These results form the core of a paper currently in preparation (Young-Brun, Méjean and Zuber, 2023). We focus here on a global climate policy pathway compatible with the Paris agreement, a "below 2° pathway", and contrast it with the baseline where no carbon tax is implemented.

Our "below 2°C pathway" implies a sharp short-term decrease in GHG emissions, so that they are near zero by 2070 (see Figure 4, panel a). Our scenario actually limits temperature well below the 2°C threshold (Figure 4, panel b). The policy induces an intertemporal trade-off illustrated in panel c) of Figure 4. Near-term consumption will decrease because of the cost of climate policy, while in the long-term consumption will increase because of the reduction in climate damages. By 2100, climate damages in BAU induce a decrease of 1.5% of average consumption compared to the 2°C policy.

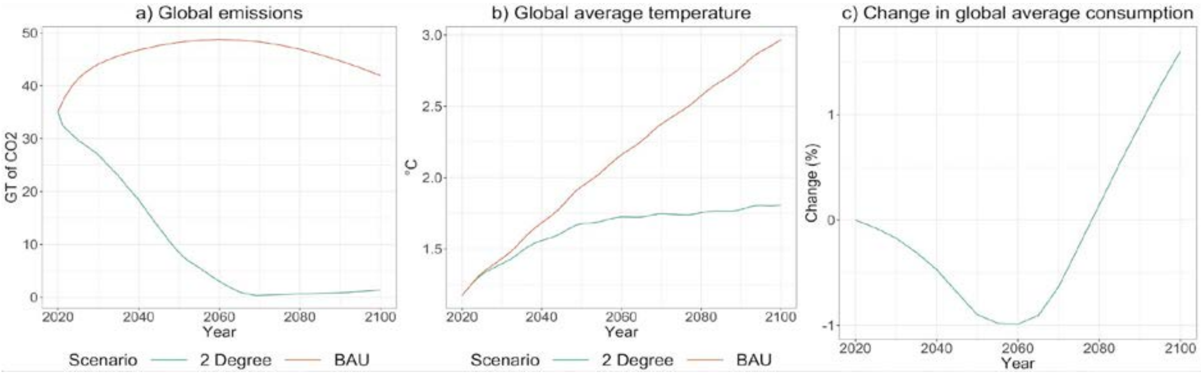

Figure 4: *Global emissions, global average temperature and change in the average consumption from BAU*

The key question we address is: what are the effects of carbon tax revenue recycling on inequality and poverty? It has been argued that climate policy and the carbon tax can increase inequality and poverty because poorer households face a proportionally larger share of the cost of climate policy. But revenue recycling can alleviate those negative effects if appropriate redistribution is performed (Budolfson et al. 2021). Redistribution can be done within each country to reduce inequalities between income groups. But it can also be done between countries by transferring funds between world regions.

In the recent COP27, there have been discussions that richest economies should contribute to compensate for the irreversible losses faced by poorer regions that are more vulnerable to climate change. In particular, some countries have called for a global carbon tax, either on airline travels or other highly emitting activities, to fund "loss and damages". Such a scheme may induce large redistributions between countries.

In this study, we approach this proposal by considering different policy scenarios. In all cases, a global carbon tax on all emissions is implemented (which is broader than a tax on some economic activities only). Then the revenues of the carbon tax are redistributed according to different rules:

- § Either the redistribution is done so as not to modify preexisting inequalities ("Distributionally neutral" case);
- § Or the redistribution is lump-sum within each of the world regions of the NICE model ("Country-level" scheme);
- § Or lump-sum at the global level ("Global" scheme);
- § Or proportionally to the damages faced by the country – but lump-sum within the country ("Proportional to damages" scheme);
- § Or lump-sum but only to poor countries ("Poor countries" scheme).

Figure 5 shows the results of the consequences of these different schemes on inequality at the global level. The results are in terms of change in the Gini coefficient: the Figure displays the differences between the value of the Gini index in BAU and the value of the index in each recycling scenario. Positive numbers thus mean reduced inequality.

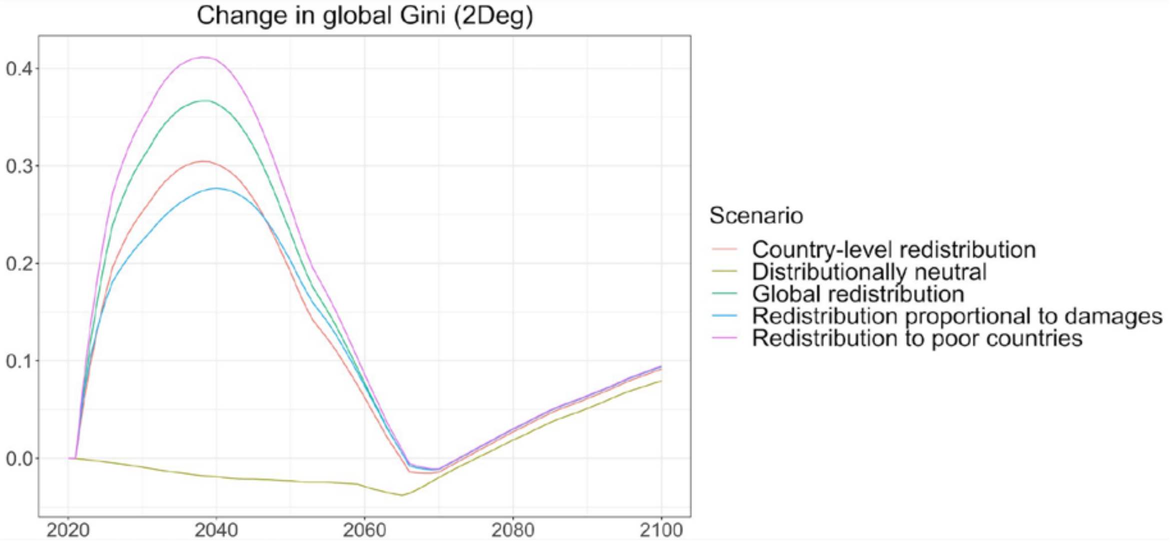

***Figure 5:** Change in inequality (measured by the Gini index) from the BAU depending on how carbon tax revenue is recycled.*

A first key finding is that climate policy may increase global inequality if redistributive measures are not implemented. In the "Distributionally neutral" recycling scenario, there is a small increase in the Gini coefficient compared to the BAU (less than 0.05 percent points) until 2080: this is due to the regessive nature of the carbon tax. Eventually, the Gini may improve because of the avoided climate damages that hurt poorer countries.

