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## Climate Warming Mitigation from Nationally Determined Contributions

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1 **Running head: Regional NDC contributions to climate mitigation**

2 **Climate Warming Mitigation from Nationally Determined Contributions**

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## 12 **ABSTRACT**

13 Individual countries are requested to submit nationally determined contributions  
14 (NDCs) to alleviate global warming in the Paris Agreement. However, the global climate  
15 effects and regional contributions are not explicitly considered in the countries' decision-  
16 making process. In this study, we evaluate the global temperature slowdown of the NDC  
17 scenario ( $\Delta T = 0.6^\circ\text{C}$ ) and attribute the global temperature slowdown to certain regions of  
18 the world with a compact earth system model. Considering reductions in CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O,  
19 BC, and SO<sub>2</sub>, the R5OECD (the Organization for Economic Co-operation and  
20 Development in 1990) and R5ASIA (Asian countries) are the top two contributors to global  
21 warming mitigation, accounting for 39.3% and 36.8%, respectively. R5LAM (Latin

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22 America and the Caribbean) and R5MAF (the Middle East and Africa) followed behind,  
23 with contributions of 11.5% and 8.9%, respectively. The remaining 3.5% is attributed to  
24 R5REF (the Reforming Economies). Carbon Dioxide emission reduction is the decisive  
25 factor of regional contributions, but not the only one. Other greenhouse gases are also  
26 important, especially for R5MAF. The contribution of short-lived aerosols is small but  
27 significant, notably SO<sub>2</sub> reduction in R5ASIA. We argue that additional species beyond  
28 CO<sub>2</sub> need to be considered, including short-lived pollutants, when planning a route to  
29 mitigate climate change. It needs to be emphasized that there is still a gap to achieve the  
30 Paris Agreement 2-degree target with current NDC efforts, let alone the ambitious 1.5-  
31 degree target. All countries need to pursue stricter reduction policies for a more sustainable  
32 world.

33

34 **Key words:** climate mitigation, nationally determined contributions, attribution, regional  
35 contribution, integrated assessment models

36 **Article Highlights:**

- 37 ● Compared with a no climate policy scenario, the NDC scenario shows a slowed  
38 global warming of 0.6°C by the end of the century, although there is still a gap when  
39 considering the Paris Agreement target.
- 40 ● R5OECD and R5ASIA are the top two contributors to global warming mitigation,  
41 accounting for 39.3% and 36.8% on average, respectively.
- 42 ● CO<sub>2</sub> reduction is the decisive factor of regional contributions to climate mitigation,  
43 while non-CO<sub>2</sub> reductions are small but significant.

44

45

46 **1. Introduction**

47 Anthropogenic activities have been the main driving force behind climate change, and  
48 the impact of global warming on human society and natural systems is increasing (IPCC  
49 2014). The Paris Climate Agreement has set a target of 2°C above the preindustrial level  
50 while also pursuing a 1.5°C target (UNFCCC 2015). Mitigating global climate change  
51 requires domestic emission reduction policies. Individual countries are supposed to submit  
52 nationally determined contributions (NDCs) to achieve these global climate goals  
53 (UNFCCC 2015).

54 NDCs are bottom-up commitments, not top-down allocations such as the Kyoto  
55 Protocol, which mainly consider their own ambitions and feasibility. Other countries'  
56 emission reductions or global climate effects are not necessarily considered. It is  
57 meaningful to quantify the regional contributions to global climate change mitigation.  
58 Previous literature has conducted some research on regional contributions. Regional  
59 carbon emission reductions are the most intuitive evaluation indicator and are widely used  
60 [e.g., (Roelfsema et al., 2020)]. Some studies also use emissions metrics (Denison et al.,  
61 2019). Historical emissions of long-lived gases remain important for future contributions  
62 to global warming and play an important role in strong mitigation scenarios (Skeie et al.,  
63 2021). Mitigating non-CO<sub>2</sub> emissions such as SLCFs is also critical for meeting the Paris  
64 Agreement ambitions and sustainable development goals (Lund et al., 2020). However,  
65 there is currently no literature that absolutely attributes the slowdown of temperature rise  
66 to national emission reductions. This study aims to calculate the relative contributions by

67 region to climate mitigation, providing a perspective on the emission reduction impact of  
68 the NDC scenario compared with the no climate policy (NP) scenarios.

69 Thus, this study first estimates the global temperature slowdown and then attributes  
70 this response to particular world regions. Section 2 describes the data and methods,  
71 including scenario datasets, OSACR v3.1 model, simulation framework and attribution  
72 method, and uncertainty analysis. Section 3 describes the climate mitigation of the NDC  
73 scenario relative to the NP scenario. Section 4 attributes climate mitigation to regional  
74 emission reductions. Finally, section 5 presents discussions and conclusions.

## 75 **2. Data and methods**

### 76 *2.1 Scenario datasets*

77 The CD-LINKS project (Linking Climate and Development Policies - Leveraging  
78 International Networks and Knowledge Sharing) is an international collaborative project  
79 that brings together research from integrated assessment modeling and explores the  
80 complex interplay between climate action and development through global and national  
81 perspectives (<http://www.cd-links.org/>). This study uses emission scenario datasets from  
82 the CD-LINKS project to drive a simple climate model. We downloaded CD-LINKS  
83 scenario datasets from IMAC 1.5°C Scenario Explorer hosted by IIASA (Huppmann,  
84 Rogelj et al., 2018), available at <http://data.ene.iiasa.ac.at/iamc-1.5c-explorer>. Emissions  
85 of five species are considered in this study: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous  
86 oxide (N<sub>2</sub>O), black carbon (BC), and sulfur dioxide (SO<sub>2</sub>). A set of consistent national and  
87 global low-carbon development pathways that take current national policies and nationally  
88 determined contributions (NDCs) is developed in the CD-LINKS project as an entry point  
89 for short-term climate action and then transition to long-term goals of 1.5 °C and 2°C as

90 defined by the Paris Agreement (Roelfsema, van Soest et al., 2020). The CD-LINKS  
91 scenarios were originally developed in late 2017.

92 The NP scenario and NDC scenario are the two scenarios at the core of this paper.  
93 Emissions in the NDC scenario relative to the NP scenario are considered mitigation, and  
94 the differences in global mean surface temperature (GMST) and atmospheric CO<sub>2</sub> are the  
95 intended targets to be attributed. The 2-degree scenario (each country implements its  
96 current implemented policies until 2020 and starts with cost-effective implementation to  
97 achieve the 2-degree target between 2020 and 2030 with high probability) and the 1.5-  
98 degree scenario (each country implements current implemented policies until 2020 and  
99 starts with cost-effective implementation to achieve the 1.5-degree target between 2020  
100 and 2030 with high probability) are also simulated as supporting data to show the  
101 mitigation gaps of climate goals and current NDC. Detailed information on the scenario  
102 definitions can be found at <http://data.ene.iiasa.ac.at/iamc-1.5c-explorer>. For each  
103 scenario, data from the five integrated assessment models (IAMs) are available: AIM/CGE  
104 2.1, IMAGE 3.0.1, MESSAGEix-GLOBIOM 1.0, REMIND-MAgPIE 1.7-3.0, and  
105 WITCH-GLOBIOM 4.0. These IAMs differ at the national and sectoral integration levels,  
106 and they simulate climate policy decisions in different ways. Therefore, there are  
107 differences in the emission data calculated by these IAMs.

