Impacts of nationally determined contributions on 2030 global greenhouse gas emissions: uncertainty analysis and distribution of emissions

Supplementary Material

1. INDC/NDC mitigation targets and additional assumptions

Table S1 lists the parameters related to the ambition level of INDCs/NDCs for the countries and country groupings considered in the analysis. We consider NDCs from individual countries when these are available, and INDCs otherwise. It should be noted that the NDCs of a few countries (in particular Morocco, Argentina, Pakistan) are different from their original INDCs. The SSP GDP scenarios are used for countries with INDCs/NDCs expressed in terms of a reduction in the carbon intensity of GDP (e.g., China, India, Chile and Singapore). GDP levels provided in the INDC/NDC are not considered when they are only indicative (as it is the case for India where the GDP presented is "a reflection of [its] future needs"). We use the GDP scenarios to estimate the 2030 GHG (or CO_2 in the case of China) emissions for those INDCs/NDCs expressed or interpreted as a target with a carbon intensity reduction, α, in year y_1=2030 with respect to a reference year y_0:

$$E(y_1) = (1-\alpha) \cdot E(y_0) \cdot \mathrm{GDP}(y_1) / \mathrm{GDP}(y_0) \qquad (1)$$

A number of special treatments are performed which are now listed:

- NDCs expressed for target years other than 2030 (2025 for the USA and Micronesia) are converted into a 2030 target assuming a linear reduction in absolute emission with time. When targets for both 2025 and 2030 are provided, we directly use the 2030 target provided in the NDC.

- When NDCs provide either sectoral or incomplete information (e.g., emissions reductions relative to a BAU that is not specified), we use our expert judgement and apply a carbon intensity target for those countries. In particular, we assume the Chilean NDC to be representative of the Philippines and the 55 countries from the Rest of the World grouping whose NDC cannot be used directly by fixing a 30 to 45% reduction in carbon intensity of GDP between 2005 and 2030. For main oil exporters and the Other Oil exporting countries, we assume a slightly smaller reduction range of 30 to 40%. Eq. (1) is used for these countries.

- In the case of Mali, which provides an NDC with sectoral information along with aggregated information in the form of a BAU target, we still use the same assumption as for other sectoral NDC: a 30 to 45% reduction in carbon intensity of GDP between 2005 and 2030. The reason is that there are substantial inconsistencies between our historical LULUCF emission data and those spelled out in the Mali NDC itself.

- We account for Taiwan separately from China, to be consistent with the primary emission dataset that we use in this study (see below). Taiwan, although not an official UNFCCC Party, has published an unofficial INDC that we take into account here.

- The NDC of Malaysia does not yet consider emissions from non-forest land. We assume that taking these into account will not change their target.

- International aviation emissions for 2030 are approximated to lie within a range of 906 to 1200 Mt CO_2 yr-1, based on a traffic growth assumption of +4.6% yr-1 in revenue passenger kilometres [1] and a fuel efficiency improvement of 2% [1] to 2.7% of kg fuel/km/passenger yr-1 [2].

- International shipping emissions are based on projections from the 3rd International Maritime Organization Greenhouse Gas study [3], resulting in a range of emissions of 940 to 1200 MtCO_2eq yr-1 in 2030.

Country	Country grouping	Ambition range	Type of INDC/NDC	Base year / BAU level	Assumption to translate INDC/NDC to 2030 emissions
United States	N/A	-26 to -28% in 2025	Absolute /base year	2005	linear reduction in absolute emissions in 2025-2030
European Union	N/A	-40% in 2030	Absolute /base year	1990	Direct NDC
China	N/A	-60 to -65% in 2030; peak by 2030	Intensity + peak	2005	GDP scenario + constraint on peak
India	N/A	-33 to -35% in 2030	Intensity	2005	GDP scenario
Australia	LEA	-26 to -28% in 2030	Absolute /base year	2005	Direct NDC
Brazil	LEA	-43% in 2030	Absolute /base year	2005	Direct NDC
Canada	LEA	-30% in 2030	Absolute /base year	2005	Direct NDC
Japan	LEA	-25% in 2030	Absolute /base year	2005	Direct NDC
Kazakhstan	LEA	-15 to -25% in 2030	Absolute /base year	1990	Direct NDC
Russian Fed.	LEA	-25 to -30% in 2030	Absolute /base year	1990	Direct NDC
Ukraine	LEA	-40% in 2030	Absolute /base year	1990	Direct NDC
Egypt	LENA	N/A	Sectoral	N/A	-30 to -40% intensity in 2030/2005. GDP scenario
Indonesia	LENA	-29 to -41% in 2030	Absolute /BAU	2869 Mt CO_2eq	Direct NDC
Iran	LENA	-4 to -12% in 2030	Absolute /BAU	Not available	-30 to -40% intensity in 2030/2005. GDP scenario
Korea Republic	LENA	-37% in 2030	Absolute /BAU	850.6 MtCO_2eq	Direct NDC
Malaysia	LENA	-35 to -45% in 2030	Intensity	2005	Emissions from non-forest land are included
Mexico	LENA	-22 to -36% in 2030	Absolute /BAU	973 MtCO_2eq	Direct NDC
Saudi Arabia	LENA	-130 Mt CO_2eq in 2030	Absolute /BAU	Not Available	-30 to -40% intensity in 2030/2005. GDP scenario
South Africa	LENA	398 to 614 Mt CO_2eq in 2030	Value	N/A	Direct NDC
Taiwan	LENA	-50% in 2030	Absolute /BAU	428 Mt CO_2eq	Direct NDC
Thailand	LENA	-20 to -25% in 2030	Absolute /BAU	555 Mt CO_2eq	Direct NDC
Turkey	LENA	-21% in 2030	Absolute /BAU	1175 Mt CO_2eq	Direct NDC
United Arab Emirates	LENA	N/A	Sectoral	N/A	-30 to -40% intensity in 2030/2005. GDP scenario