A second finding of Figure 5 is that, on the contrary, redistributing the carbon tax induces gains in terms of inequality reduction. This is even more the case when there is cross-country redistribution like in the "Global" and "Poor countries" policy scenarios (green and pink curves). We can gain up to 0.4 percentage points in Gini (equivalent to a 0.4% increase in equivalent income for a Gini welfare function).

The result at the global level mixes between country and within country inequality redistribution. To get a better sense of the redistribution within each country, Figure YY displays Gini changes from BAU in five countries: Germany, the USA, China, Brazil and Nigeria.

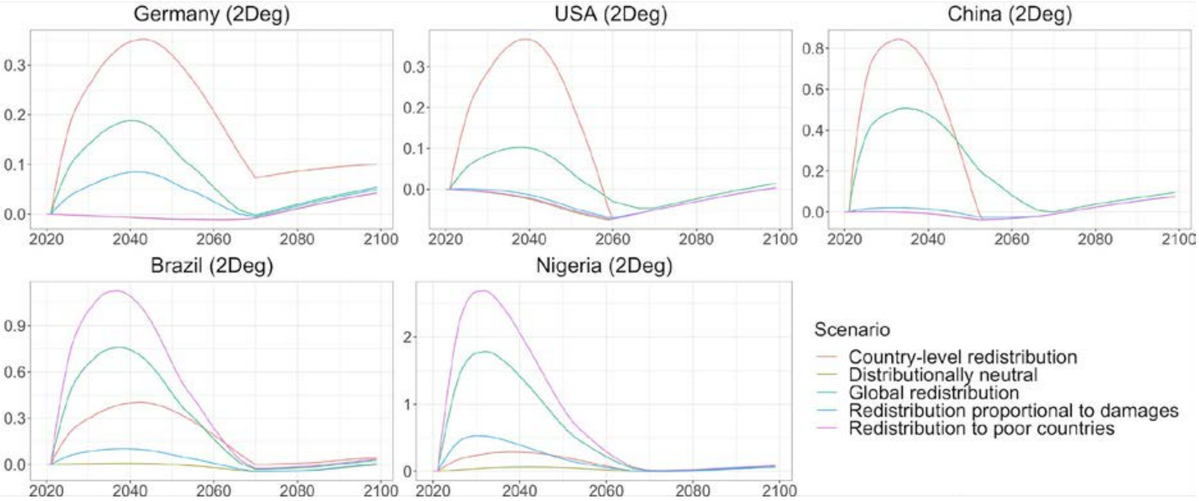

***Figure 6:** Change in inequality (measured by the Gini index) from the BAU depending on how carbon tax revenue is recycled in selected countries.*

Figure 6 shows that inequality is reduced in the short run because of the lump-sum redistribution of the carbon tax revenues. In the “Country-level” scheme, the effect is larger in regions with more baseline inequality and more GHG abatement. This explains the stronger effect in China. In the “Global” and “Poor countries” schemes, poorer regions benefit from the redistribution because some of the resources from richer regions are transferred to them and help reduce their inequality (see the cases of Brazil and Nigeria). Richer countries on the contrary have negative impacts on their inequality in the “Poor countries” case, because they only pay the tax (which is regressive) without benefitting from redistribution. The case of the redistribution proportional to damages is more diverse as countries have very different exposure to climate change, and there is not a perfect correlation with being a rich or poor country. Interestingly, redistributing a global carbon tax can have sizable effects on inequality: up to more than 2.5 percentage points in South Africa and India for instance, although this is much less in richer regions.

Figure 7 shows the effects of redistribution on poverty at the global level, where poverty corresponds to the extreme poverty definition of the World Bank (living with less than $1.9 per day). Note that a complementary analysis on poverty effects of climate policy with the REMIND model can be found in section 4 below. Figure 7 shows the number of persons that are able to get out of poverty compared to the BAU baseline (or said differently, the reduction in the number of poor from the baseline). A positive number represents a reduction in poverty.