108 In this study, the world is divided into five regions, the same as the shared  
109 socioeconomic pathways (SSP) database (Riahi et al., 2017). The five regions are  
110 abbreviated as the Organization for Economic Co-operation and Development in 1990  
111 (R5OECD), Asian countries (R5ASIA), Latin America and the Caribbean (R5LAM), the  
112 Middle East and Africa (R5MAF), and the Reforming Economies (R5REF).

## 113 ***2.2 OSCAR v3.1 model***

114 OSCAR v3.1 is used in this study to simulate and attribute climate change mitigation  
115 from the NDCs. OSCAR v3.1 is a reduced-complexity Earth system model that contains  
116 all the components needed to simulate climate change, including modules such as the  
117 carbon cycle, tropospheric and stratospheric chemistry, aerosols, and climate response  
118 (Gasser, Ciais et al., 2017, Gasser, Kechiar et al., 2018, Gasser, Crepin et al., 2020).  
119 OSCAR v3.1 is available at <https://github.com/tgasser/OSCAR/tree/v3.1>. In addition,  
120 OSCAR is built as an emulator with parameters calibrated by more complex models or  
121 observations, such as CMIP5, WETCHIMIP, ACCMIP, and TRENDY, making it capable  
122 of emulating the sensitivity of models of superior complexity (Gasser et al., 2017). The  
123 model is driven by emission datasets of greenhouse gases and aerosol precursors, which  
124 calculate the corresponding changes in atmospheric concentrations before predicting  
125 radiation forcing and climate change. OSCAR has widely been used in projections and  
126 attributions in climate change communities (Ciais et al., 2013; Gasser et al., 2018),  
127 especially for regional climate contributions (Li et al., 2016; Fu et al., 2021). In this study,  
128 we use OSCAR v3.1 to simulate future GMST and atmospheric CO<sub>2</sub> changes in different  
129 scenarios and to attribute the contributions of climate mitigation to different regions.

## 130 ***2.3 Simulation framework and attribution method***

131 The temperature mitigation ( $\Delta T$ ) between the NDC and NP scenarios represents the  
132 objective of this study, which reflects the climate change mitigation of NDC emission  
133 reductions relative to the no climate policy scenario. The temperature difference between  
134 the experiments in the NDC and NP scenarios is regarded as warming mitigation and is  
135 attributed to various regions of the world. First, we run a base simulation to obtain the

136 temperature mitigation. The OSCAR model is driven by the NP scenario and NDC scenario  
 137 data from CD-LINKS to simulate the global temperature in the two scenarios before  
 138 calculating the temperature mitigation ( $\Delta_{base}T = T_{NP} - T_{NDC} = OSCAR(E_{NP,globe}) -$   
 139  $OSCAR(E_{NDC,globe})$ ).

140 To attribute the temperature slowing specific to the regions, the ‘normalized marginal  
 141 attribution method’ is used in this study. Applying the normalized marginal attribution  
 142 method is advised by the United Nations Framework Convention on Climate Change  
 143 (UNFCCC) to solve nonlinear climate attribution problems (UNFCCC 2002). One study  
 144 discussed seven attribution methods and concluded that the normalized marginal  
 145 attribution method is one of the two most suitable for climate attribution (Trudinger and  
 146 Enting, 2005). The normalized marginal attribution method evaluates the contributions of  
 147 individual regions proportional to their marginal effects and constrains the total of  
 148 individual contributions equal to the global effect. In many early studies, this method  
 149 attributed climate changes to processes or specific regions (Ciais et al., 2013; Li et al.,  
 150 2016; Fu et al., 2020; Fu et al., 2021).

151 To implement the normalized marginal method in this study, we ran the basic  
 152 simulation, and changed the regional emissions mitigation of each region (noted as  $r_i$ ) by  
 153 a small fraction  $\varepsilon$  as input for each simulation and repeatedly calculated temperature  
 154 mitigation ( $\Delta_{r_i}T$ ). The mathematical expression is  $\Delta_{r_i}T = T_{NP} - T_{NDC,r_i-\varepsilon} =$   
 155  $OSCAR(E_{NP,globe}) - OSCAR(E_{NDC,globe} + \varepsilon(E_{NP,r_i} - E_{NDC,r_i}))$ . The purpose of these  
 156 marginal experiments is to calculate the marginal effect of emission reduction in each  
 157 region. Then, the marginal effects are normalized to calculate the relative contributions of



158 each region  $\alpha_i = \frac{\Delta_{\text{base}T} - \Delta_{r_i}T}{\sum_{j=1}^m \Delta_{\text{base}T} - \Delta_{r_j}T}$  and the absolute contributions are calculated by  
159  $\alpha_i \Delta_{\text{base}T}$  following the normalization marginal method. The  $\varepsilon$  value is 0.1%, similar to  
160 early studies that applied the OSCAR model, while several studies found that the results  
161 are insensitive to  $\varepsilon$  values (UNFCCC 2002, Trudinger and Enting, 2005).

## 162 *2.4 Uncertainty analysis*

163 This study considers the uncertainties from two aspects: the model parameters and the  
164 scenario data. For parameter uncertainties, all simulations are run under a Monte Carlo  
165 ensemble ( $n = 3000$ ). Parameters are randomly drawn from the pool available in OSCAR  
166 v.3.1. OSCAR has approximately 200 parameters, which play a role in the carbon cycle  
167 module, tropospheric and stratospheric chemistry, aerosols, climate response, etc. They are  
168 listed in the OSACR model manual  
169 (<https://github.com/tgasser/OSCAR/blob/v3.1/MANUAL.pdf>). As an emulator, different  
170 configurations of OSCAR emulate different models of higher complexity, so the Monte  
171 Carlo ensemble shows the model uncertainties. For scenario data, the CD-LINKS dataset  
172 contains scenario data from five different IAMs. Data from different IAMs have large  
173 variances, so we show both the average and the standard deviation of the results as well as  
174 the results for each IAM separately.

## 175 **3. Climate mitigation from NDCs**

176 As mentioned in section 2.3, this study focuses on the difference in climate effects  
177 between NDC and NP scenarios. Their carbon dioxide emissions are shown in red and  
178 orange in Fig. 1. In the NP scenarios, R5ASIA and R5OECD emit significantly more CO<sub>2</sub>  
179 than other regions, followed by R5MAF, while the CO<sub>2</sub> emissions of R5LAM and R5REF

180 remain low for an extended time. Compared with the NP scenario, R5ASIA and R5OECD  
181 have the most prominent contributions to CO<sub>2</sub> emission reduction, with cumulative  
182 emission reductions of 123.01 PgC and 106.89 PgC, respectively. The reductions of  
183 R5REF are rather small, which can also be seen in Fig. 2. The ranges of CO<sub>2</sub> emissions  
184 under both the NP and NDC scenarios show significant growth after 2030. Although the  
185 ranges of CO<sub>2</sub> emissions are affected by the simulation results of different IAMs, the ranges  
186 of CO<sub>2</sub> mitigation are mainly derived from the variance of the NDC scenario. The other  
187 two scenarios (the 2-degree and 1.5-degree) are also shown in Fig. 1. These two ideal  
188 scenarios are significantly different from the NP and NDC scenarios. The carbon emissions  
189 scenario shows an overall downward trend, gradually reaching carbon neutrality in the  
190 future. The 2-degree scenario achieves carbon neutrality in 2062–78, while the 1.5-degree  
191 scenario achieves carbon neutrality ten to twenty years earlier than the 2-degree scenario.  
192 This is similar to the result of Soest et al. (2021), who reported the realization of carbon  
193 neutrality by 2065–80 (2-degree) and 2045–60 (1.5-degree). Obviously, to achieve the  
194 climate goals of the Paris Agreement, it is not sufficient to rely solely on the existing NDCs.

