

Temporal and spatial distribution of global mitigation cost:

INDCs and generational equity

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Abstract

Each country's Intended Nationally Determined Contribution (INDC) pledges an emission target for 2025 or 2030. Here, we evaluated the INDC emission pathway's inter- and intra-generational equity by comparing the INDC pathway with an immediate emission reduction pathway by using AIM/CGE (Asian-Pacific Integrated Model/Computable General Equilibrium). The results showed that, as compared with an immediate emission reduction pathway, the inter-generational equity status for INDC and post-INDC emission pathways is not favorable and the future generation suffers more from mitigation. Moreover, this conclusion was robust to the inequality aversion parameter of the discount rate. On the other hand, the INDC pathway has better intra-generational equity in the early part of the century than does the immediate emission reduction pathway with uniform carbon price across countries. However, intra-generational equity worsens later in the century. We suggest that an additional 20% emissions reduction in the INDCs would improve both inter- and intra-generational equity as compared to the current INDCs. We also suggest that countries should commit to more emissions reductions in the follow-up INDC communications and that continuous consideration for low-income countries is needed for global climate change cooperation after 2030.

Introduction

In the IPCC's fifth assessment report (AR5) [1], Working Group III noted several scenarios corresponding to the 450 ppm CO₂ equivalent concentration stabilization. These scenarios mostly have immediate GHG emissions reductions, and CO₂ emissions become zero or negative in the latter half of this century. The Paris Agreement reaffirmed that the ultimate climate goal is the 2 °C target, which corresponds to about 450 ppm CO₂ equivalent concentration stabilization in 2100 [2]. In addition, each country is to submit an INDC (Intended Nationally Determined Contribution) pledge of emission targets for 2025 or 2030. The summation of all countries' submitted emission targets in 2030 is expected to be larger than the least-cost 2 °C scenarios shown in AR5, leading to a projected level of 55 GtCO₂eq in 2030. To achieve the 2 °C target, an additional emission reduction of approximately 15 GtCO₂eq will be required to fill the gap between the post-INDC trajectory and the least-cost 2 °C scenarios after 2030 [2].

The spatial and temporal distribution of mitigation costs would be different in a mitigation scenario consistent with the INDCs and achieving the 2 °C target and in the least-cost 2 °C scenarios. This difference implies that the INDCs influence equity both inter- and intra-generationally.

The discount rate used in projections has a notable influence on the conclusions and policy implications of generational equity issues. Social cost of carbon varies with discount rate and people have conflicting opinions about the urgency for the need for climate policy depending on the discount rate [3]. There have been discussions about how to determine the discount rates. The IPCC's second assessment report (SAR) [4] summarized two major approaches of discounting future values, namely the prescriptive and descriptive approaches. The former begins with ethical considerations, whereas the latter begins with evidence from decisions that people and governments actually make. AR5 [1] looked deeper into the prescriptive approach and reviewed the use of the Ramsey rule of discounting. AR5 concluded that a relative consensus has emerged in favor of setting the pure rate of time preference at 0 and the inequality aversion parameters somewhere from 1 to 3.

Several studies have examined numerical INDC assessment. For example, Iyer et al. [5] compared INDC scenarios with an alternative emissions path in which nations cannot undertake mitigation within the INDC period. They found that the use of INDCs made important contributions towards achieving the 2 °C target. Meinshausen et al. [6] assumed one major emitting economy would take the lead in the international emission allocation scheme as an INDC approach and the results showed that there would be a large gap between what emission target was required for this leading country and its current INDC pledge. Fawcett et al. [7] studied Paris pledges from a probabilistic perspective and found that INDCs contribute both to reducing the risks of severe outcomes of global warming and to increasing the probability of limiting warming to 2 °C. However, no studies have yet focused on a quantitative generational equity assessment of the INDC and post-INDC time intervals.

To address this gap, we attempted to answer three research questions. (1) Does the use of INDCs lead to more mitigation costs for future generations as compared with the least-cost 2 °C scenarios presented in AR5? (2) How do the INDCs affect intra-generational equity? (3) Does greater reduction of emissions in INDCs help to improve generational equity?

Section 2 presents the model we used and the scenario framework. The analytical method applied to analyze the results derived from the model is also introduced. Section 3 presents the

model results for some of the main indicators and the results for the inter- and intra-generational equity analysis. In Section 4, we discuss the interpretations and implications of the results, limitations of the study, and future work in this area.

2 Methodology

2.1 AIM/CGE

We used AIM/CGE (Asia-Pacific Integrated Model/Computable General Equilibrium), which has been widely used in climate mitigation and impact assessment [8-12]. AIM/CGE is a recursive dynamic general equilibrium model that includes 17 regions and 42 industrial classifications. Energy sectors, including power sectors, are disaggregated in detail. Moreover, to assess bioenergy and land use competition appropriately, agricultural sectors are also highly disaggregated [13]. This CGE model was developed based on the “Standard CGE model” [14], and details of the model structure and mathematical formulas are described in the AIM/CGE basic manual [15].

The production sectors are assumed to maximize profits under multi-nested Constant Elasticity Substitution (CES) functions and each input price. Energy transformation sectors input energy and value added as fixed coefficients of output. They are treated in this manner to appropriately deal with energy conversion efficiency in the energy transformation sectors. Power generation values from several energy sources are combined with a Logit function. This method is adopted in consideration of energy balance because the CES function does not guarantee a material balance. Household expenditures on each commodity are described by a Linear Expenditure System (LES) function. The saving ratio is endogenously determined to balance saving and investment, and capital formation for each good is determined by a fixed coefficient. The Armington assumption is used for trade, and the current account is assumed to be balanced.