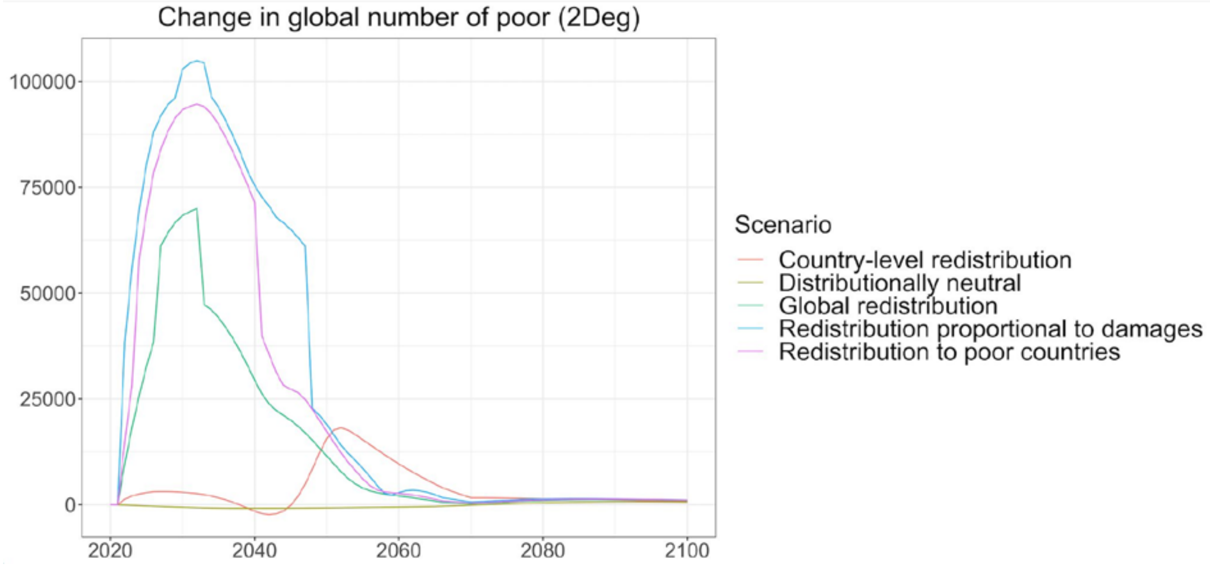

Figure 7: *Change in the number of poor (in thousands) from the BAU depending on how carbon tax revenue is recycled (number of poor people that can get away from absolute poverty through climate policy and recycling).*

Figure 7 highlights a reduction in poverty in all our policy scenarios, compared to the distributionally neutral case, thanks to the redistribution of the carbon tax revenues. The reduction is small in the country-level redistribution case, and there may eventually be more poor people globally, when there are no more carbon tax revenues to be redistributed. This is because the cost of climate mitigation (for instance increased food prices) are still there and they are regressive. Then another effect may kick-in: the reduction in climate damages that affect the poor.

It must be noted that the reduction in poverty can be high: up to almost 100 million people in 2030 when redistribution is targeted on poor countries or when it is proportional to damages. As expected, the country-level redistribution scheme that does not allow transfers between world regions has much less impact on poverty than the other schemes.

Discussion

The study is a first step to better assess how some redistribution of the carbon tax revenues at the global level can help achieve some of the UN Sustainable Development Goals, especially the reduction in poverty and inequality. We find that especially for poverty the effect may be large. The reduction in inequality can also be significant in some world regions, namely the poorest and most unequal ones.

There are several ways the analysis could be further developed. First, the damage function we use is the Nordhaus one that has been criticized a lot: it implies limited effects of climate change and limited regional disparities in damages. Second, only a few policy options have been explored and they may not correspond to existing proposals. For instance, only a global carbon tax on part of the emissions (for instance airplane tickets) has been discussed. We may try to get closer to such a proposal by changing our modeling.

Outlook

We are preparing a paper to publish this analysis in the near future. There are still on-going developments that need to be finalized. First, we are developing alternative policy scenarios, including cases where only part of the global carbon tax is redistributed at the global level and/or different carbon prices are used for different regions. Second, we also want to better understand the welfare gains of different policy options to measure how valuable it might be to propose more ambitious forms of redistribution at the global level.

Benefits and challenges of climate policy - a decomposition analysis using the REMIND model

We apply the REMIND model in its “least-total-cost” setting, combining the two climate policy targets (1.5° and below 2°) with climate impacts, and with the newly developed representation of distributional consequences from both avenues. We differentiate two types of revenue redistribution: proportional, i.e. distributionally neutral, and equal per capita, i.e. progressive.

Including inequality affects the emission pathway as illustrated in Figure 8. While the differences in absolute terms are small, one should note that there is fairly little flexibility in the near term due to the very stringent emission reductions demanded by the target (in particular for the 1.5° case). Therefore, even small shifts are significant for the policy strategy. Considering inequality leads to more ambitious mitigation in the near term, enhanced further in the case of progressive redistribution which limits the negative effects of higher mitigation costs for inequality. Over the long run emission reduction is less ambitious with inequality, preserving to some degree the revenue source for redistribution. In the 1.5° scenario revenues for redistribution are lost more quickly due to the faster emission reduction, therefore the equal per capita scenario actually leads to slightly higher emissions in the medium term than without inequality or progressive redistribution. That is then compensated in the longer term. Note that these small changes in the emission pathways have little effect on the temperature pathway, but there is a slight reduction in near-term temperature increase which plays a role for long-term climate damages, in particular if they are persistent.