195 In addition to CO<sub>2</sub>, the pathways of CH<sub>4</sub>, N<sub>2</sub>O, BC, and SO<sub>2</sub> are also considered in  
196 this study and used to drive the model. The cumulative reduction (for CO<sub>2</sub>, CH<sub>4</sub>, and  
197 N<sub>2</sub>O) or annual reductions (for BC and SO<sub>2</sub>) are shown in Fig. 2. Their emissions can be  
198 seen in Fig. S1. The region with the largest N<sub>2</sub>O emission reductions is the R5OECD,  
199 with an average of 19.59 TgN. R5OECD, R5ASIA, and R5LAM contribute significantly  
200 to CH<sub>4</sub> emission reductions, with average emission reductions reaching 1975.36 TgC,  
201 1627.76 TgC, and 1309.02 TgC, respectively. The critical regions for BC emission  
202 reduction are R5ASIA and R5LAM, both reaching approximately 0.02 TgC. SO<sub>2</sub> is

203 mainly reduced in R5ASIA, with an average of 0.57 TgS, accounting for more than 50%  
204 of global emission reductions. Notably, some data from specific IAMs show that the  
205 NDC scenario has larger regional emissions of some species than the NP scenario. For  
206 example, the emission reductions in R5REF obtained by the WITCH-GLOBIOM 4.0  
207 simulation are small negative values except for CH<sub>4</sub>. The emission reduction of BC in  
208 R5OECD obtained by IMAGE 3.0.1 simulation is -0.31 TgC, which is quite different  
209 from the results of other IAMs. There may be some inconsistency in how clean air  
210 policies are assumed in the IAMs. The uncertainty of IAMs is considerable, although  
211 they are less important to climate change than CO<sub>2</sub>.

212 The increase in temperature and atmospheric CO<sub>2</sub> relative to preindustrial times  
213 (~1850) is simulated by OSCAR v3.1, driven by the CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, BC, and SO<sub>2</sub> scenario  
214 datasets from CD-LINKS (Fig. 3 and Table 1). The average of the five IAMs shows that  
215 the global CO<sub>2</sub> change relative to 1850 will reach 531.9±128.4 ppm in the NP scenario and  
216 425.1±111.1 ppm in the NDC scenario in 2100. Adherence to NDC policy can avoid an  
217 increase of nearly 110 ppm in atmospheric CO<sub>2</sub>. Table 1 shows the increase in atmospheric  
218 CO<sub>2</sub> ( $\Delta$ CO<sub>2</sub>) simulated using scenario datasets from five IAMs. For the NP scenario,  
219 AIM/CGE 2.1 and IMAGE 3.0.1 result in an increase of approximately 500 ppm, while  
220 MESSAGEix-GLOBIOM 1.0, REMIND-MAgPIE 1.7-3.0, and WITCH-GLOBIOM 4.0  
221 result in an increase of approximately 550 ppm. For the NDC scenario, the results are also  
222 different; that is, AIM/CGE 2.1 and REMIND-MAgPIE 1.7-3.0 optimistically yield less  
223 than 400 ppm, while MESSAGEix-GLOBIOM 1.0 results are almost as high as 500 ppm.  
224 Comparing the effects of NP and NDC, the estimation of atmospheric CO<sub>2</sub> mitigation  
225 ranges from 56.05 ppm (MESSAGEix-GLOBIOM 1.0) to 151.34 ppm (REMIND-

226 MAgPIE 1.7-3.0). The range of  $\Delta\text{CO}_2$  for the NP scenario is 54.56 ppm, and that for the  
227 NDC scenario is 116.68 ppm. The range of  $\text{CO}_2$  mitigation calculated by the five IAMs is  
228 95.29 ppm, significantly higher than that for the NP scenario. Therefore, the range of  $\text{CO}_2$   
229 mitigation is mainly derived from the variance of the NDC scenario from IAMs.

230 The temperature increases in the four scenarios are also simulated (Fig. 3b). If no  
231 climate policy is implemented, the temperature will rise by  $4.1^\circ\text{C}\pm 0.9^\circ\text{C}$  relative to the  
232 preindustrial level. With NDC implemented, the temperature increase is controlled at  
233  $3.5^\circ\text{C}\pm 0.8^\circ\text{C}$ . Although there is still a large gap between the NDC scenario and the goals  
234 of the Paris Agreement, significant mitigations ( $0.6^\circ\text{C}$  on average) are achieved, which is  
235 the core focus of this article. The temperature in the NP scenario simulated by all IAMs is  
236 significantly larger than that in the NDC scenario. The temperature mitigations are  
237 calculated as the difference between the NP and NDC emission scenarios from the same  
238 IAM (Fig. 3b), ranging from  $0.3^\circ\text{C}$ – $0.8^\circ\text{C}$ . To enhance the reliability of the results, we  
239 also calculate the transient climate response to cumulative carbon emissions (TCRE) in  
240 Fig. S2, which ranges from  $1.54^\circ\text{C}$ – $1.94^\circ\text{C}/\text{PgC}$ , close to the estimates from the existing  
241 literature (Matthews, Gillett et al., 2009, Leduc, Matthews et al., 2016).

#### 242 **4. The contributions to temperature mitigation**

243 Furthermore, we attribute the temperature mitigation to regions according to the  
244 normalized marginal attribution method, in which relative contributions are proportional  
245 to the marginal climate effect of regional emission reductions. If only  $\text{CO}_2$  reduction is  
246 considered in the attribution, R5OECD and R5ASIA are the top two contributors, each  
247 accounting for more than 40% of the temperature mitigation on average (Fig. 4). The three  
248 IAMs conclude that R5OECD is the largest contributor, while the other two IAMs are more

249 confident about R5ASIA (Table 2). R5LAM accounts for 10.9% of the temperature  
250 mitigation, on average, and is the third-largest contributor. The remaining temperature  
251 mitigation is attributed to R5REF and R5MAF, and their contributions are very small (no  
252 more than 5% on average).

253 Considering additional climate forcings, the relative contribution of temperature  
254 mitigation has changed. Considering all GHG reductions, R5MAF becomes much more  
255 important, accounting for an average of 8.9%. This is because the global CH<sub>4</sub> and N<sub>2</sub>O  
256 reduction proportion of R5MAF is greater than that for CO<sub>2</sub> (Fig. 2). Correspondingly, the  
257 share of R5ASIA dropped by approximately six percentage points, while the shares of  
258 R5OECD, R5LAM, and R5REF showed little change. In addition, we also included  
259 aerosols (BC and SO<sub>2</sub>) in the attribution. Although there are significant changes between  
260 aerosol-included attribution ('GHGs+BC', 'GHGs+SO<sub>2</sub>', and 'all' in Table 2) and aerosol-  
261 excluded attribution ('GHGs' in Table 2), they are very small. This is because GHGs have  
262 a long atmospheric lifetime, and cumulative emissions determine their climate effects. In  
263 contrast, the climate effects of short-lived aerosols are essentially determined by the current  
264 year's emissions. Since the attribution is conducted for a long period (2014–2100), GHGs  
265 are much more important than aerosols in the mitigation attribution.