In addition to energy-related CO₂ emissions, CO₂ from other sources, CH₄, and N₂O are treated as GHG emissions in this model. Non-energy related CO₂ emissions consist of land use change and industrial processes. CH₄ has various sources, but the main sources are the rice production, livestock, fossil fuel mining, and waste management sectors. N₂O is emitted by fertilizer applications and livestock manure management, as well as by the chemical industry. Energy-related emissions are associated with fossil fuel consumption and combustion. Non-energy-related emissions, other than land use change emissions, are assumed to be in proportion to the level of activities (i.e., output). Land use change emissions are derived from the difference of forest land area from that of the previous year multiplied by the carbon stock density.

The implementation of mitigation is represented by either a global emissions constraint or country-level emission constraints. A carbon tax is employed to meet the global or country-level emission constraints, and it is therefore either globally uniform or variable across regions, depending on the type of constraint. The carbon tax makes the price of fossil fuel goods higher when emissions are constrained and promotes energy savings and the substitution of fossil fuels by lower emission energies and also acts as an incentive to reduce the non-energy-related emissions. Gases other than CO₂ are weighted by global warming potential and summed as GHG emissions in CO₂ equivalents. The revenue from the carbon tax is assumed to be received by households.

2.2 Scenarios

Table 1 outlines the four scenarios simulated in this study: Baseline, 450CO₂e, INDC_450CO₂e, and SINDC_450CO₂e. The Baseline scenario entails no emissions constraints and follows current trends in energy technologies. The 450CO₂e scenario includes emissions constraints that approximately meet the emission radiative forcing target of 2.6–2.8 W/m² in 2100, which can be interpreted as being in the range of the 2 °C target. The scenario employs a uniform global carbon price subject to particular emission targets discussed later. The INDC_450CO₂e scenario also meets a similar radiative forcing target. INDC pledges are satisfied before 2030. The resulting gap between INDC_450CO₂e and 450CO₂e in cumulative CO₂ emissions prior to 2030 is addressed by further reducing emissions from the 450CO₂e emission trajectory after 2030 in INDC_450CO₂e. The SINDC_450CO₂e scenario is similar to the INDC_450CO₂e scenario, but the INDC target for each country is 20% higher as compared with the target in INDC_450CO₂e. The emissions pathway after 2030 is determined in the same manner as in the INDC_450CO₂e scenario.

Table 1 Scenario descriptions			
	Emissions constraints		Radiative forcing in 2100 (W/m ²)
	Before 2030	After 2030	
Baseline	No emission constraints		7.28
450CO ₂ e	Global emission constraint		2.86
INDC_450CO ₂ e	Each country's emission constraint	Global emission constraint	2.83
SINDC_450CO ₂ e	Each country's emission constraint + additional emission reduction	Global emission constraint	2.79

The simulation period is 2005 to 2100. The socioeconomic assumptions behind all of the scenarios follow SSP2 (Shared Socioeconomic Pathways) [16] socioeconomic assumptions. Socioeconomic assumptions generally include assumptions not only on demographics and economic scale but also on other aspects, such as changes in energy technologies and dietary preference changes. Population and gross domestic product (GDP) growth are assumed to be the same as in Samir and Lutz [17] and Dellink et al. [18]. Other energy, land use, and agricultural assumptions are based on Fujimori et al. [19]. Countries are grouped into three regions: developing countries, industrial countries, and transition countries.

2.3 Analytical methods

After we obtained the scenario results, we analyzed the mitigation costs with respect to generational equity. Here, consumption loss or its rate is treated as a representative metric of mitigation costs. To make current and future mitigation costs comparable for inter-generation comparisons and to be able to aggregate the costs across time for both inter- and intra-generational analyses, a discount rate is introduced. The computation of the rate is explained in Section 2.3.1.

We made three types of analysis in section 3. First, we divided the years 2020–2100 into two

generations to analyze inter-generational equity. The current generation was defined as 2020–2060 and the future one as 2060–2100. Then, we compared the net present value (NPV) of both generations in terms of absolute consumption loss in the various scenarios. Using the discount rate, we converted future mitigation costs into an equivalent present value for 2020 and aggregated the values. The second and third are for intra-generational equity by evaluating the relationship between the consumption loss rate and GDP per capita across regions in each year as well as the average values for the entire period.

2.3.1 Ramsey rule and the discount rate

The discount rates were determined by Eq. 1 based on the Ramsey rule [20]:

$$\rho_{t,r} = \delta + \eta g_{t,r} \quad (1)$$

Here $\rho_{t,r}$ is the discount rate at time t for region r , and δ is the pure rate of time preference for the present. We assumed that the pure rate of time preference was 0 following the practice of previous studies [21–23], because there is broad consensus for a zero or near-zero pure rate of time preference for the present [1]. The parameter $g_{t,r}$ is the consumption growth rate in region r , and η can be viewed as a measure of intertemporal inequality aversion [24–27]. AR5 [1] explained η with the following thought experiment. Imagine an economic policy the aim of which is to increase consumption by 1 unit for every person in a poor group by reducing consumption for every wealthy person by x units. The maximum value of x that a person would accept to implement the policy is a metric of that person's inequality aversion. Values of 1–3 were often used for inequality aversion, with 2 being the most common value [1, 28]. This implies that the x from the thought experiment ranges from 2 to 8. Arrow et al. [28] suggested that η reflects the maximum sacrifice one generation should make to transfer income to another generation.