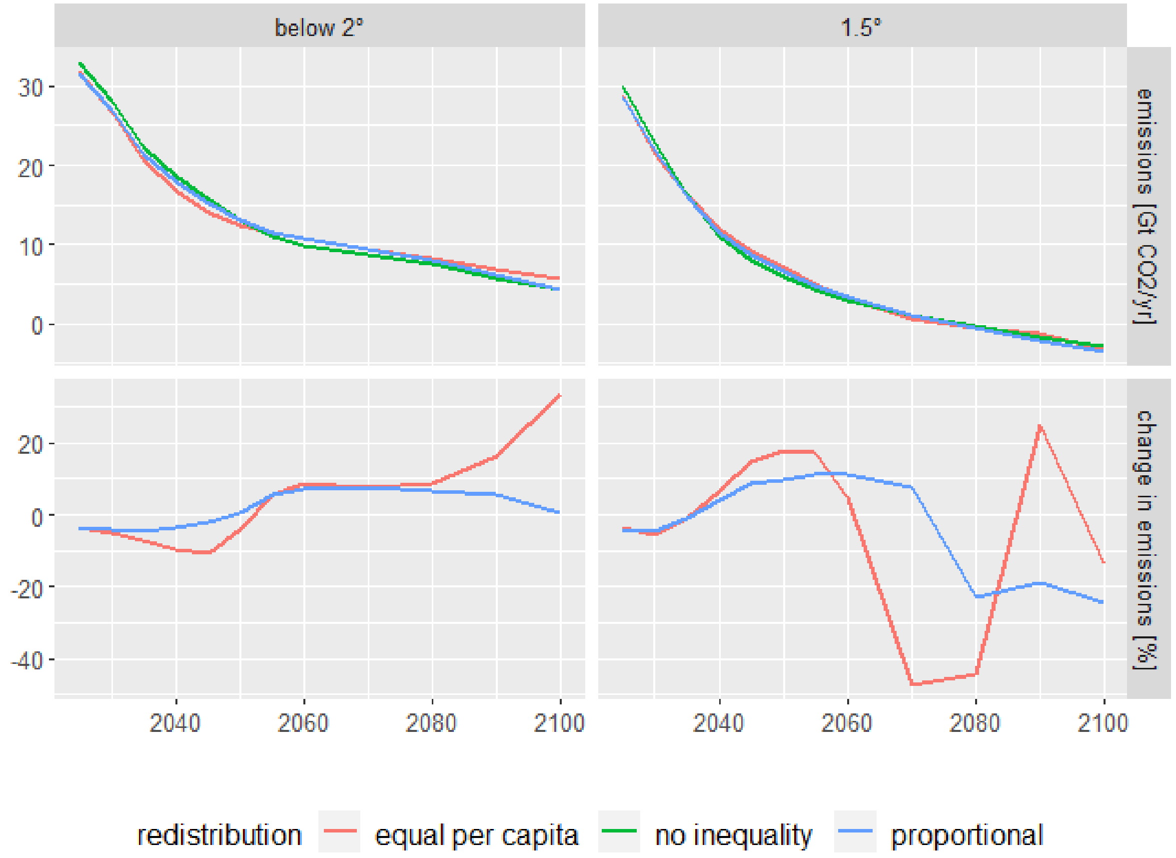

Figure 8: *Global CO2 emissions (top) and change in emissions compared to a scenario with the same climate target but without inequality (bottom), for the two different climate targets (panels) and revenue redistribution schemes (line colors). Climate damages are included.*

We now analyze the change in GDP as a measure of costs and in the Gini index as a measure of inequality in the climate policy scenarios compared to a baseline with damages but without climate policy beyond what is presently implemented. This is shown globally in Figure 9, rightmost panel ("mitigation benefits"). While mitigation leads to near-term GDP losses and corresponding increases in inequality due to the additional expenditures for households, we highlight the long-term benefits both in terms of GDP and inequality. This shows the crucial importance of comparing to a baseline with damages and therefore capturing the benefits of mitigation, to avoid misleading conclusions. We decompose the overall effects into the effect of mitigation, the effect of avoided damages (i.e. the benefits of the climate policy) and the effect of the residual damages at the targeted warming levels (shown in the remaining panels of Figure 9). The increases in inequality due to climate policy can be efficiently remedied by equal per capita redistribution in the near term (dashed lines), while in the longer term no revenues are available anymore as emissions are eliminated. In the 1.5° scenario, costs are higher but long-term damages are lower, so towards the end of the century the more ambitious climate target is beneficial. Note that in this calculation we miss a large number of climate risks, in particular extreme events and also non-market damages like health risks or ecosystem impacts, which provide compelling reasons to limit warming to 1.5° (see e.g. Rising et al. 2022).