266 Considering 'all' climate forcings in this study (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, BC, and SO<sub>2</sub>),  
267 R5OECD and R5ASIA represent the two major contributors to global warming mitigation,  
268 accounting for 39.3% and 36.8%, respectively. R5LAM and R5MAF followed R5OECD  
269 and R5ASIA, contributing 11.5% and 8.9%, respectively. R5REF only contributed 3.5%.  
270 The relative contributions depend on regional emission reductions but are not limited solely  
271 to CO<sub>2</sub> emission reductions. Figure 5 shows that the regional contributions to climate

272 mitigation are positively correlated with the CO<sub>2</sub> emission reductions but are not  
273 completely linear. This is attributed to non-CO<sub>2</sub> climate forcing and the nonlinear processes  
274 of the climate system. The reductions in other GHGs and SO<sub>2</sub> are also worthy of attention,  
275 especially in certain regions, e.g., CH<sub>4</sub> in R5MAF and SO<sub>2</sub> in R5ASIA.

## 276 **5. Conclusion and discussion**

277 This study first assessed the regional contributions to the world's climate mitigation.  
278 According to our estimation, R5OECD and R5ASIA make similar contributions, covering  
279 almost three-quarters of climate change mitigation. At the same time, R5OECD and  
280 R5ASIA are the largest emitters of greenhouse gases and aerosols. The emission reduction  
281 actions of major emitters are essential to curb global climate change. R5LAM and R5MAF  
282 are of the second tier, each contributing approximately 10%. R5REF is a less critical  
283 contributor to slowing down warming, only 3.5%.

284 Our estimation of the regional contributions to climate mitigation is based on the  
285 deviation of the NP and NDC scenarios. This means that regional emission reductions  
286 determine future emission reduction contributions. Although, to a certain extent, high-  
287 emitting regions are more likely to contribute to greater emission reductions and cooling  
288 contributions, such as R5ASIA, while low-emitting regions, such as R5REF, are less likely  
289 to do so. However, this does not mean that larger emissions correspond to larger  
290 contributions. For example, the CD-LINKS dataset shows that CO<sub>2</sub> emissions in the  
291 R5MAF will rise in the future, becoming the world's second-largest emitter by 2100.  
292 However, the contribution of R5MAF to temperature mitigation is very small at 8.03%, a  
293 contribution that only surpasses the R5REF's contribution and is disproportionate to its  
294 emissions. Such results indicate that R5MAF has room to optimize the energy structure

295 and develop stricter climate policies to control the climate. At the same time, technical  
296 assistance from developed countries and regions may help reduce R5MAF emissions due  
297 to historical responsibilities. It is not inappropriate to simply think that the greater the  
298 contribution in this study, the more commendable it is.

299 We noticed that the scenario data significantly determine the evaluation results, and  
300 the scenario data of different IAMs vary greatly. In the CD-LINKS datasets, there are  
301 significant variances in the five IAMs, with the opposite sign possibly being found in some  
302 regions and species. There is a great deal of uncertainty in the process of translating  
303 national policy documents into future global emission forecast data. Different possible  
304 evolutions of NDC assumptions, which have resulted in estimated emissions ranging from  
305 47 to 63 TgCO<sub>2</sub> yr<sup>-1</sup> in 2030, have a significant impact on the feasibility and cost of  
306 predicting future global warming (Rogelj et al., 2017). We argue that the reliability and  
307 consistency of IAM datasets are vital for future scenario projection and attribution analysis.

308 Apart from the data differences caused by different IAMs, the gap between NDC and  
309 climate goals should be noted. The fact is that most existing emission reduction programs  
310 exceed the 2°C target set out in the Paris Agreement. In other words, current actions are  
311 not sufficient to achieve the goals of sustainable development (Sörgel et al., 2021). In  
312 addition, even if NDCs are assumed to be achieved, there is still a wide range of future  
313 possibilities because of the definition of the long-term carbon budget (Riahi et al., 2021).  
314 However, this does not mean that NDCs cannot be evaluated. Instead, we need to assess  
315 currently proposed NDCs with a clearer picture. Only when we have a clearer  
316 understanding of the contributions, gaps, and uncertainties of NDCs, can we plan and  
317 evaluate more ambitious policies and pathways. The legacy of excessive temperatures and

318 the feasibility of limiting warming to 1.5°C or less are central to the post-Paris Agreement  
319 scientific agenda (Schleussner et al., 2016).

320 At present, 157 Paris Agreement Parties (representing 156 countries) have submitted  
321 their new or updated NDCs (Climate Watch, 2020). According to the recent NDC synthesis  
322 report released by the UNFCCC, new or updated NDCs are expected to result in 3.5% and  
323 11.3% lower emission levels in 2025 and 2030, respectively, compared to the first NDCs,  
324 (UNFCCC, 2021). It is worth simulating the temperature mitigation and relative  
325 contributions of different regions under the updated NDC scenario. Unfortunately, the  
326 newest emission scenario pathway datasets of countries are still unavailable. We believe  
327 that the introduction of carbon-neutral policies will result in contribution increases for the  
328 current major carbon emitters, such as China (in R5ASIA), the United States, and the  
329 European Union (in R5OECD), both in absolute and relative aspects.

330 Meanwhile, the results of this paper can still be valuable as a reference for reflecting  
331 upon the necessary ambition to achieve the Paris goals and for discovering how countries  
332 can leverage their climate goals to achieve their sustainable development objectives. Of  
333 course, we strongly recommend evaluating the relative contributions under the updated  
334 NDCs when the newest datasets are available. Different countries give different peak  
335 carbon or carbon-neutral times, which affects their relative contributions.

336 We argue that all countries should introduce more ambitious emission reduction plans  
337 as soon as possible based on the current NDCs, and more international technical assistance  
338 to developing countries is needed to achieve a low-carbon world. These considerations  
339 represent important directions for climate policy research.

340



341 #: Bo Fu and Jingyi Li equally contributed to this work.

342

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350

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352 contributed to this study, who prepared the model set-up, conducted the simulations and  
353 wrote the text. T.G., P.C., S.P. and S.T. contributed to the interpretation of the results and  
354 to the text. G.S., Y.L., and L.H. contributed to the figures and the text.