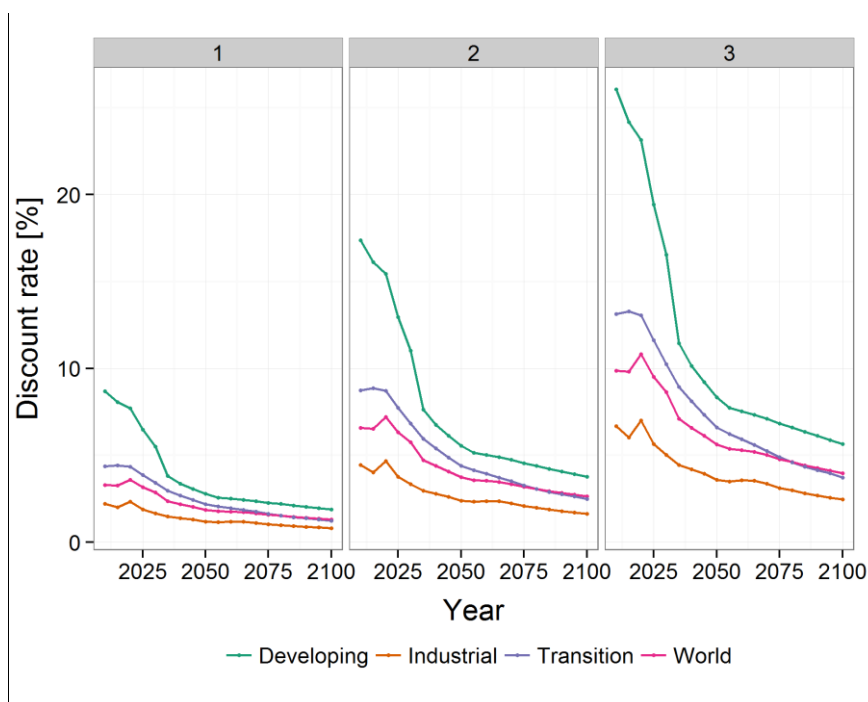


Figure 1 Regional and global discount rates for inequality aversions of 1, 2, and 3 in the Baseline

scenario.

Figure 1 shows how the discount rate varies over time with different values of inequality aversion. Although only the Baseline scenario is shown in Fig. 1, scenarios 450CO₂e and INDC_450CO₂e would show a similar consumption growth rate and implied discount rate. All of the curves show a declining trend after 2020.

2.3.2 Equity principles

Three equity principles are operationalized in our study. First, the use of a discount rate involves equity. The discount rate is determined on the basis of people's inequality aversion, as noted above. Different inequality aversion values are used in the analysis, and their effects on the results are discussed. Second, inter-generational equity was measured by the mitigation cost for current and future generations. In our calculations, we assumed that equity was improved once the relative difference of the NPVs of both generations' absolute consumption losses decreased. Finally, intra-generational equity was defined such that mitigation costs for different regions should be as equal as possible.

3 Results

3.1 Main indicators

3.1.1 GHG emissions

Figure 2 shows the emission paths for the Baseline, 450CO₂e and INDC_450CO₂e scenarios. To meet the 2 °C target, the 450CO₂e scenario assumes a gradually declining global emission path. Total global emissions are 48.9 GtCO₂eq in 2020 and 8.76 GtCO₂eq in 2100. In the INDC_450CO₂e scenario, each country's emissions between 2020 and 2030 are consistent with its INDC pledge. After 2030, the gap in cumulative CO₂ emissions from before 2030 as compared with emissions in the 450CO₂e scenario will be filled by allocating additional emissions reductions to the latter part of the period. Starting in 2060, emissions in the INDC_450CO₂e scenario would be lower than in the 450CO₂e scenario. After 2080, total global emissions reach a lower limit and then remain steady.

Emissions in developing countries, transition countries, and globally are greater in the INDC_450CO₂e scenario than those in the 450CO₂e scenario from 2020 to 2030, whereas they are about the same in industrial countries. Industrial countries' emissions increase slightly after 2030, primarily because the global uniform carbon price after the INDC period is much lower than it is during the INDC period.

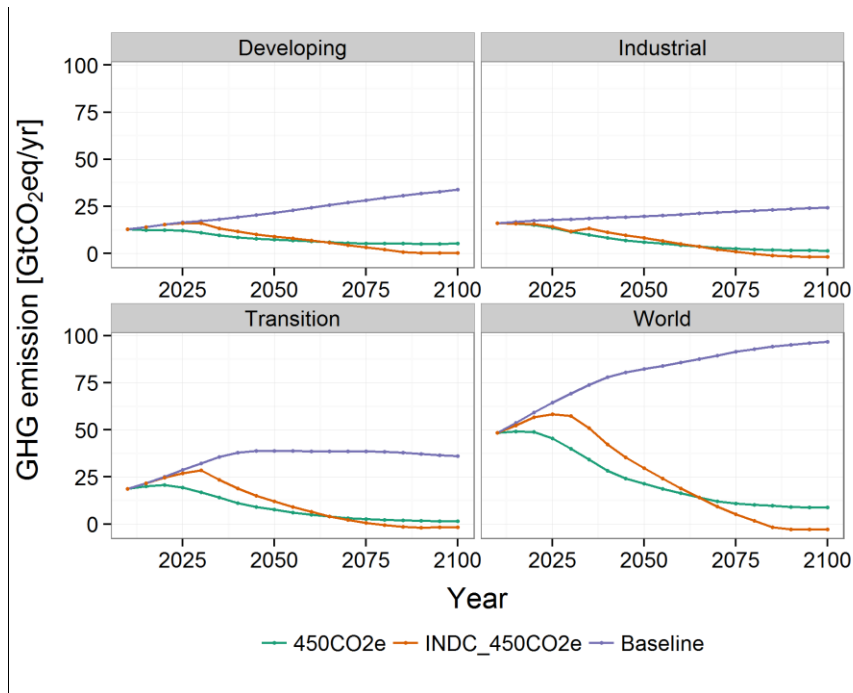


Figure 2 Regional GHG emission paths for scenarios Baseline, 450CO₂e and INDC_450CO₂e.