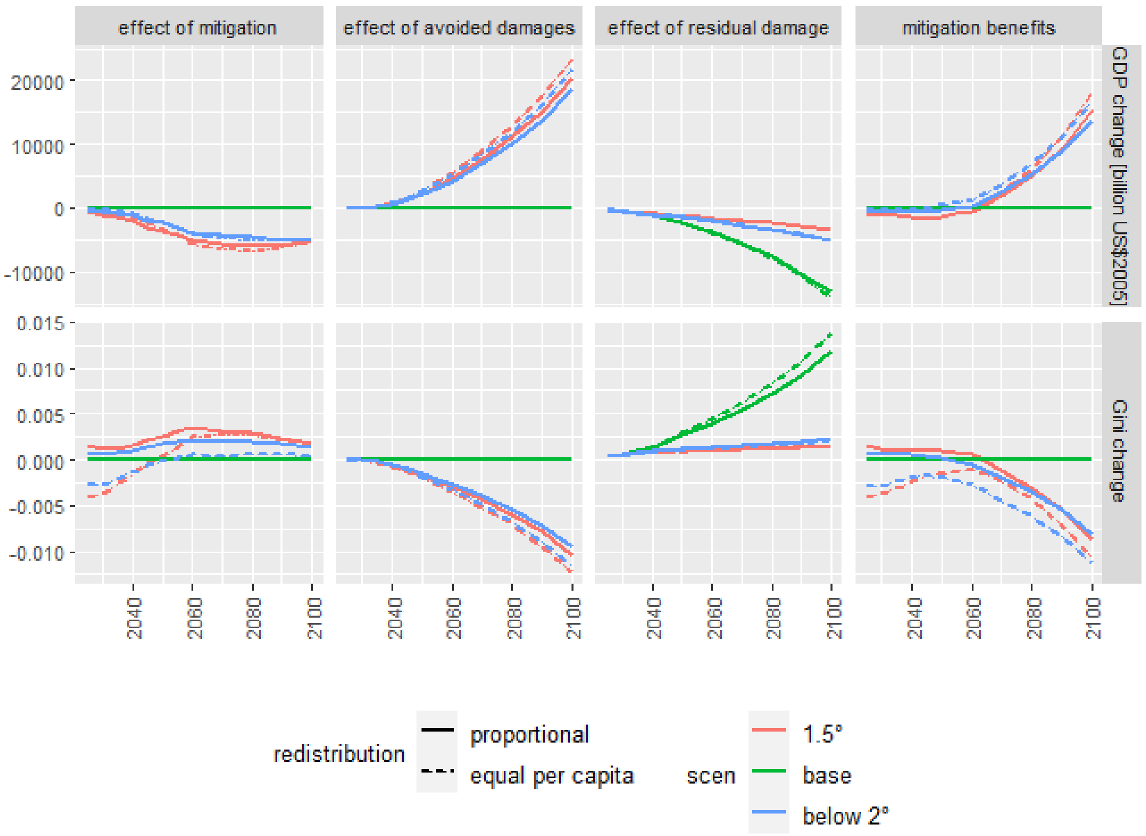

Figure 9: *Global change in GDP (left panel) and Gini index (right panel) compared to a baseline without damages (solid lines) or a baseline with damages (dashed lines). The colors indicated the climate target. Redistribution is distributionally neutral (proportional to income). Note that a higher Gini index indicates higher inequality, therefore a reduction in the Gini index compared to the baseline means reduced inequality.*

The losses and benefits differ between regions, depending on the regional characteristics. The overall change in GDP and Gini compared to a baseline with damages for the 12 REMIND regions is shown in Figure 10. Regions are grouped into developed regions including China in the top panel and in the bottom panel fossil-fuel exporting regions followed by developing regions (note the different scales of the two panels). Long term mitigation benefits and inequality improvements are larger for developing regions than for developed. They also benefit more from progressive redistribution (dashed lines), some also in the longer term as they do not fully phase out emissions (e.g. SSA, IND but also NEU). Developed regions with high near-term mitigation costs have the highest increases in inequality in the near-term without redistribution, but also benefit from long-term decreases due to avoided damages. Note also the larger differences between the 1.5 and 2° scenario in the case of progressive redistribution, in particular for fossil fuel exporting regions, but also China, CAZ or OAS. Higher carbon prices lead to higher revenues and therefore more funds for redistribution. However, the more ambitious climate target also incurs higher costs in terms of near- and medium-term GDP losses in many regions.

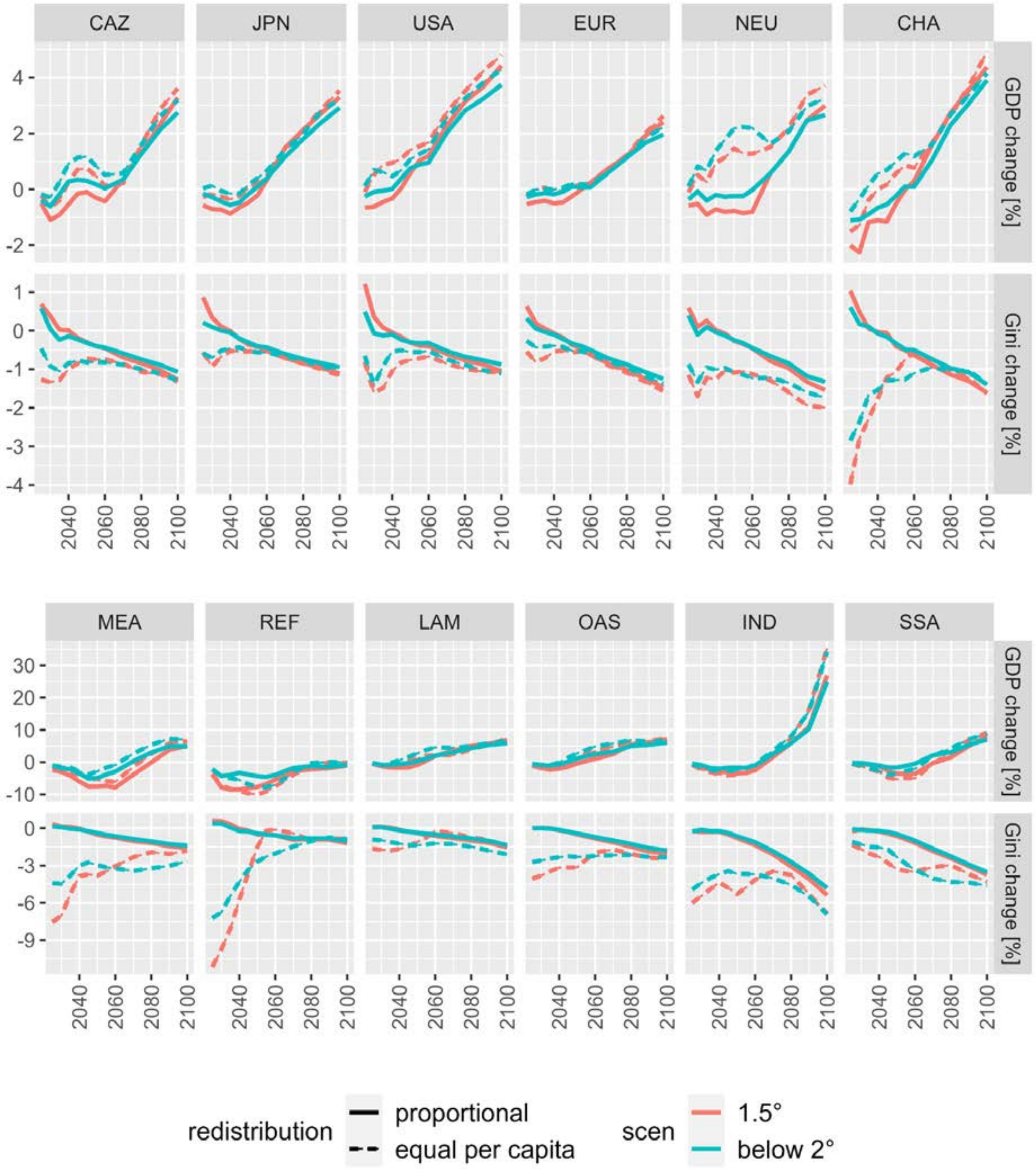

Figure 10: *Same as Figure 9 but for the 12 REMIND regions.*

The role of behavioral change

Aside from top-down policy measures like carbon pricing moving forward the transformation towards lower emissions, a further dimension are changes in behavior by people. Such changes can be triggered for example by shifts in what is considered acceptable behavior in a society, by expectation formation regarding future policies or price changes, or by changing habits on a larger scale than what a specific policy might target. Some research even considers the existence of societal tipping points (Moser & Dilling 2007, Otto et al. 2020). While the possibilities to investigate this with the REMIND model are limited, we explore one area of behavioral change specifically relevant to the inequality question, the transport sector. In a sensitivity scenario we assume that people show a stronger and faster shift of their transport preferences in climate policy scenarios towards public transport and electric vehicles.