Country	Country grouping within World Other	Ambition range	Type of NDC	Base year / BAU level	Assumption to translate NDC to 2030 emissions
Andorra	Other Annex 1 countries	-37% in 2030	Absolute /BAU	0.53 Mt CO_2eq	Direct NDC
Belarus	Other Annex 1 countries	-28% in 2030	Absolute /base year	1990	Direct NDC
Iceland	Other Annex 1 countries	-40% in 2030	Absolute /base year	1990	Direct NDC
Monaco	Other Annex 1 countries	-50% in 2030	Absolute /base year	1990	Direct NDC
New Zealand	Other Annex 1 countries	-30% in 2030	Absolute /base year	2005	Direct NDC
Norway	Other Annex 1 countries	-40% in 2030	Absolute /base year	1990	Direct NDC
Switzerland	Other Annex 1 countries	-50% in 2030	Absolute /base year	1990	Direct NDC
Chile	Other Emerging countries	-30 to -45% in 2030	Intensity	2005	GDP scenario
Philippines	Other Emerging countries	-70% in 2030	Absolute /BAU	Not Available	-30 to -45% intensity in 2030 GDP scenario Based on Chilean NDC
Singapore	Other Emerging countries	-36% in 2030	Intensity	2005	GDP scenario
Viet Nam	Other Emerging countries	-8 to -25% in 2030	Absolute /BAU	787 Mt CO2eq	Direct NDC
Bahrain, Brunei Darussalam, Kuwait, Oman	Other Oil exporting countries	N/A	Sectoral, or Absolute /BAU not available	N/A	-30 to -40% intensity in 2030/2005 GDP scenario
International Aviation	Transport	N/A	N/A	N/A	906 to 1200 Mt CO_2eq: 2 scenarios of fuel efficiency improvement 1 traffic forecast
International Shipping	Transport	N/A	N/A	N/A	940 to 1200 Mt CO_2eq: 3rd IMO Report

Country	Country grouping within World Other	Ambition range	Type of INDC/NDC	Base year / BAU level	Assumption to translate INDC/NDC to 2030 emissions
Afghanistan, Albania, Angola, Argentina, Azerbaijan, Bangladesh, Barbados, Benin, Bhutan, Bosnia and Herzegovina, Botswana, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, Colombia, Comoros, Congo, Congo Democratic Republic, Costa Rica, Djibouti, Dominica, Dominican Republic, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Georgia, Ghana, Grenada, Guatemala, Guinea, Haiti, Jamaica, Kenya, Kiribati, Korea Democratic People's Republic of, Lebanon, Liberia, Macedonia, Madagascar, Maldives, Marshall Islands, Mauritania, Mauritius, Micronesia, Moldova, Mongolia, Morocco, Namibia, Niger, Nigeria, Pakistan, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, San Marino, Sao Tome and Principe, Senegal, Serbia and Montenegro, Seychelles, Solomon Islands, Tajikistan, Tanzania, Togo, Trinidad and Tobago, Tunisia, Uganda, Venezuela, Zambia	Rest of World	N/A	Various	N/A	Direct INDC/NDC
Algeria, Antigua and Barbuda, Armenia, Bahamas, Belize, Bolivia, Cabo Verde, Cook Islands, Cote d'Ivoire, Cuba, Ecuador, El Salvador, Fiji, Gabon, Guinea-Bissau, Guyana, Honduras, Iraq, Israel, Jordan, Kyrgyzstan, Laos, Lesotho, Libya, Malawi, Mali, Mozambique, Myanmar, Nauru, Nepal, Nicaragua, Niue, Palau, Panama, Papua New Guinea, Qatar, Rwanda, Samoa, Sierra Leone, Somalia, Sri Lanka, Sudan, Suriname, Swaziland, Syria, Timor-Leste, Tonga, Turkmenistan, Tuvalu, Uruguay, Uzbekistan, Vanuatu, Yemen, Zimbabwe	Rest of World	N/A	Sectoral, incomplete or not submitted	N/A	-30 to -45% intensity in 2030/2005 GDP scenario

Table S1 - Parameters related to the ambition level of INDCs/NDCs for the countries and country groupings considered in the analysis. Groups LEA and LENA gather the 19 largest emitters after the USA, the EU, China and India. Countries from **LEA** (Large Emitters with Absolute reduction) provided an INDC/NDC with an absolute reduction with respect to a base year target; **LENA** countries (Large Emitters with Non Absolute reduction) provided other types of targets in their INDC/NDC. Other countries are gathered in group “World Other”, subdivided into four subgroups, namely “Other Annex 1 countries”, “Other Emerging countries”, “Other Oil exporting countries” and “Rest of World”. Because of the database used, Serbia and Montenegro are considered together, whereas Taiwan is considered separately from China (Taiwan, although not an official UNFCCC party, published an INDC/NDC, taken into account here). South Sudan is not considered. All other countries correspond to the UNFCCC parties. For some, either emissions, or GDP, or population data are not provided in data sources, and therefore amounted to zero.

2. Datasets of emissions, GDP and population

Table S2 summarizes the sources and contents of emissions, GDP and population datasets used in this study. Based on the under-mentioned emissions datasets, we compute CO_2eq emissions using Global Warming Potentials (GWP) from the IPCC Second Assessment Report for a 100-year time horizon in line with other studies. It should be noted that the results would have been slightly different should we have used 100-year time horizon GWP from the IPCC Third, Fourth or Fifth Assessment Reports.

The GDP scenarios are provided with a time resolution of 10 years starting in 2010, but the OECD and PIK datasets also provide a GDP estimate for 2005. The GDPs are all expressed in Purchasing Power Parity 2005 US$. The GDP data from PIK is disaggregated from the 32 regions down to the country level using an assumption of partial convergence of per capita GDP within each region [4; see Section 4 for a discussion of the downscaling method]. The GDP data from CEPII is provided on a per capita basis and is multiplied by the population at the country level of the corresponding SSP from the IIASA projections. For the IIASA scenario that does not provide GDP data for 2005, we use corresponding data from the World Bank in order to compute the carbon intensity in 2005 which is used as baseline. It is worth stressing that World Bank and IIASA data are consistent for 2010 (global GDP 0.8% lower in World Bank than in IIASA).