3.1.2 Carbon price

In the 450CO₂e scenario, a uniform global carbon price is assumed throughout the period. In the INDC_450CO₂e scenario, we set country-level carbon prices from 2020 to 2030 and a uniform global carbon price from 2030 to 2100. Carbon price climbed dramatically after 2075 in the INDC_450CO₂e scenario (Fig. 3a), primarily because greater emission reductions are required in the latter part of the century and the marginal cost of emission reduction is rising. Developing countries and transition countries have lower carbon prices in the INDC_450CO₂e scenario than in the 450CO₂e scenario from 2020 to 2030, whereas industrial countries have higher prices (Fig. 3b).

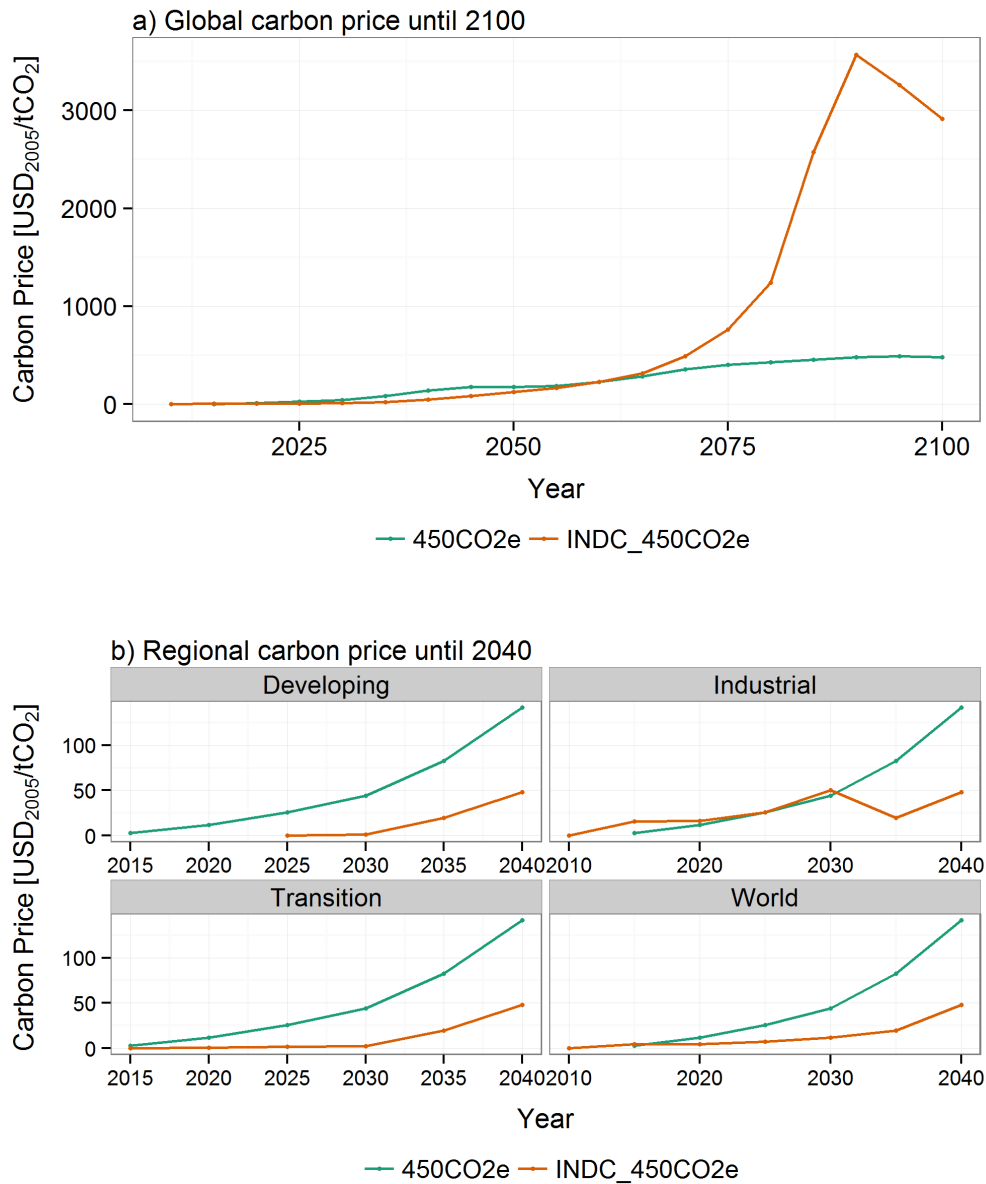


Figure 3 (a) Global carbon price through 2100 and (b) regional carbon price through 2040 for scenarios 450CO₂e and INDC_450CO₂e.