Additionally, it is assumed that traditional gas-powered vehicles become more costly and harder to produce and sell. Therefore the price of electric vehicles declines and their share increases strongly. Also the share of electric buses and trains increases, and the train share as well as the share of non-motorized transport both approximately double. As a consequence, a lower carbon price is required to achieve a given climate target and mitigation in general becomes cheaper and somewhat easier. In terms of inequality, this generally means lower energy expenditures but also lower tax revenues for redistribution. Therefore, for the scenario with proportional redistribution, this additional behavioral dimension results in improvements in inequality as shown in Figure 11. With equal per capita redistribution the reduced availability of revenues does mean slightly smaller improvements in some regions, mostly developing regions, than before in the near term.

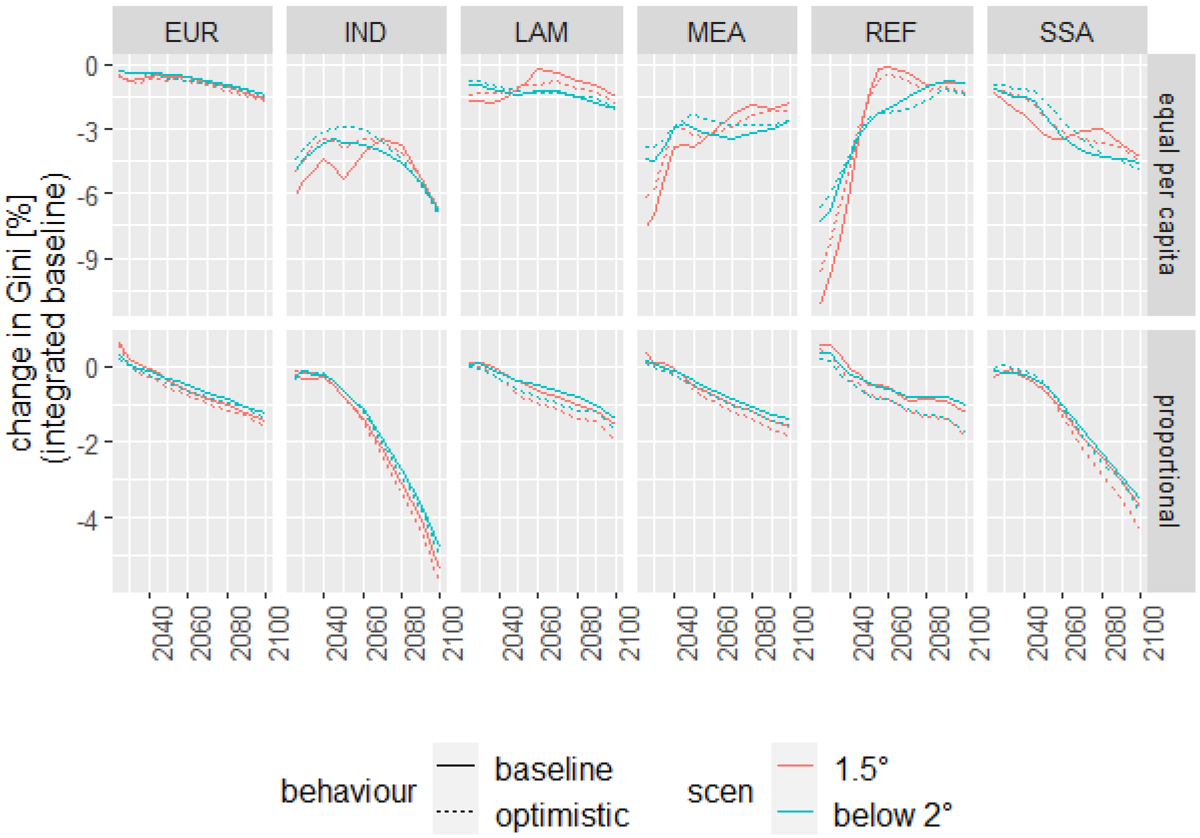

Figure 11: *Regional changes in Gini index (compared to an integrated baseline with damages), for two different redistribution schemes (rows). Line colors indicate the two different climate targets, line styles indicate the behavioral assumptions as discussed in the text, where the solid line is the standard specification.*

Discussion

Our analysis of distributional effects of climate policy and impacts is one of the first using a process-based integrated assessment model. It complements other studies, e.g. the ones with the NICE model, with an alternative methodological approach using the log-normal distribution instead of income groups. We highlight the importance of integrating the mitigation and impacts dimensions to allow a quantification of the benefits of climate policy instead of purely focusing on challenges. Furthermore, we highlight large regional differences, in particular the challenges for regions with higher near-term emission reductions. However, progressive redistribution can largely alleviate increases in inequality related to near-term mitigation also in those regions. Comparing the results for the 2° and the 1.5°