Data type	Source	Content
Emissions data	Emissions Database for Global Atmospheric Research (EDGAR) Liu et al. [22 in the main text]	CO_2 except from LUC, CH_4, N_2O, HFC, PFC, SF_6 Emissions per country for 1990, 1995, 2000, 2005, 2010 For China, corrections from Liu et al. (graph reading) are applied to CO_2 emissions (see Table S4).
	BLUE (bookkeeping of land use emissions)	CO_2 from Land Use and Land Cover Change (LULCC) Emissions per country for 1990, 1995, 2000, 2005, 2010
	United Nations Framework Convention on Climate Change (UNFCCC)	Net CO_2 emissions/removals from Land Use, Land Use Change and Forestry (LULUCF) Emissions for the USA, Canada and Russian federation for 1990, 1995, 2000, 2005, 2010
GDP data	CEPII - EconMap	5 SSP – 5 datasets GDP per capita in PPP, billion US$ 2005 Data per country for 2005, 2010, 2020, 2030
	OECD – IIASA database	5 SSP – 5 datasets GDP in PPP, billion US$ 2005 Data per country for 2005, 2010, 2020, 2030
	IIASA – IIASA database	5 SSP – 5 datasets GDP in PPP, billion US$ 2005 Data per country for 2010, 2020, 2030
	PIK – IIASA database	5 SSP – 5 datasets GDP in PPP, billion US$ 2005 Data for 32 regions for 2010, 2020, 2030
	World Bank World Development Indicator – IIASA database	Historical data – 1 dataset GDP in PPP, billion US$ 2005 Data per country for 2005
	World Bank World Development Indicator – latest update (Sept. 2017)	Historical data – 1 dataset GDP in PPP, constant 2011 international $ converted to US$ 2005 using the US inflation rate over that period Data per country for the 2005-2015 period
Population data	SSP population scenarios – IIASA database	5 SSP – 5 datasets Population in million people Data per country for 2005, 2010, 2030

Table S2 – Sources and contents of emissions, GDP and population datasets used in this study.

Historical Chinese emissions are still subject to substantial uncertainty [20, 21 in the main text] and it is difficult to argue that one or the other dataset is better. For instance, Liu et al. [22 in the main text] use specific emissions factors for Chinese coal types whereas EDGAR considers non-specific emission factors. Furthermore, as discussed in [17 in the main text], the actual carbon content of ashes may be somewhere between the Liu et al. (8 %) and the EDGAR (0%) assumptions. For these reasons, we used an average between the EDGAR and the Liu et al. datasets (Table S3).

Year	1990	1995	2000	2005	2010
Chinese CO_2 emissions from EDGAR, in $GtCO_2$ yr-1	2.45	3.47	3.79	6.70	9.05
Chinese CO_2 emissions based on Liu et al. [22], in $GtCO_2$ yr-1	2.32	3.12	3.56	5.89	7.88
Average between EDGAR and Liu et al., in GtCO2 yr-1	2.39	3.30	3.68	6.30	8.47

Table S3 - Historical Chinese CO_2 emissions from the Emissions Database for Global Atmospheric Research (EDGAR) dataset from Liu et al. [22 in the main text], and their average as used in the main study.

3. Land Use, Land Use Change and Forestry (LULUCF) emissions

The Chinese NDC, expressed in cubic meters of forest stock increase, is converted into a CO_2 sink assuming a 0.9175 t CO_2/m^3 conversion factor. This factor is based on an estimation of the forest carbon content of 0.25 tC/m^3 (as the average between 0.3 tC/m^3 for broadleaf trees and 0.2 tC/m^3 for conifers) converted into tCO_2 with a 44/12 multiplying factor [5]. We also assume a uniform distribution of forest stock increase over time. Therefore, our 2030 additional LULUCF carbon sink for China is -139 Mt CO_2 yr-1. The Indian NDC indicates a goal of creating an additional carbon sink of 2.5 to 3 billion t CO_2eq through additional forest and tree cover by 2030. We consider it as an addition to the net Indian LULUCF emissions of 2010, reported as 60 Mt CO_2 yr-1 in ref. 17 in the main text. This addition is counted over 15 years, so we spread this sink equally over 2015-2030 to obtain a yearly rate of -170 to -200 Mt CO2 [6]. Then we combine it with the 2010 LULUCF balance. For groups of countries for which we assume intensity targets, those only apply to emissions other than from LULUCF so that LULUCF emissions need to be accounted for separately. For Other Oil exporting countries, we assume equal LULUCF emissions between 2010 and 2030. For countries from the Rest of World that do not provide a directly usable INDC/NDC, we consider a reduction range of 0% to 50% of the (positive) LULUCF emissions between 2010 and 2030. For the United States, Canada and

Russia, whose INDCs or NDCs are expressed in net-net emissions, we consider their LULUCF balance (emissions + sinks) reported to the UNFCCC. We only consider half of the additional carbon sinks as anthropogenic but apply the INDC/NDC objective on the total UNFCCC accounting. Table S4 summarizes our treatment of LULUCF emissions and their treatment.

Parameters related to LULUCF emissions	**Assumption**
Chinese additional sink from LULUCF in 2030	-139 Mt CO_2 yr-1
Indian additional sink from LULUCF in 2030	-200 to -170 Mt CO_2 yr-1
Chilean additional sink from LULUCF in 2030	- 2.7 Mt CO_2 yr-1
Fraction of carbon sinks considered as anthropogenic, used for the USA, Canada, Russia	0.5
LULUCF emissions in 2030 for Other Oil exporting countries	Equal to those of 2010
LULUCF emissions in 2030 for Rest of World	No change to 50% reduction as compared to 2010 level

Table S4 - Parameters and assumptions related to Land Use, Land Use Change and Forestry (LULUCF) emissions for 2030.

4. Pre-processing of GDP scenarios

GDP scenarios from PIK, unlike scenarios from other sources, provide data for 32 regions. In order to disaggregate those data to the country level, we use the partial convergence method implemented in van Vuuren et al. [4].

We first compute the constant annual per capita income growth rate per country C in region R with convergence year CY and baseline year BY:

$$CA_C = [(GDP_R(CY) / POP_R(CY)) / (GDP_C(BY) / POP_C(BY))] \wedge (1/(CY-BY))$$

It follows that the preliminary income of a country C in year *y* is:

$$GDP_C^*(y) = GDP_C^*(y-1) \cdot POP_C(y) / POP_C(y-1) \cdot CA_C$$

$$= [GDP_C(BY) / POP_C(BY)] \wedge ((CY-y)/(CY-BY)) \cdot [GDP_R(CY) / POP_R(CY)] \wedge ((y-BY)/(CY-BY)) \cdot POP_C(y)$$

Then the final income of a country C in year *y* is computed as:

$$GDP_C(y) = GDP_C^*(y)$$

$$+ [GDP_R(y) – \Sigma_{C\ in\ R}\ GDP_C^*(y)] \cdot [(GDP_C^*(y) - GDP_C^*(y-1)) / (\Sigma_{C\ in\ R}\ GDP_C^*(y) - \Sigma_{C\ in\ R}\ GDP_C^*(y-1))]$$

We perform calculations with 2040 as the year of GDP per capita convergence and 2005 as the baseline year within each of the 32 regions. A later year of convergence would imply relatively slower growth for lower income countries, which would slightly decrease emissions for these countries. In the limit case of an infinity convergence year, i.e. with an equal growth rate for all countries in a group, global emissions are 0.2% to 2.5% lower, depending on the SSP scenario.