3.1.3 Mitigation cost

Figure 4 presents regional and global consumption loss rates as an indicator of mitigation costs. For industrial countries, mitigation costs from 2010 to 2030 in the INDC_450CO₂e scenario are slightly higher than they are in the 450CO₂e scenario. However, from 2030 to 2065, they are lower because the global carbon price helps to reduce mitigation costs. Global mitigation costs in the INDC_450CO₂e scenario are less than those in the 450CO₂e scenario before 2060, but they are higher afterwards. Because the discount rate is not accounted for in these figures, the mitigation cost of the current and the future generations are not comparable.

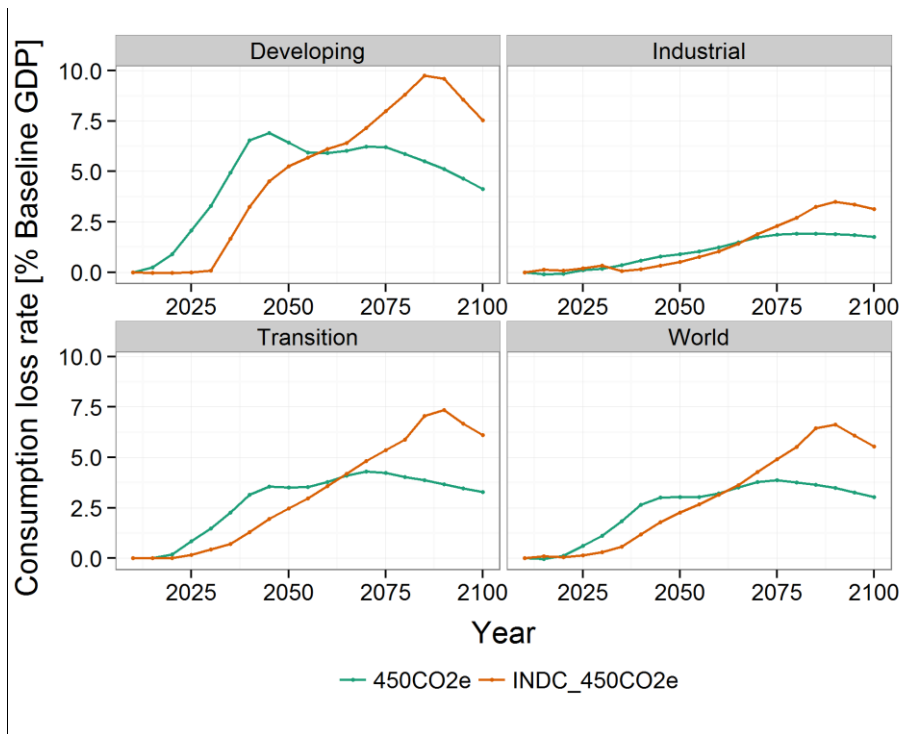


Figure 4 Regional mitigation costs for scenarios 450CO2e and INDC_450CO2e.

3.2 Inter-generational equity

We calculated the NPV of consumption losses for the current (2020–2060) and future (2060–2100) generations, as well as the relative differences between the two generations in each scenario. The relative difference was calculated as $(\text{NPV of the current generation} - \text{NPV of the future generation}) / \text{NPV of the future generation}$. This difference reflects the relative gap in mitigation costs between the two generations. Hence, it is an indicator of inter-generational equity—smaller values indicate greater inter-generational equity. It is important to note that it is only the absolute value of the relative difference that matters, not whether the value is positive or negative.

Figure 5 shows the consumption losses for the two generations and the relative differences between the two generations' global consumption losses. The discounted consumption loss is lower in the current generation and higher in the future in the INDC_450CO2e scenario as compared with the 450CO2e scenario for all inequality aversion values. The relative difference decreases as inequality aversion increases in both scenarios, but the relative difference in the 450CO2e scenario is always lower and approaches 0 when the inequality aversion is 3. Except for the case when the inequality aversion is 3 in the 450CO2e scenario, both scenarios favor the current generation over the future generation. In addition, the INDC_450CO2e scenario always has worse inter-generational equity, regardless of the inequality aversion value.