climate target, not surprisingly higher near-term costs and pressures on inequality emerge. However, In the long run, lower damages lead to reductions in inequality compared to the 2° scenario, while costs in terms of GDP loss are not (or very late in the century) reduced for all regions (e.g. REF, MEA, SSA). For redistribution higher revenues in the near-term due to higher carbon prices help to alleviate near-term pressures, but revenues are lower in the 2nd half of the century due to very low emissions. Note that the damage function used in this analysis is a rather conservative choice and misses many important impact channels both in terms of magnitude of costs and their regressivity. This includes in particular extreme events, sea-level rise effects or indirect consequences like conflict and migration. A sensitivity analysis with higher damages would therefore be important, as well as further efforts to include these channels directly (see also Deliverable D2.2). That would also require knowledge of their elasticity, however, and as discussed above, quantitative knowledge on the elasticity of climate impacts is very scarce. A sensitivity analysis on the value of the elasticity of damages with the current aggregate damage function shows that as expected more regressive damages lead to higher benefits of mitigation in terms of reduction of elasticity compared to the baseline with damages. With proportional redistribution, more regressive damages lead to slightly larger advantages of the 1.5° climate target compared to the less ambitious “below 2°”, as there are less damages in the long run. Progressive equal per capita redistribution can counteract that, leading to smaller differences between the climate targets the more regressive damages are.

Outlook

We are preparing a paper to publish this analysis in the near future. In the longer term we plan to refine the modeling in different directions. A first goal is to use robust estimates of the elasticity of damages based on the empirical analysis and to furthermore investigate region-specific elasticities based on different vulnerabilities of regions. An important dimension not included here is the inequality effect of changing food prices in response to mitigation, which has been identified as an even more important component than energy expenditures (Soergel et al. 2021a). Both for the energy side as well as climate impacts more refined channels would allow a better identification of where countermeasures should be focused on. Finally, it should be stressed that this analysis only addresses climate-related inequality issues. However, this is related to underlying, non-climate related inequality and embedded in a broader policy framework allowing other measures than carbon tax revenue redistribution. Therefore, an analysis with a broader set of policy instruments would be of great interest.

4. Synergies of climate policy with poverty eradication and other SDGs

Climate action and the reduction of inequality are highlighted as two goals of the UN Sustainable Development Goals (SDGs 13 & 10). Furthermore, they are also closely connected to several other SDGs, most notably to poverty eradication (SDG 1) and decent work and economic growth (SDG 10), but also to a broader set of targets for decent living (e.g. zero hunger and energy access, SDGs 2 & 7).

In order to evaluate the scenarios developed in CHIPS along this broader SDG space, we developed and applied models for projecting poverty rates (SDG 1) for both the NICE (described above) and REMIND (Soergel et al. 2021a, summarized here) models. For the REMIND poverty analysis, we developed a model for projecting future poverty headcounts based on historical poverty and inequality data from the World Bank and scenarios for future socio-economic development (population, GDP/capita, Gini coefficient). Climate policies can change poverty rates through their effect on the macro-economy, through energy and food price changes that tend to affect poorer households more severely, and through a potential redistribution of carbon pricing revenues. Based on results from REMIND, and making use of its coupling to the land-use model MAgPIE, we estimate the distributional effects of all of these channels and translate the results into changes in poverty rates caused by climate policy. While carbon pricing in line with the 1.5°C target and without associated redistribution policies would lead to an increase in the population in extreme poverty ($1.90/day line) by around 50 million people globally by 2030, this increase can be more than compensated through a progressive redistribution of the carbon pricing revenues (Figure 12). However, regional disparities remain: in Sub-Saharan Africa the domestic carbon pricing revenues are insufficient to fully compensate for the poverty side effects of climate policies. Therefore, also international transfers, e.g. as part of an international climate finance scheme, are required for climate policies and poverty reduction to work hand in hand.