Because the various GDP scenarios diverge from year 2005 across GDP data sources, and after 2010 across SSP scenarios, we have implemented a correction procedure at the country level using actual historical GDP data from the World Bank's World Development Indicators' latest update (September 2017). We rely on the World Bank GDP data for the 2005-2015 period (converted from US$ 2011 to US$ 2005 using the US inflation rate over that period), and then propagate the GDP growth rates of the SSP scenarios until 2030 but with some memory from the historical GDP trajectory to account for temporal auto-correlation in GDP growth. Indeed, since Cochrane [7], many studies have shown that GDP trends have little autocorrelation for time horizons higher than 2 years. The GDP for country *c* in year *y* (≥2016) is thus expressed as:

$$GDP_c(y) = GDP_c(y-1)\ [\ x_1\ g_{c,SSP}(y) + x_2\ g_c(y-1) + x_3\ g_c(y-2)\ ]$$

where $g_{c,SSP}(y)$ is the growth rate for year *y* in the original SSP GDP dataset estimated from a cubic interpolation of the decadal GDP between 2010 and 2040, and *g* is the growth rate after correction with $g_c(y) = GDP_c(y) / GDP_c(y-1)$. For years up to 2020, $x_1 = x_2 = x_3 = 1/3$, while for years between 2021 and 2030, x_1 increases linearly from 1/3 to 1, and x_2 , x_3 decreases linearly from 1/3 to 0.

This generally (but not always) results in smaller GDP levels in 2030 than assumed in the SSP scenarios because actual growth factors are less in the historical data over the 2005-2015 period than assumed in the SSP scenarios. A noticeable exception is the CEPII scenarios which show a late rise in the GDP growth.

5. Economic growth scenarios for China

The 20 GDP scenarios used are differentiated by SSP narrative and by GDP data source (Figure S1). First, we show the original scenarios for China, before corrections for actual historical values up to 2015 (Fig. S1a). Then, we correct on the basis of the historical 2005-2015 data from the World Bank World Development Indicators database (release from September 15, 2017), as explained in Section 4 above (Fig. S1b). This generally results in smaller GDP levels in 2030 than assumed in the SSP scenarios because actual growth factors are less in the historical data over the 2005-2015 period than assumed in the SSP scenarios. A noticeable exception is the CEPII scenarios, which show a late rise in the GDP growth for some countries. For China, scenarios SSP5 (yellow colors) and SSP1 (green colors) have higher GDP values in 2030 than scenarios SSP3 (red colors) and SSP4 (purple colors).

In terms of growth timing (Fig. S1c), CEPII scenarios present the latest growth projections for China (highest growth values in 2030) whereas IIASA scenarios present the earliest growth projections. Growth timing has a crucial impact on whether or not the Chinese peaking target dominates over the carbon intensity of GDP target.

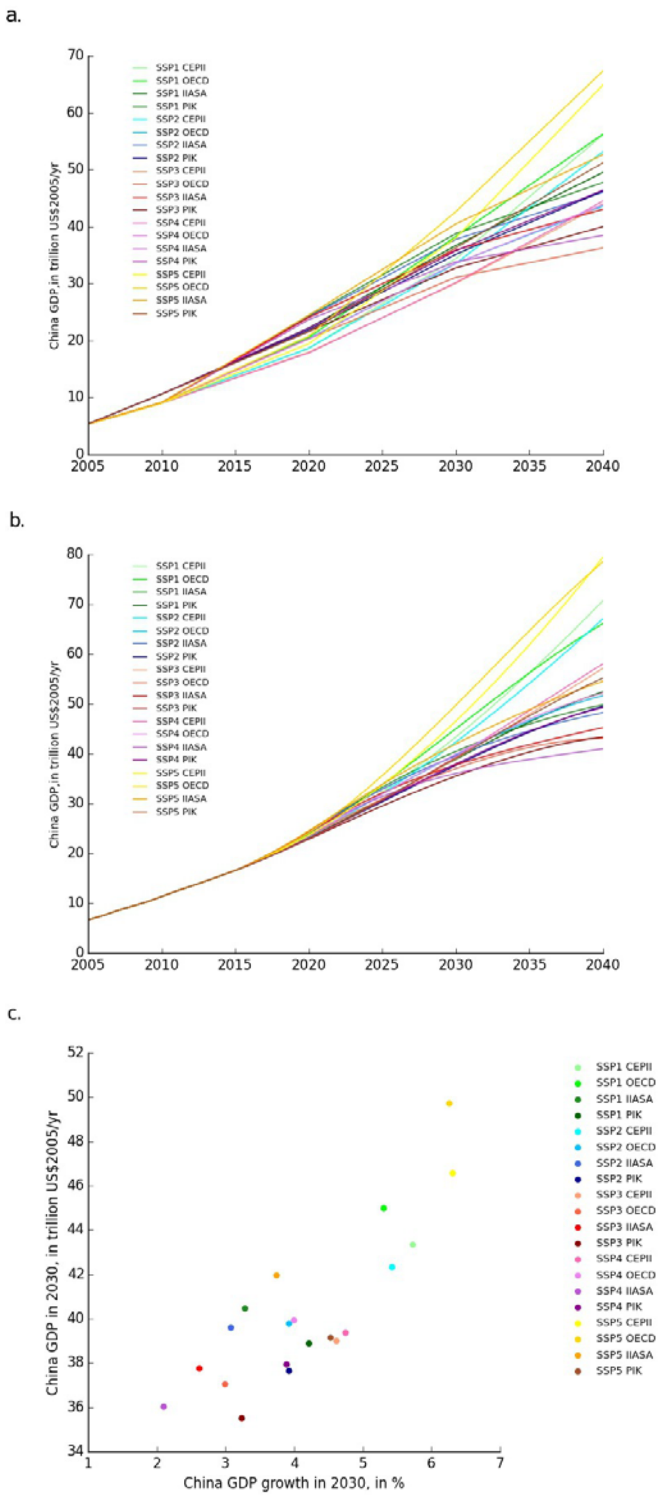


Figure S1: Evolution of the Chinese Gross Domestic Product (GDP) for a) the 20 original economic scenarios and b) corrected scenarios based on historical data. c) scatter plot of 2030 GDP value versus 2030 GDP growth rate for the corrected scenarios. The scenarios are based on the five Shared Socioeconomic Pathways (SSP) and the four different data sources (CEPII, OECD, IIASA, PIK).