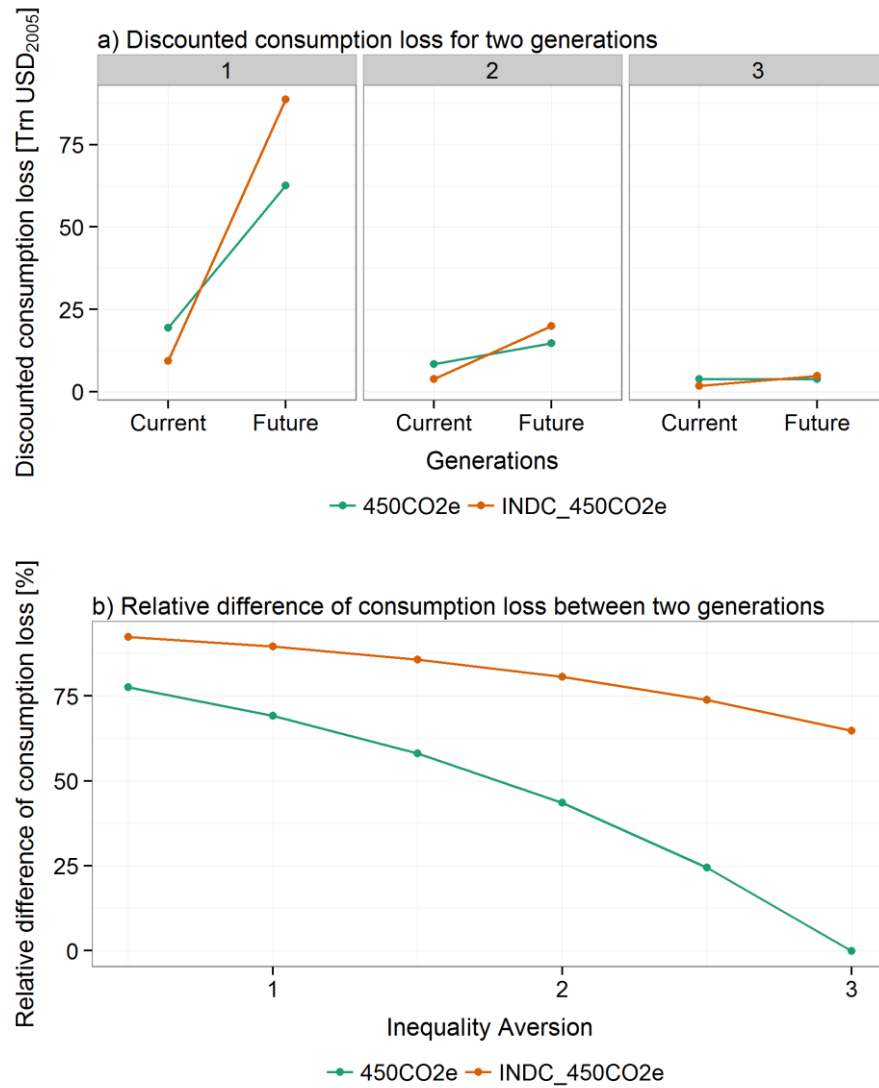


Figure 5 (a) Discounted consumption loss for two generations and (b) relative difference of consumption losses ($[\text{NPV current generation} - \text{NPV future generation}] / \text{NPV future generation}$) for scenarios 450CO2e and INDC_450CO2e. 1, 2, and 3 represent inequality aversion.

3.3 Intra-generational equity

Figure 6 shows scatter plots for the NPV consumption loss rates of the entire time period of 17 regions versus GDP per capita for the 450CO2e and INDC_450CO2e scenarios. We used the NPV consumption loss rate for each region to represent the average mitigation cost throughout the entire time period. The trend lines of the scatter plots show the trend of the relationship between income and mitigation cost for the different scenarios. A negative sloping trend line indicates that mitigation causes low-income countries to have higher consumption loss rates. The slope of the trend line in scenario INDC_450CO2e is more negative than that of scenario 450CO2e when the inequality aversion is small (i.e., 1). When the inequality aversion is 2 or 3, the slope in the INDC_450CO2e scenario is greater than that of the 450CO2e scenario. This occurs because the impact of the latter part of the century become less important to the NPV of the entire time period when the discount rate is relatively high, and the earlier part of the

century is more heavily weighted.

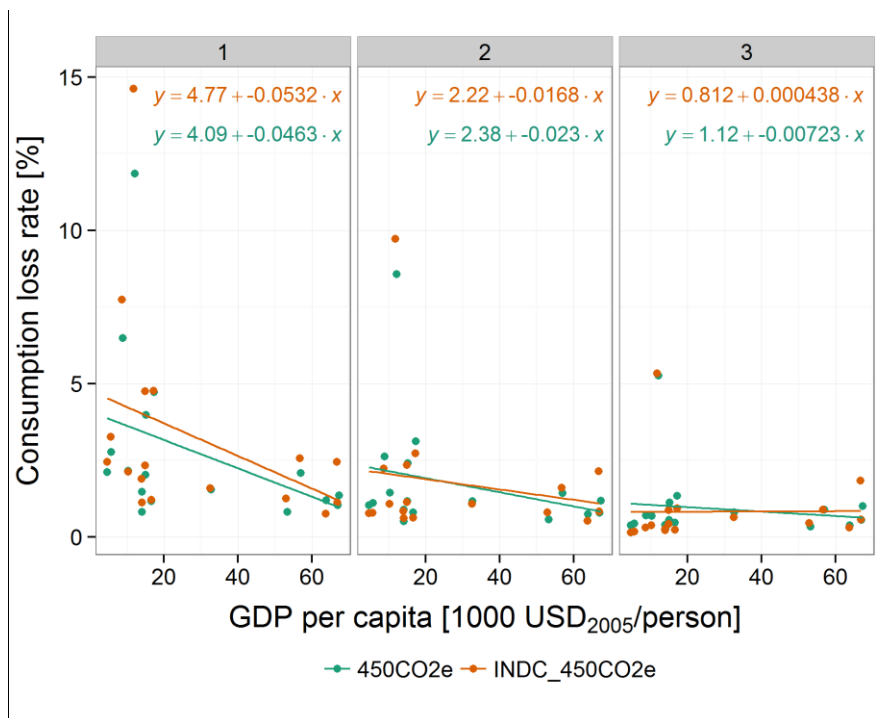


Figure 6 Intra-generation scatter plots for scenarios INDC_450CO2e and SINDC_450CO2e with inequality aversions of 1, 2, and 3.

We evaluated variations in intra-generational equity over time from the regression parameters of the intra-generation scatter plots in different years (Fig. 7). The discount rate is not used here. In the first part of the period, scenario INDC_450CO2e has better intra-generational equity compared to scenario 450CO2e. After about 2060, however, the situation is reversed.