355

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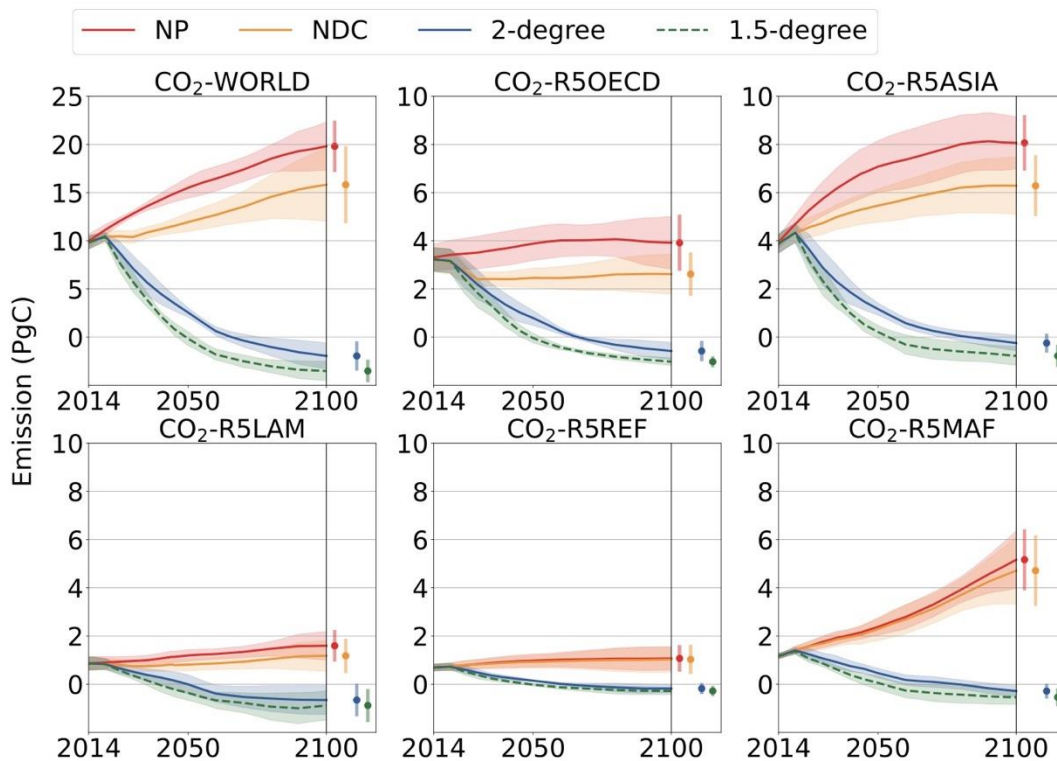
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448 **Table 1.** Future CO<sub>2</sub> increase ( $\Delta\text{CO}_2$ ) and temperature changes ( $\Delta\text{T}$ ) relative to 1850 in  
 449 2100.

Model	NP	NDC	2-degree	1.5-degree
Future CO <sub>2</sub> increase $\Delta\text{CO}_2$ (ppm)				
AIM/CGE 2.1	502.20±122.34	380.78±93.59	132.61±30.85	94.89±22.57
IMAGE 3.0.1	504.66±118.69	426.50±102.01	143.03±35.40	93.31±23.09
MESSAGEix- GLOBIOM 1.0	553.51±126.24	497.46±117.21	122.43±33.05	82.85±22.42
REMIND-MAgPIE 1.7-3.0	542.64±132.83	391.30±100.34	124.01±32.08	84.63±22.56
WITCH-GLOBIOM 4.0	556.76±130.53	430.10±102.42	121.36±28.68	83.96±20.79
average	531.89±128.42	425.07±111.14	128.69±33.12	87.93±22.29
Future temperature changes $\Delta\text{T}$ (°C)				
AIM/CGE 2.1	4.10±0.92	3.52±0.81	1.91±0.51	1.57±0.45
IMAGE 3.0.1	3.91±0.89	3.49±0.80	1.96±0.53	1.62±0.45
MESSAGEix- GLOBIOM 1.0	4.01±0.90	3.74±0.85	1.79±0.51	1.43±0.43
REMIND-MAgPIE 1.7-3.0	4.20±0.95	3.40±0.80	1.89±0.52	1.59±0.45
WITCH-GLOBIOM 4.0	4.00±0.90	3.35±0.78	1.61±0.45	1.32±0.40
average	4.05±0.92	3.50±0.82	1.83±0.52	1.51±0.44

450 **Table 2.** The contributions of regional NDC to climate change mitigation (%).

Model	Region	CO <sub>2</sub>	GHGs	GHGs+BC	GHGs+SO <sub>2</sub>	all
AIM/CGE 2.1	ASIA	31.3	27.8	27.4	28.3	27.9
	LAM	7.0	7.8	7.8	7.8	7.8
	REF	4.0	3.8	3.8	3.8	3.8
	OECD	51.2	51.6	51.9	51.2	51.4
	MAF	6.4	9.0	9.1	9.1	9.2
IMAGE 3.0.1	ASIA	31.0	28.4	28.5	27.1	27.2
	LAM	18.1	16.8	16.7	17.4	17.4
	REF	2.3	4.9	4.8	4.8	4.8
	OECD	36.8	34.6	34.3	36.0	35.7
	MAF	11.9	15.4	15.7	14.7	15.0
MESSAGEix- GLOBIOM 1.0	ASIA	37.1	31.7	31.4	31.6	31.4
	LAM	11.0	11.8	12.0	11.8	12.1
	REF	0.5	2.1	2.0	2.2	2.1
	OECD	51.1	52.7	52.5	52.6	52.4
	MAF	0.2	1.8	1.9	1.8	2.0
REMIND- MAgPIE 1.7- 3.0	ASIA	45.8	41.3	41.4	41.1	41.2
	LAM	10.6	11.4	11.4	11.5	11.5
	REF	1.1	3.3	3.3	3.4	3.4
	OECD	40.2	36.0	35.8	36.1	36.0
	MAF	2.4	7.9	8.0	7.9	8.0
WITCH- GLOBIOM 4.0	ASIA	69.5	56.6	56.6	56.2	56.2
	LAM	7.8	8.9	8.9	9.0	9.0
	REF	-1.6	3.2	3.2	3.4	3.4
	OECD	22.4	20.9	20.9	21.0	21.0
	MAF	1.9	10.4	10.3	10.4	10.4