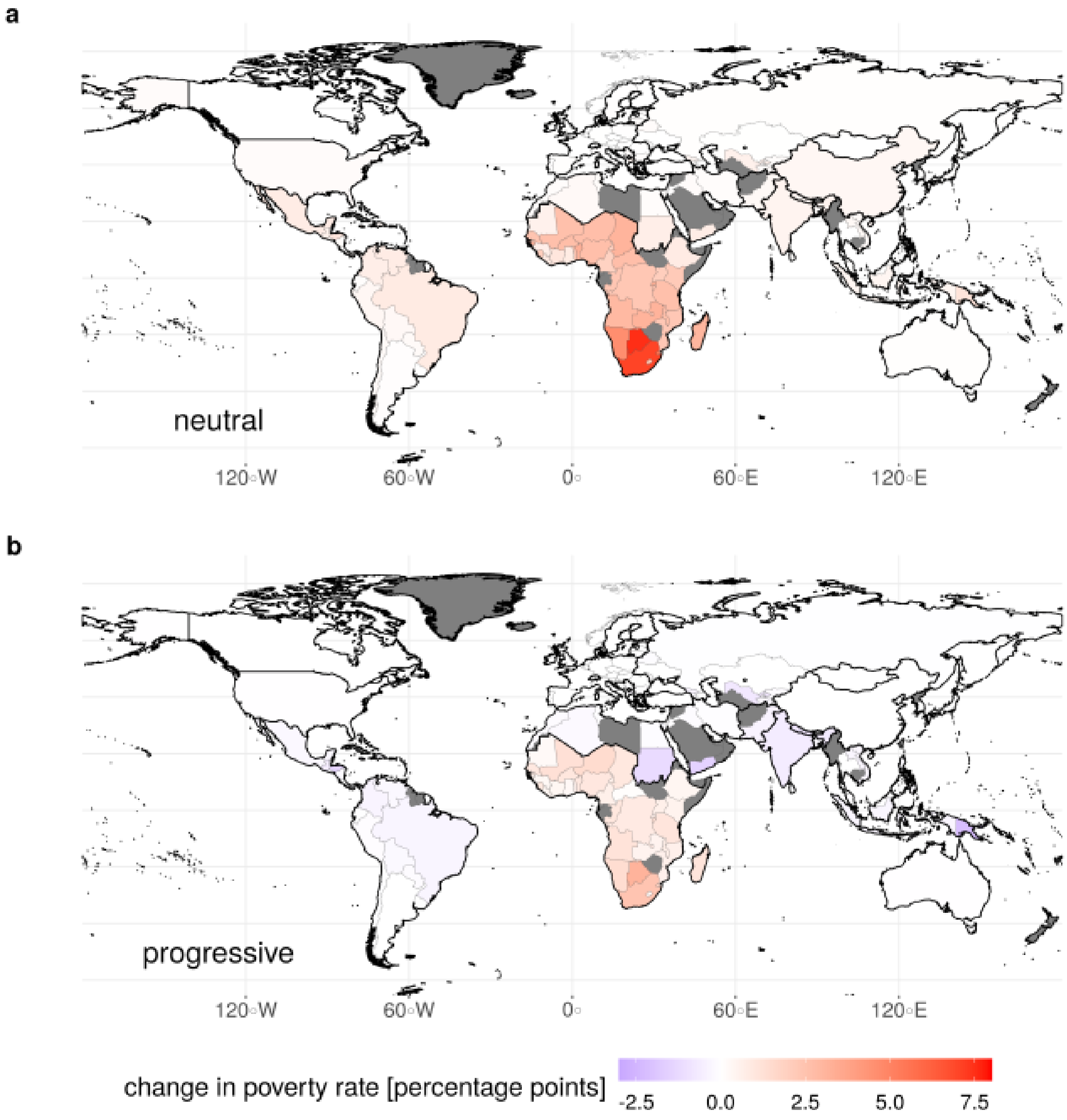

Figure 12: *Effect of climate change mitigation policies on poverty rates in 2030: While climate policy without associated progressive redistribution (panel a, 'neutral') would lead to a substantial increase in poverty rates, this policy side effect could be reduced or largely overcome by redistributing the associated carbon pricing revenue (panel b, 'progressive'). (Figure from Soergel et al. 2021a)*

We further applied this model in a holistic assessment of climate and sustainable development strategies (undertaken as part of the sister project SHAPE, Soergel et al. 2021b). Here we integrated the poverty and inequality indicators into a broader set of over 50 SDG indicators from all 17 SDGs, with the goal of identifying a sustainable development pathway that jointly advances climate action and the SDG implementation. The results of this broader SDG assessment show that an integrated strategy for climate action, poverty eradication, decent living and biosphere protection is required. Such a holistic strategy leverages synergies between different targets, avoids or compensates for trade-offs, and is therefore able to make much larger progress towards the goals than narrowly designed strategies for individual targets. For example, we find that a broad shift towards healthier and sustainable nutrition leads to large co-benefits for reducing pressure on climate and ecosystems (lower emissions, land requirements, water & fertilizer use). Simultaneously, it also avoids food price increases associated with climate policies, and therefore contributes to reconciling climate policy with meeting the targets for zero hunger and poverty eradication.

5. Conclusions and avenues for future research

The analyses summarized here highlight the importance of an integrated assessment of climate policy including the effects of climate impacts. Despite its costs it yields long-term benefits both in terms of reduced inequality and reduced losses from climate damages. However, in the near-term the required transformation to reduce emissions induces costs with adverse inequality consequences. In line with the analyses on the micro level (Deliverable 3.1) we show that redistribution of carbon tax revenues is an efficient way to address this issue. Importantly, a global redistribution scheme improves global inequality and in particular has a positive effect in developing countries. These results are well in line with the findings by Feindt et al. (2021) for the European Union, however a direct comparison is not possible since the latter does not include climate impacts. While a redistribution specifically to poor countries is even more beneficial to global inequality, it places a burden on richer countries by potentially leaving negative effects on inequality unaddressed. Such a targeted redistribution scheme is found to be beneficial in the country/regional context in the European Union and Mexico (see Deliverable 3.1).

Relating to the broader context of the sustainable development goals, we find that, while climate policy alone increases the number of people in poverty, this can be addressed also via the redistribution of tax revenues, in particular in global schemes and even more so if the poor and those countries affected most by climate damages are benefiting directly. The more holistic SDG analysis undertaken in the SHAPE project highlights the mutual benefit of transformations towards SDG goals and climate policy, e.g. reduced food prices from dietary shifts in line with lower pressures on ecosystems. This analysis should be extended to cover climate change impacts, which so far are not part of it.

While these results are outlining how unintended consequences of climate policy can be addressed, a number of open issues remain. The most important one relates to the concrete implementation of redistribution schemes, both nationally and internationally. This requires strong institutions, channels through which this redistribution can happen most efficiently, and support by the public. The channels can range from direct cash transfers to support for heating and transport costs to general investment into public transport which benefits the lower income groups more. A more detailed analysis of these policy options requires other modeling tools and depends also strongly on the national context. Furthermore, other work in the CHIPS project (see Deliverable 3.3) has shown that the population might not actually support redistribution over other uses of the carbon tax revenues. Given the considerable risk of protests and public unrest in response to the burdens of climate policy, in particular in the context of other societal challenges like the ongoing war in Ukraine, communication of policy measures is of crucial importance. Furthermore, the analysis of behavioral change as one avenue of transformation towards a low carbon society shows that a broadening of policy analysis beyond carbon pricing is important also in the context of inequality. Finally, other work in CHIPS (Young-Brun & Feindt, forthcoming, see also Deliverable 4.1) has shown the importance of further differentiating damage channels relevant for inequality like labor and capital. The distributional consequences of extremes are also crucial (see Deliverable 2.1). Therefore, a focus of future work should be the improvement of the representation of impacts and their link to inequality. This should be further supported by microsimulation work which was not achieved in the CHIPS project due to a shift of focus to inflation rates as an indicator for distributional consequences of economic shocks in response to the pandemic and the energy crisis (see Deliverable 3.3).

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