We assumed a uniform carbon price across regions for the entire period in the 450CO2e scenario and from 2030 to 2100 in the INDC_450CO2e scenario. A global carbon price would have a greater adverse impact on low-income countries than on high-income countries. Before 2030, INDC pledges ensure that intra-generational equity improves because low-income regions gain opportunities to develop their economies by pledging lower emission reductions during this period. The low-income countries continue to benefit from this economic development from 2030 to 2055 even though the global carbon price increases. Thus, before 2060, intra-generational equity is better in the INDC_450CO2e scenario, but the carbon price after 2060 becomes much higher in the INDC_450CO2e scenario than in the 450CO2e scenario, and mitigation costs increase for the low-income countries. At this point, the impact of the global carbon price becomes dominant, and the INDC_450CO2e scenario performs worse than the 450CO2e scenario in terms of intra-generational equity.

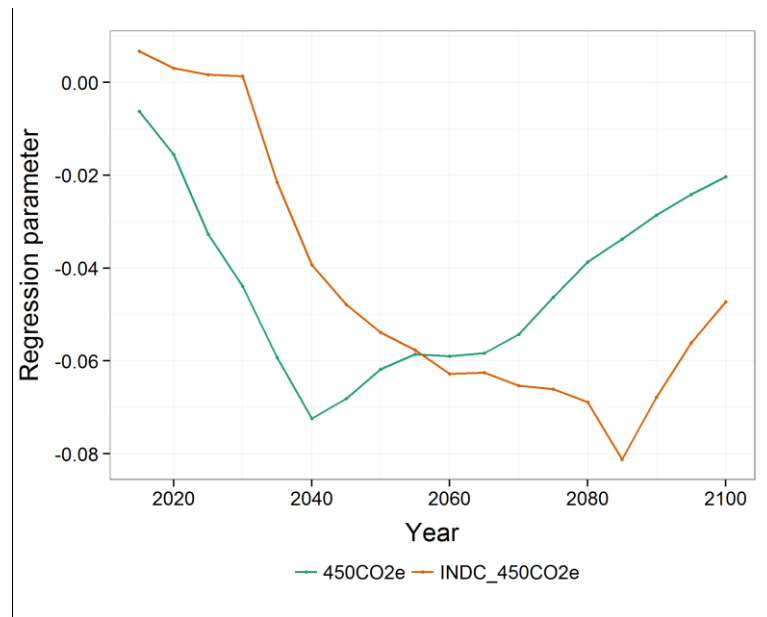


Figure 7 The regression parameters of the intra-generation scatter plot through 2100 for scenarios 450CO2e and INDC_450CO2e.

3.4 Stringent INDC scenario analysis

In the SINDC_450CO2e scenario, we assumed each region had more stringent INDC emission targets to explore how it would affect inter- and intra- generational equity. Increasing the emissions reduction target in the INDC period reduced the relative difference of consumption losses between current and future generations compared with the INDC_450CO2e scenario (Fig. 8).

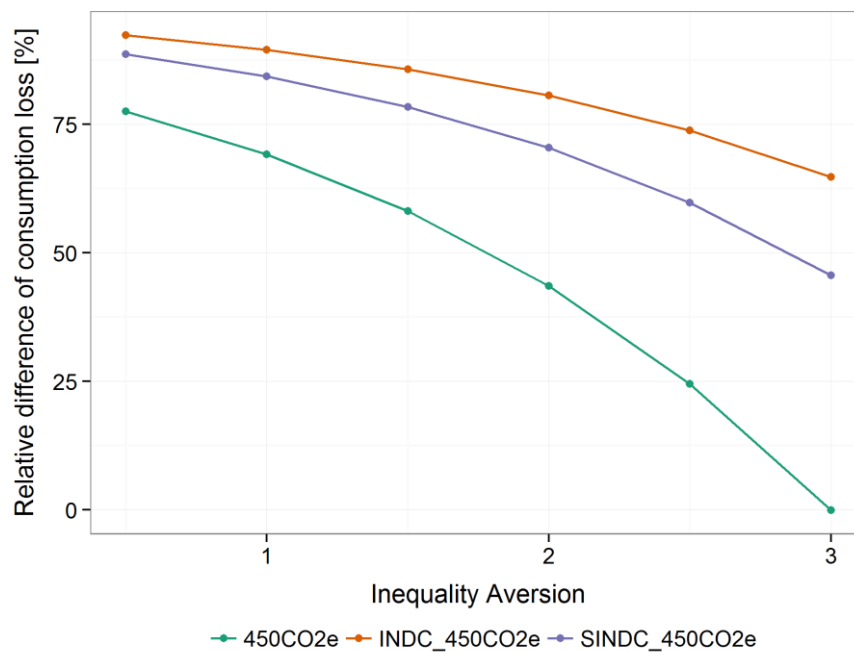


Figure 8 Mitigation cost comparison between current and future generations for inequality aversions of 1, 2, and 3 in scenarios 450CO2e, INDC_450CO2e, and SINDC_450CO2e.

That the SINDC_450CO2e scenario has a regression line slope that is less negative than the slope of the INDC_450CO2e scenario regression line when the inequality aversion is below 2 (Fig. 9) indicates greater intra-generational equity. The turning point of inequality aversion at which scenario SINDC_450CO2e becomes preferable to scenario 450CO2e is also lower than that of scenario INDC_450CO2e, primarily because the carbon price is lower in SINDC_450CO2e than it is in INDC_450CO2e, particularly in the latter half of the century.