6. Effect of 2030 economic growth and carbon intensity profile on the stringency of the Chinese emissions peak. Impact of current trends on future Chinese CO_2 emissions

In order to account for the Chinese peaking target by 2030, requiring that the reduction rate of the carbon intensity in 2030 to exceed the growth rate in the same year, we interpolate the carbon intensity between 2005 and 2030, for sampled reduction targets between 60% and 65% in 2030 compared to 2005. When examining the temporal evolution of carbon intensity of industrialized countries over the last 20 years, there are both examples of linear and less than linear decrease in the carbon intensity. Data for China shows a decrease followed by a rebound of its carbon intensity over the period 2002 to 2005 [8]. For the 2005-2030 period, we use a weighted average of an exponential and a linear interpolation of the carbon intensity:

$I_{mix}(y) = \lambda \,.\, I_{exp}(y) + (1-\lambda) \cdot I_{lin}(y)$ for year y such that y_0=2005 $\leq y \leq y_1$=2030 (3)

where λ is a weight varying between 0 and 1 and

$I_{exp}(y) = I(y_0) \cdot (\, I(y_1) / I(y_0)\,)$ ^ $((y-y_0) / (y_1-y_0))$

$I_{lin}(y) = I(y_0) + (\, I(y1)-I(y_0)\,) \cdot ((y-y_0) / (y_1-y_0))$

with $I(y_1) = (1-\alpha) \cdot I(y_0)$ and $I(y_0) = E(y_0) / \mathrm{GDP}(y_0)$.

The reduction rate (counted positive) in the carbon intensity in 2030 can then be estimated as

$\mathrm{IRR}(2030) = 1 - I_{mix}(2030) / I_{mix}(2029)$ (4)

If IRR(2030) is less than the GDP growth rate in 2030, then we iteratively increase the carbon intensity reduction α until IRR(2030) exceeds the GDP growth rate. This minimal carbon intensity reduction can be more stringent than the more ambitious 65% rate (depending on the growth scenario and the intensity reduction profile), effectively forcing the peak by 2030. In such case, it is the peak target that is the effective constraint and the carbon intensity reduction target is overachieved.

Figure S2 illustrates how GDP growth rates at the end of the 2010-2030 period govern the effect of considering the Chinese peak target. In CEPII quantifications GDP growth evolution over time is “flatter” than in IIASA quantifications (which have fast growth at the beginning, but low growth in 2030). Therefore, accounting for the peak target reduces emissions associated with the CEPII scenarios, but almost does not for the IIASA scenarios. The fact that the range in Chinese 2030 emissions is smaller with GDP corrections than without corrections, while the range in 2030 GDP itself is larger with corrections, is due to the peak constraint, which is especially binding for late growth scenarios such as CEPII.

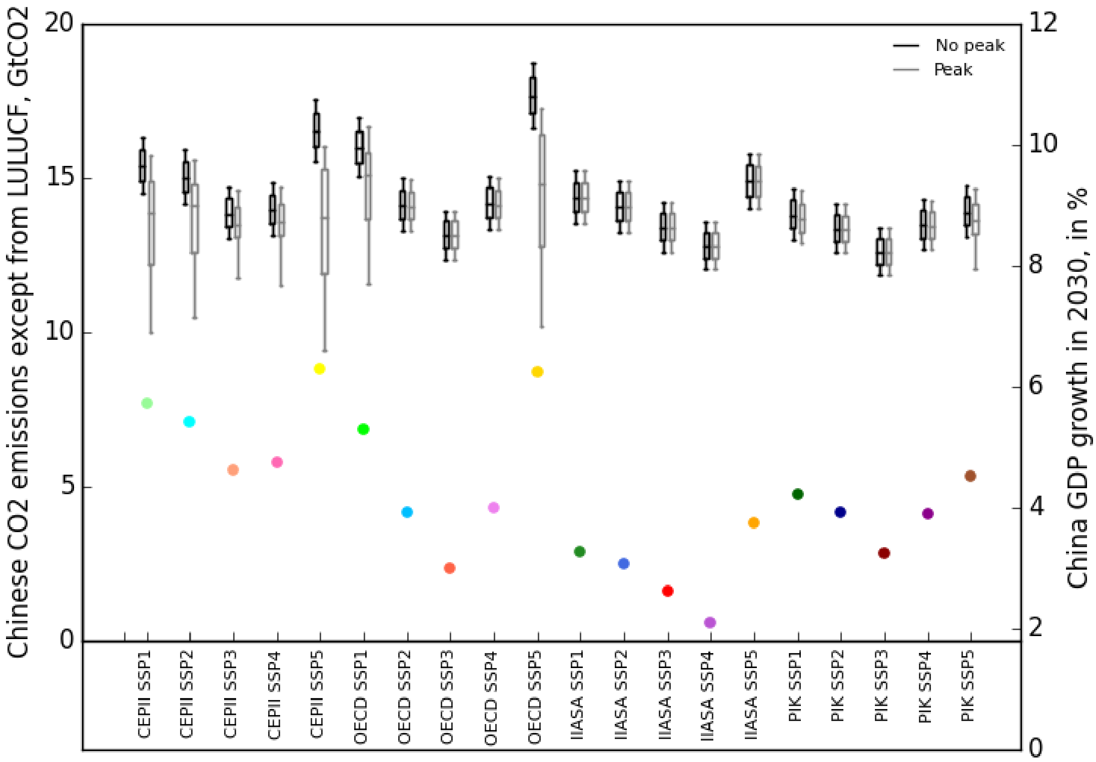


Figure S2: Box-and-whisker plots of Chinese CO_2 emissions in 2030 with (in light grey) and without (in dark grey) the NDC peak constraint (left scale), and corresponding 2030 GDP growth rate (right scale) under the 20 GDP scenarios considered. The box plots show the median, 25 and 75th percentiles and the lines show 5th and 95th percentile values.