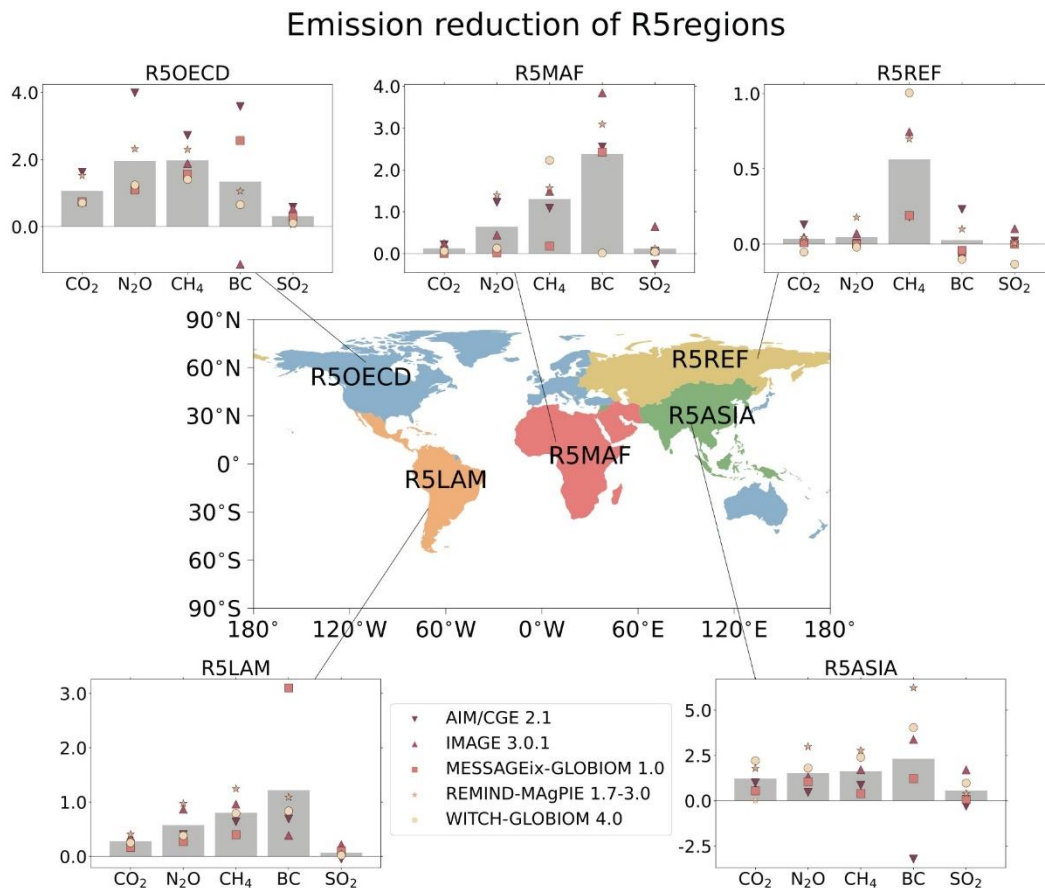


452

453 **Fig. 1.** CO<sub>2</sub> emissions of the R5 regions based on the CD-LINKS scenario dataset. Future  
 454 CO<sub>2</sub> emissions in the R5 region under four climate scenarios. The line is the average of  
 455 the results of the five emission IAMs, and the shaded areas show the range of the  
 456 scenario data. ‘NP’, ‘NDC’, and ‘2-degree’ scenarios are marked by red, orange, and  
 457 solid blue lines. The ‘1.5-degree’ scenario is marked by green dashed lines. Pathways of  
 458 other species (CH<sub>4</sub>, N<sub>2</sub>O, BC, and SO<sub>2</sub>) can be found in Fig. S1.

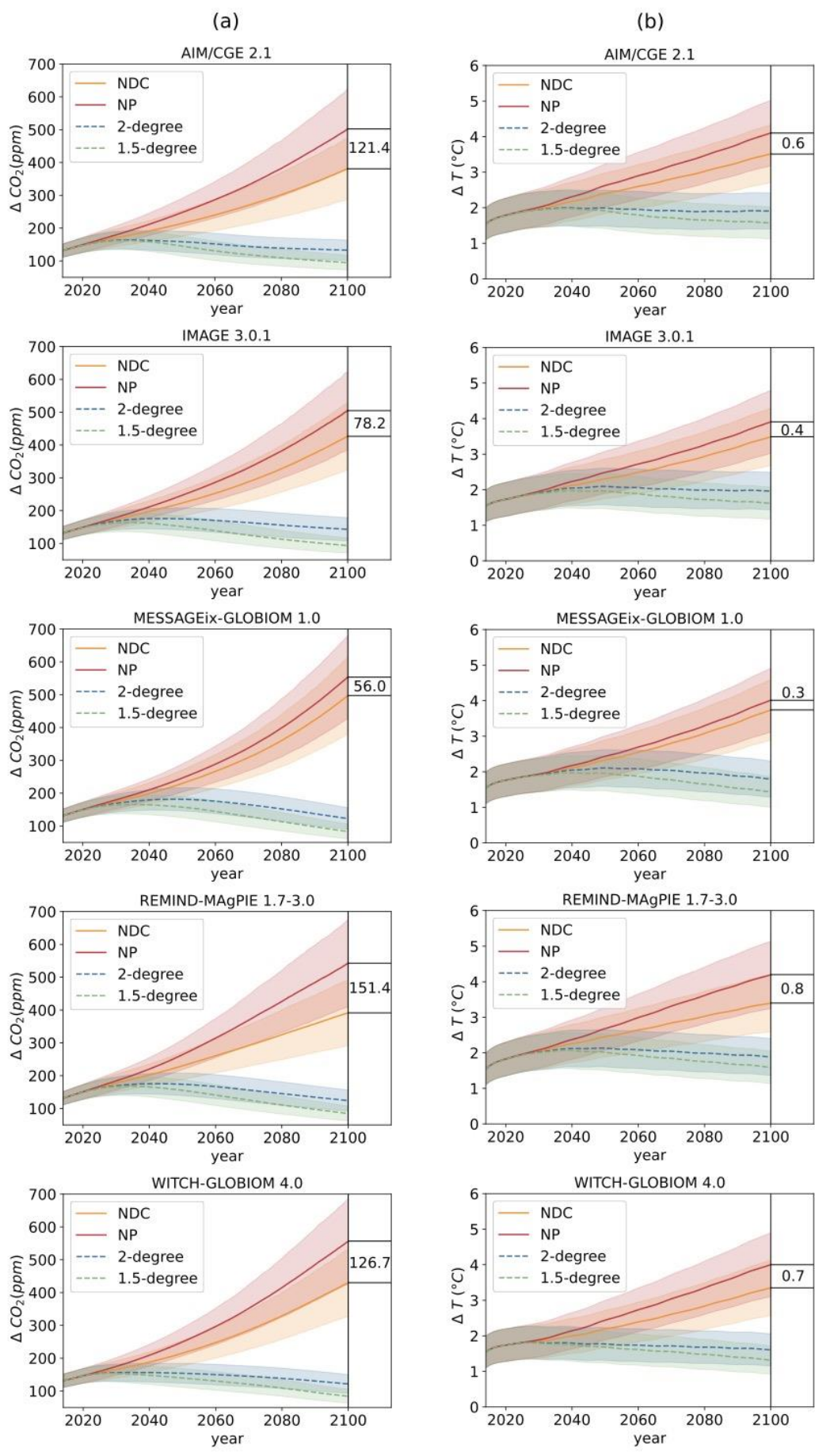


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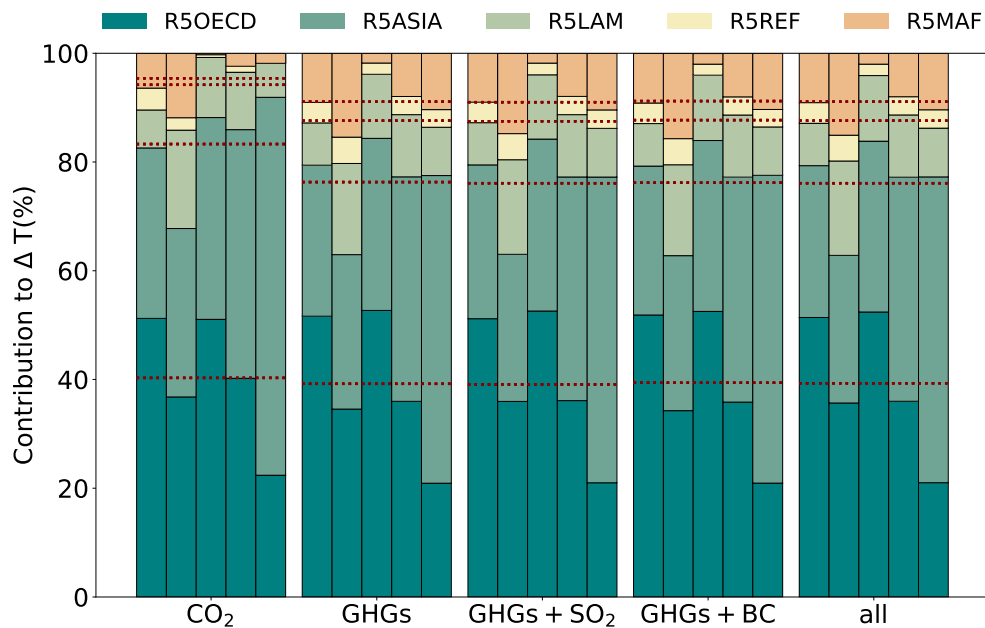


460

461 **Fig. 2.** The mitigation of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, BC, and SO<sub>2</sub> emissions of the R5 regions based  
 462 on the CD-LINKS scenario dataset. The map shows the regionalization (R5 regions) in  
 463 this study. The bars around the map show emission reductions of NDC relative to NP  
 464 scenarios. The cumulative reduction (for CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O) or annual reductions (for  
 465 BC and SO<sub>2</sub>) are shown here. The height of each column is a global emission difference,  
 466 with the different colors representing the various R5 regions. The results are based on  
 467 five IAMs are marked by different markers, and their average is shown with grey bars.  
 468 The units are 100 PgC for CO<sub>2</sub>, 10 TgN for N<sub>2</sub>O, 1000 TgC for CH<sub>4</sub>, 0.01 TgC for BC,  
 469 and 1 TgS for SO<sub>2</sub> to plot the bars in one axis.