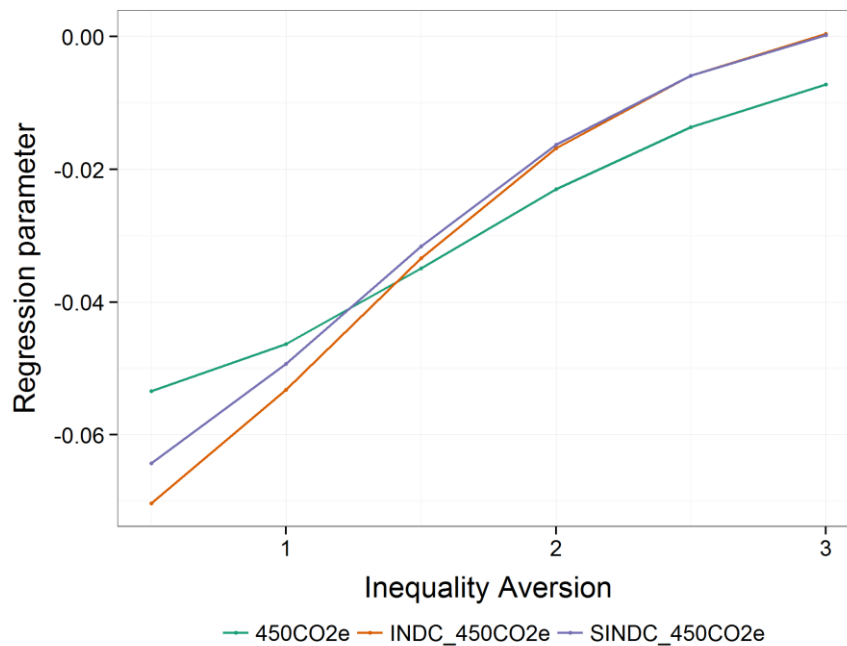


Figure 9 Regression parameters of the aggregated intra-generation scatter plots for inequality aversions of 1, 2, and 3 in scenarios 450CO2e, INDC_450CO2e, and SINDC_450CO2e.

4 Discussion and conclusions

This study assessed inter- and intra-generational equity based on the temporal and spatial distribution of global mitigation costs using AIM/CGE.

4.1 Interpretations and policy implications

There are four points to be discussed. First, we observed that inter-generational equity was worse in scenario INDC_450CO2e than it was in 450CO2e, mainly because INDC_450CO2e has a limited amount of emission reductions through 2030 and postpones the reduction efforts into the future as compared with 450CO2e. The inter-generational equity status for the INDC and post-INDC emission pathway is not favorable in this sense, because the future generation suffers from the larger emissions reductions required in the latter part of the century. This conclusion was robust for inequality aversion parameters (i.e., implied discount rates) ranging from 1 to 3. This would suggest that additional emission reduction efforts in the near term are desirable to achieve the 2 ° target from the viewpoint of inter-generational equity.

Second, scenario INDC_450CO2e performs better in terms of intra-generational equity during the entire period on average as compared with scenario 450CO2e if the inequality aversion is large. Equity was defined such that high-income regions and low-income regions have

identical consumption loss rates. Under this principle, INDC_450CO₂e has better intra-generational equity in the early part of the century as compared with that of 450CO₂e. However, this is not the case for the latter part of the century because of the drastic increase of mitigation costs in this period.

Third, the modified INDC scenario, SINDC_450CO₂e, had increased emission reductions prior to 2030. Inter-generational equity improved as compared with INDC_450CO₂e, although it still was worse than inter-generational equity with 450CO₂e. Furthermore, its average intra-generational equity was also better than that of INDC_450CO₂e. The Paris Agreement states that emissions targets will be reviewed and revised in 2020 [2]. This implies that there is still room to enforce stronger emissions reduction for 2030. Our results indicate that each country should adjust its target and commit to greater emissions reductions in the follow-up INDC communications.

Moreover, although we did not consider a specific burden-sharing scheme after 2030 in this study, we surmise from the intra-generational equity results that a global uniform carbon price is relatively harmful for developing countries and should be avoided. It seems that ongoing consideration for low-income countries will be needed as part of global climate change cooperation after 2030.

4.3 Limitations and future steps

There are four points with respect to limitations of this study and future steps. First, the 21st Conference of Parties (COP21) reached an agreement to pursue efforts to limit the global temperature increase to 1.5 °C above pre-industrial levels. How would the status of generational equity change assuming we follow the INDC pledges and the achievement of the 1.5 °C target by the year 2100? We have not yet addressed this issue but regard it as a next step in our study of equity in climate change policy. In addition,

Second, in this study we only considered the distribution equity in terms of the distribution of global mitigation costs. Historical responsibilities, compensatory justice, and other factors that may also be relevant to the equity discussion [4] were not considered. In the future, we intend to create scenarios that incorporate historical responsibilities and other factors in the distribution of emission reductions.

Third, here we only considered mitigation costs, negative impacts of climate change and adaptation costs are obviously important elements of the generational equity issue. Although mitigation cost assessment is a prioritized area in terms of INDCs and emission reduction targets, impact and adaptation aspects need to be considered in future studies.

Finally, we assumed that each year's emissions after 2030 were adjusted to fill the gap between the immediate emission reduction scenario and the INDC emission targets during the INDC period. In future studies, we may try to use an emission INDC pathway derived from some type of intertemporal model, for example, the DICE model.

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