Figure S3 compares our projected emission trajectories, based on the Chinese NDC, to current trends. As illustrated below, Chinese emissions might have started to decrease – or at least plateau in recent years. Indeed, latest data points seem to leave the upper range of our projections towards the lowest quartile. If this trend were to continue, we except China to heighten its ambition when its NDC is reviewed next.

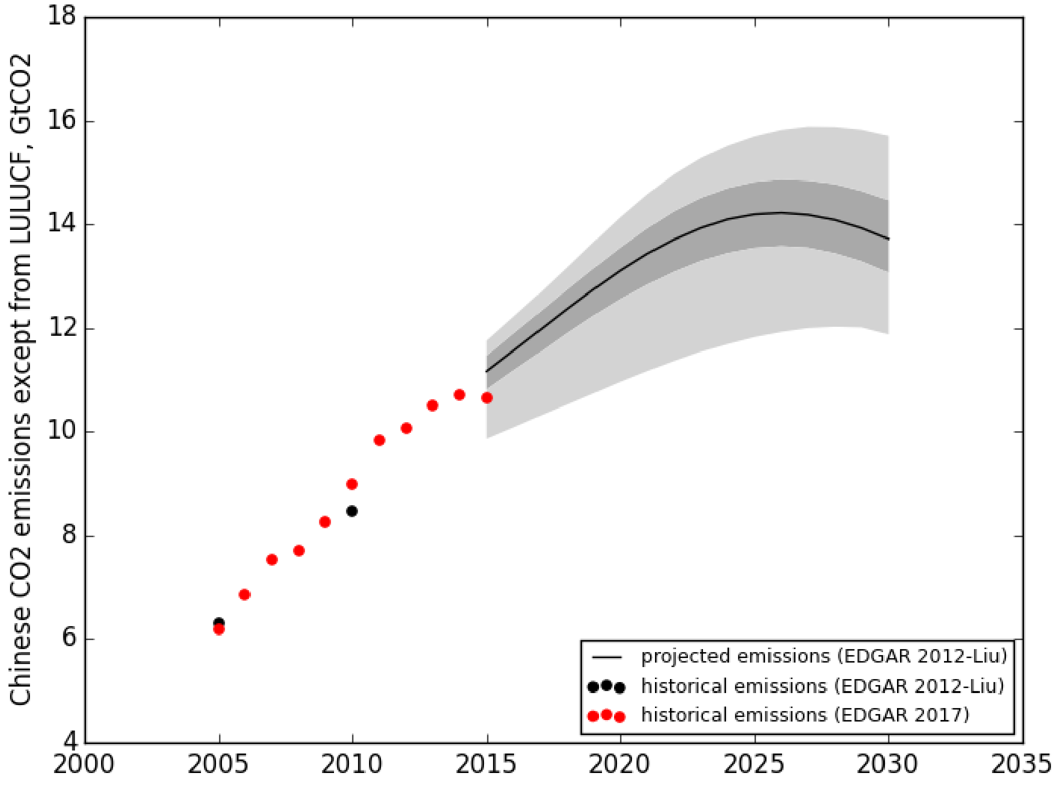


Figure S3: Probabilistic projections of Chinese CO_2 emissions over 2015-2030 based on full and sole achievement of the NDCs and comparison with the latest historical emission data. Projections show the median (middle line) as well as the 25-75th percentile (in dark grey) and the 5-95th percentile range (in light grey). Red dots illustrate historical emissions data from the latest update of EDGAR (September 2017). Black dots show the average emission values between EDGAR and Liu et al. that we use in our manuscript.

7. CO_2eq/CO_2 ratio for Chinese emissions

We use and extrapolate a CO_2eq/CO_2 relationship for China in order to derive total greenhouse gas (GHG) emissions for 2030, because the Chinese NDC is expressed in terms of CO_2 emissions only. We first estimate CO_2 emissions for 2030, then convert them to CO_2eq using a fit of the CO_2eq to CO_2 emissions ratio to the logarithm of CO_2 emissions based on the 1990-2010 period (see Figure S4):

$$R = a + b \ln(E_{CO2}) = 4.8 - 0.2 \ln(E_{CO2})$$

We take into account the uncertainty of the 2030 CO_2eq to CO_2 emissions ratio, by assuming a uniform distribution over a range encompassing $\pm 1\ \sigma$ of the least square fit:

$$R(2030) = a + b \ln(E_{CO2}(2030)) + \mu\,\sigma \qquad (2)$$

where μ is a weight varying between -1 and 1. Note that $E_{CO2}(2030)$ varies with each run of the Monte-Carlo. Thus, $R(2030)$ varies both with μ and with each run of the Monte-Carlo.

Accordingly, we predict the CO_2eq to CO_2 emissions ratio to decrease from 1.28 in 2010 to between 1.12 and 1.20 (5%-95% range over all values) in 2030 depending on the scenario. The dependence of the CO_2eq/CO_2 ratio to CO_2 is also a feature of the RCP scenarios for the Asian region (albeit with a different offset because all of Asia is considered) and is therefore believed to be a robust feature. This is not surprising because i) CO_2eq emissions are dominated by CO_2 emissions and ii) non-CO_2 emissions do not vary as much as CO_2 emissions in time and across scenarios.