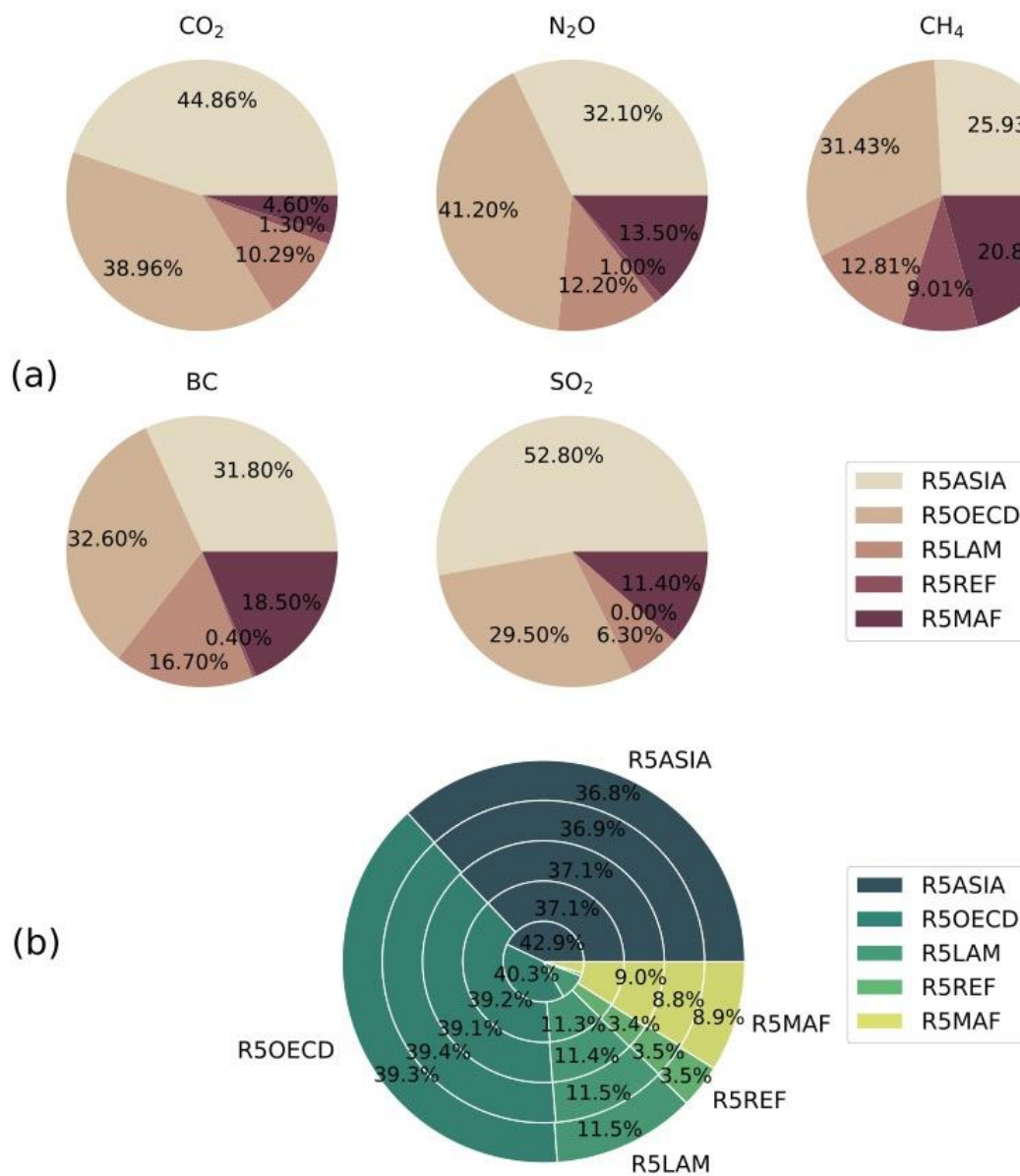


471 **Fig. 3.** Atmospheric CO<sub>2</sub> increase ( $\Delta\text{CO}_2$ ) and temperature change ( $\Delta T$ ) relative to  
472 preindustrial (1850) simulations for scenarios. (a) The simulation of  $\Delta\text{CO}_2$  based on  
473 emission data from the five IAMs. The mitigation of  $\Delta\text{CO}_2$  induced by NDC relative to  
474 NP is marked and valued in the figures.  $\Delta\text{CO}_2$  in the 2-degree and 1.5-degree scenarios  
475 are also shown in the figures for comparison. (b) The same as (a), but for  $\Delta T$ . The  
476 mitigation of temperature increases is the core concern of this study and is attributed to  
477 regions in this study.



478

479 **Fig. 4.** The relative contributions of regions to climate mitigations with different climate  
 480 forcers included. Each column represents the global climate mitigations (100%), with  
 481 relative contributions from the R5 regions marked by different colors. 'CO<sub>2</sub>', 'GHGs',  
 482 'GHGs + SO<sub>2</sub>', 'GHGs + BC', and 'all' labeled at the axis indicate which climate  
 483 forcings are considered. GHGs refer to CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O, and 'all' refers to GHGs,  
 484 BC, and SO<sub>2</sub>. The close-together columns represent results based on different IAMs, with  
 485 the model average indicated by the red dashed lines. The five IAMs are AIM/CGE 2.1,  
 486 IMAGE 3.0.1, MESSAGE<sub>ix</sub>-GLOBIOM 1.0, REMIND-MAgPIE 1.7-3.0, and WITCH-  
 487 GLOBIOM 4.0 (from left to right).



488

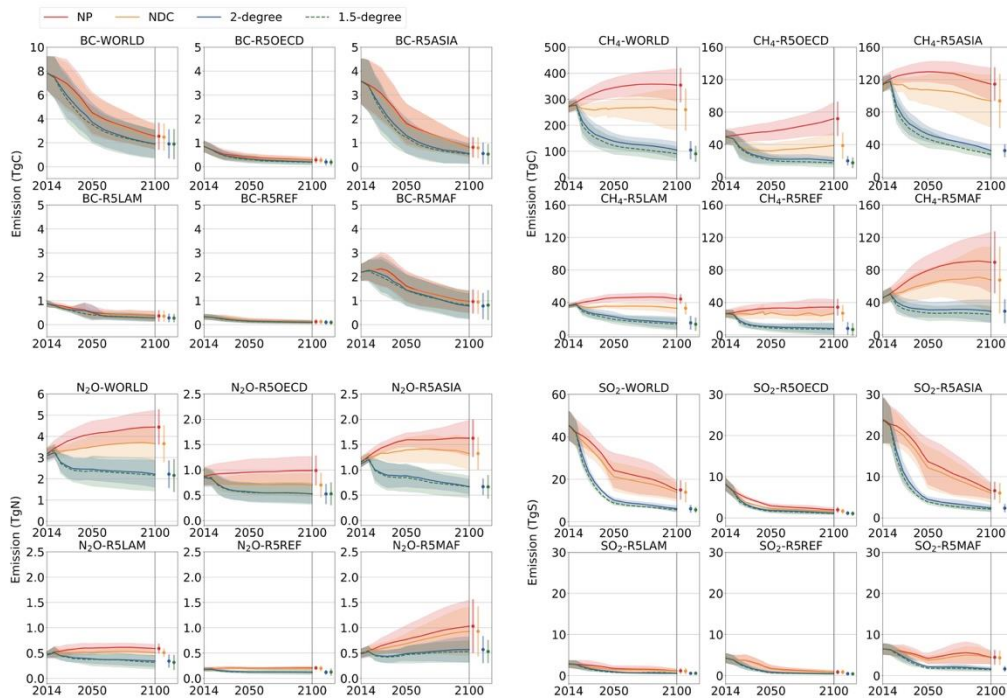
489 **Fig. 5.** Pie charts for regional emission reductions and induced climate warming490 mitigations. (a) Pie charts for regional reductions in CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, BC, and SO<sub>2</sub>. (b)

491 The nested pie chart in the center of this figure shows the regional relative contributions

492 when calculated with different amounts of substances considered. The center part of the

493 nested pie chart shows the relative contributions calculated with only CO<sub>2</sub> considered.

494 The second layer, from the inside to the outside, considers CH<sub>4</sub> and N<sub>2</sub>O in addition to  
495 CO<sub>2</sub> (abbreviated as GHGs in this study). The third layer considers GHGs and BC, and  
496 the fourth layer considers GHGs and SO<sub>2</sub>. The outermost layer considers GHGs, BC, and  
497 SO<sub>2</sub>, referred to as ‘all’ in this study.



498

499 **Fig.S1. CH<sub>4</sub>, N<sub>2</sub>O, BC, and SO<sub>2</sub> emissions of the R5regions based on the CD-LINKS**500 **scenario dataset.** Future CH<sub>4</sub>, N<sub>2</sub>O, BC, and SO<sub>2</sub> emissions in the R5 region in four

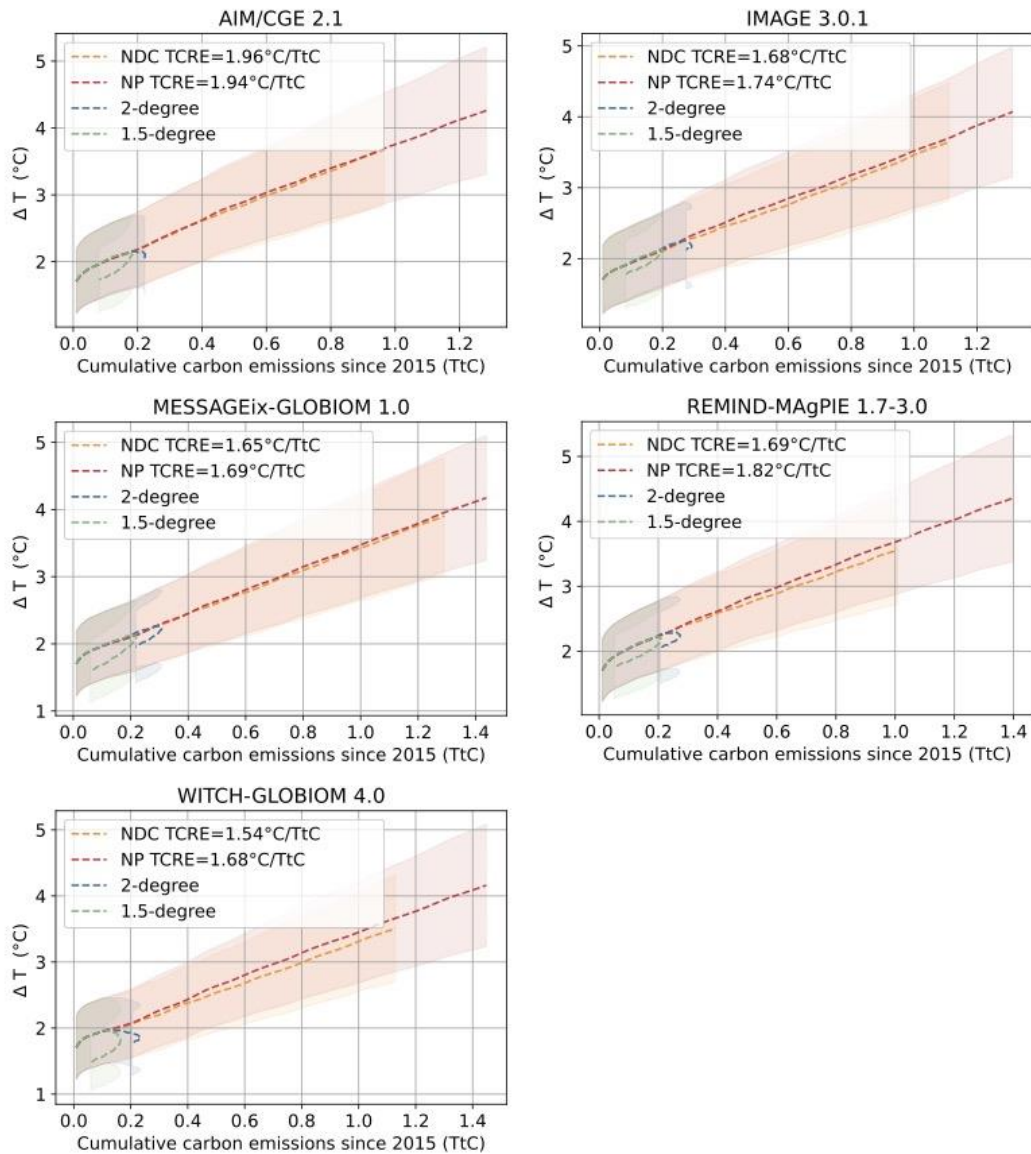
501 climate scenarios. The line is the average of the results of the five emission IAM and the

502 shade shows the range of the scenario data. ‘NP’, ‘NDC’, and ‘2-degree’ scenarios are

503 marked by red, orange, and blue solid lines. ‘1.5-degree’ scenario is marked by green

504 dashed lines.

505



506

507 **Fig.S2. The transient climate response to cumulative carbon emissions (TCRE) in**  
 508 **this study.** The lines are the average of the results of 3000 simulations and the shades  
 509 show the range of the simulated data. ‘NP’, ‘NDC’, ‘2-degree’ and ‘1.5-degree’ scenarios  
 510 are marked by red, orange, blue and green dashed lines. We calculate the TCRE for NDC  
 511 scenario and NP scenario as the slope. Considering the negative emissions of the 2-  
 512 degree and 1.5-degree scenarios, we do not calculate the TCRE for these two scenarios.