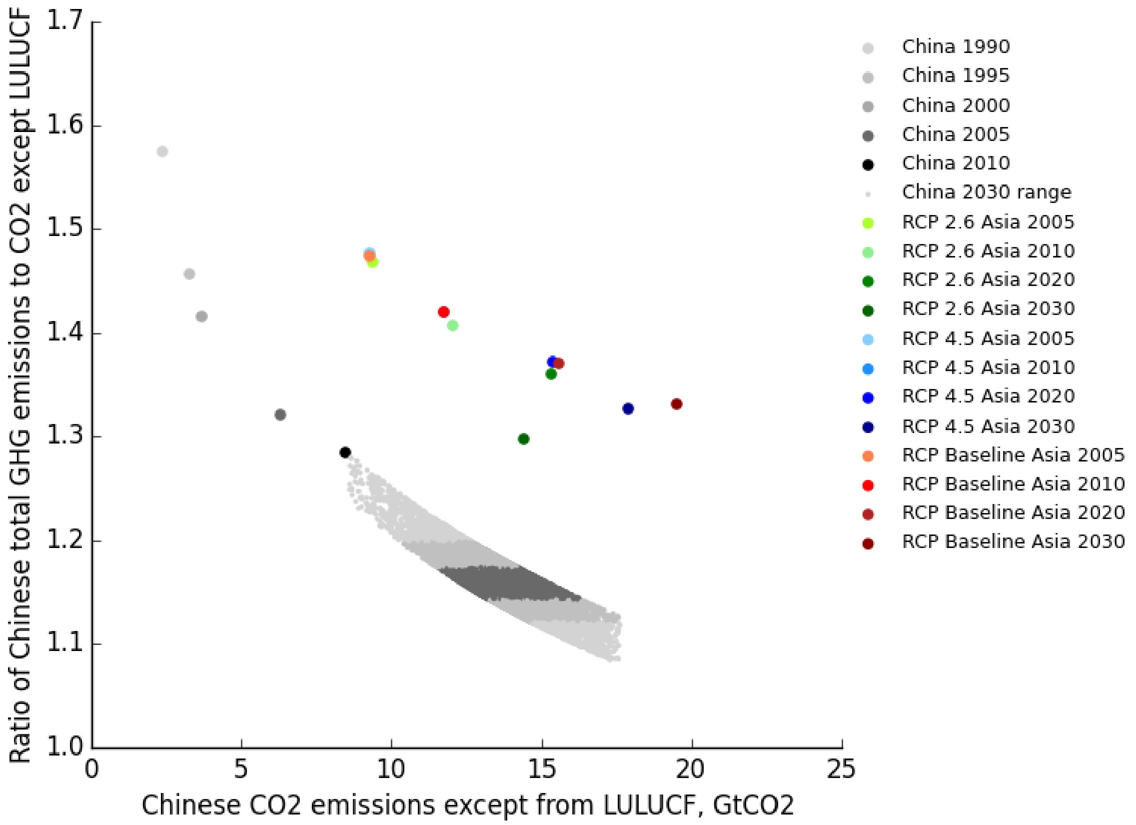


Figure S4: Ratio of Chinese CO_2eq/CO_2 emissions as a function of CO_2 emissions. Historical data are shown in grey shaded points; our probabilistic extrapolation range for 2030 based on full and sole achievement of the NDCs is displayed with a grey shading. The darkest grey represents the interquartile range of the ratio; the middle shade illustrates the 5-25th and 75-95th percentiles; the lightest grey is for the first and last 5th percentiles. Also shown are the datapoints for RCP scenarios for the Asian region including China: average over the 5 SSP for each forcing scenario: RCP2.6 (green), RCP4.5 (blue), reference (baseline, red). Emissions of CO_2 from LULUCF are not considered in these CO_2eq/CO_2 emissions ratios.

8. Reasons and limitations of not considering the non-fossil fuel targets for China and India

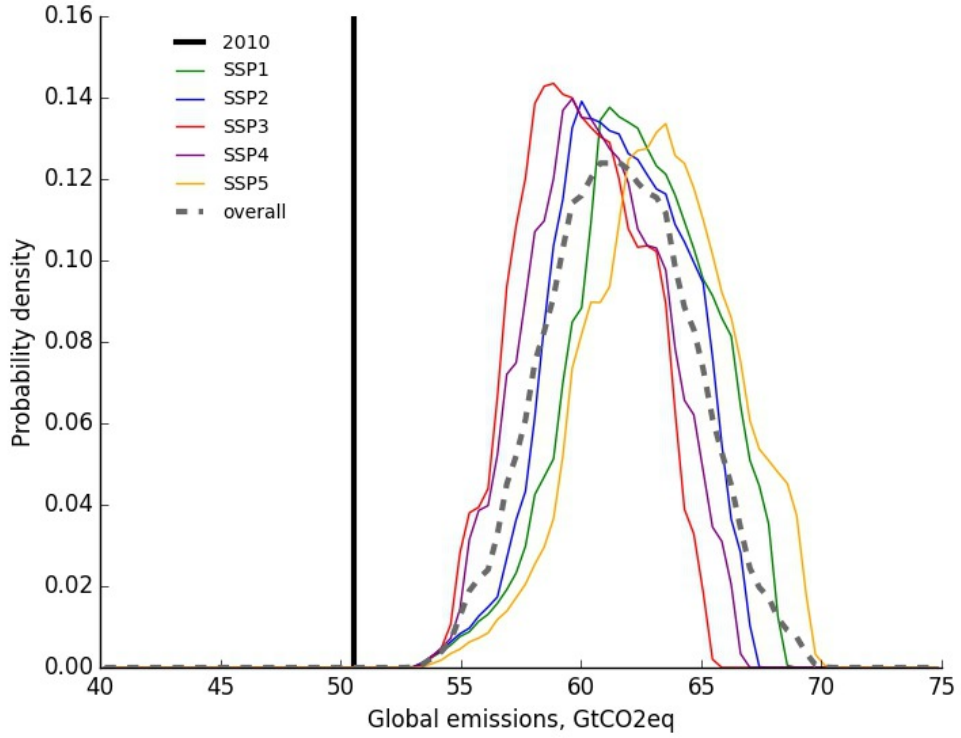
China and India also provide targets in terms of share of non-fossil fuels, of the total primary energy supply for China (20% by 2030) and of the power generation capacity for India (40% by 2030). We do not account for the non-fossil target; however there is little evidence that this target is the "dominant" one (dominant in the sense that achieving this target would lead to overachieving the other targets, in terms of emissions intensity readuction or peaking). Regarding China, there is no consensus in recent literature [9-12] regarding which of the three elements of the Chinese NDC (carbon intensity reduction, CO2 emission peak before 2030, share of non-fossil fuels) is the most constraining. In [9], the three targets are reached simultaneously (for a 65% intensity reduction). In [10], the analysis based on the FAIR/TIMER model leads to both the carbon intensity target and the share of non-fossil fuels being overachieved and the before-2030 peak target is the most constraining. The bottom-up analysis mentioned in the paper (based on [11]) infers that the non-fossil target is enough to reach a peak before 2030, making the non-fossil target the actual constraint. However, the intensity target being overachieved in this analysis is largely based on the high economic growth assumptions which imply a need for a high intensity reduction in order to reach a peak by 2030. Finally, in [12], the "continued efforts" scenario displays a share of non-fossil reaching 18% (20% when including biomass) but CO_2 emissions do not reach a peak by 2030, whereas in the "accelerated efforts" scenario the peak is barely reached and the non-fossil target is overachieved (even when excluding biomass). Therefore, in this analysis it seems that the peak target is the most constraining. We conclude from these studies that the non-fossil target for China is unlikely to be the most constraining target, and only take into account the carbon intensity reduction and the CO_2 emission peak targets. As for the Indian non-fossil target, we found few elements in the published literature. Den Elzen et al. [7 in the main text] mention in their supplementary material that the non-fossil target is the actual constraint. In Vandyck et al. [8 in the main text], Table S1 mentions that the intensity target is reached without additional policies, whereas the non-fossil target requires supplemental policies. Those few elements tend to suggest that the intensity target could be overachieved if the non-fossil target is reached. We recognize this means that our analysis probably overestimates the emissions implied from the Indian NDC.

However, in existing modeling studies, the "dominant" target is likely to depend on the model structure and assumptions on technological costs or energy markets for instance. Furthermore, and more importantly, it is likely to depend on the representation chosen by the modeling team to "translate" targets expressed in NDC into actual policy instruments (targets are policy objectives; they are different from policy instruments that correspond to the way policies are implemented to try and reach a given objective/target). In particular, we may challenge the vision that targets "interact" and that one is "dominant": in reality it is policy instruments (e.g., fiscal policies, subsidies to energies or technologies, feed-in tariffs for renewables, technology mandates, emissions trading systems with specific quota allocation provisions…) that interact with each other. Therefore, the effect of adding a target (e.g., a renewable share target) on the achievement of the other targets (e.g., an emissions target) depends on the mix of instruments chosen and does not necessarily lead to overachieving the other targets [e.g., 13, 14].

9. Global emissions in 2030 for the reference case, by SSP scenario and GDP data group

Figures S5 shows the probability distribution functions of the global GHG emissions in 2030 for the reference case decomposed by SSP scenarios (panel a) and by GDP source (panel b). We can infer that the model differences in GDP growth between data sources play a larger role than GDP assumptions within each model for various SSP narratives in explaining the large emissions range in 2030.

a.



0.16
0.14
0.12
0.10
0.08
0.06
0.04
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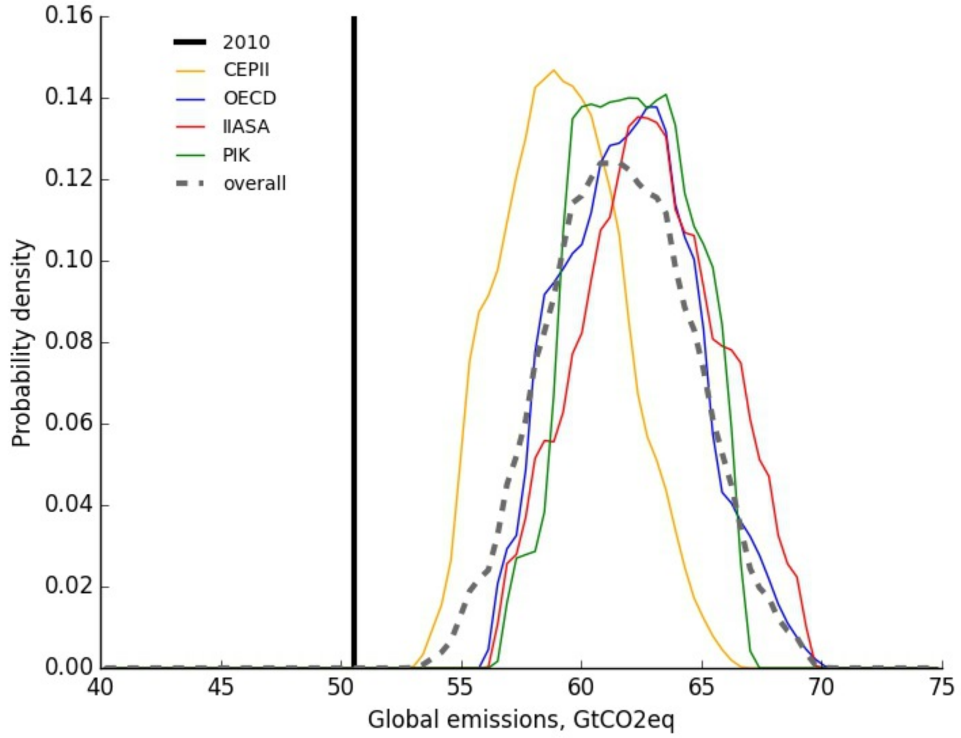
0.00
Probability density
2010
SSP1
SSP2
SSP3
SSP4
SSP5
overall
40
45
50
55
60
65
70
75
Global emissions, GtCO2eq

b.



0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Probability density
2010
CEPII
OECD
IIASA
PIK
overall
40
45
50
55
60
65
70
75
Global emissions, GtCO2eq

Figure S5: Probability distribution function of global greenhouse gas emissions distributions in 2030 based on full and sole achievement of the NDCs for the 20 growth scenarios grouped by a. SSP narrative, and b. GDP data source.

10. Sensitivity to uncertainties in historical Chinese emissions

When considering the more established EDGAR dataset without the correction for China spelled out in section 2, global emissions for 2010 are larger by 0.5 Gt CO_2eq at 51.1 Gt CO_2eq yr-1. The 2030 emissions based on our analysis of INDCs/NDCs then reach a range of 57.5 to 67.4 Gt CO_2eq yr-1. This is due to several drivers: apart from the direct effect of the change in historical emissions level when calculating a target compared to a reference year, this change implies a different ratio of CO_2eq/CO_2 emissions (1.14±0.03 instead of 1.16±0.03 with the initial correction) and therefore reduces our assumptions for non-CO_2 emissions. Furthermore, this change in historical emissions influences our calculations of intensity profiles which are by definition based on emissions and GDP, thus slightly modifying the minimal intensity reductions necessary for peaking before 2030 (it is less stringent than with the correction). This in turn raises CO_2 emissions for 2030 by 0.8 to 1.0 Gt CO_2 yr-1 in 2030, depending on the growth scenario. Figure S6 illustrates the impact of correcting historical Chinese emissions on PDFs on 2030 Chinese CO_2 emissions and 2030 global GHG emissions.

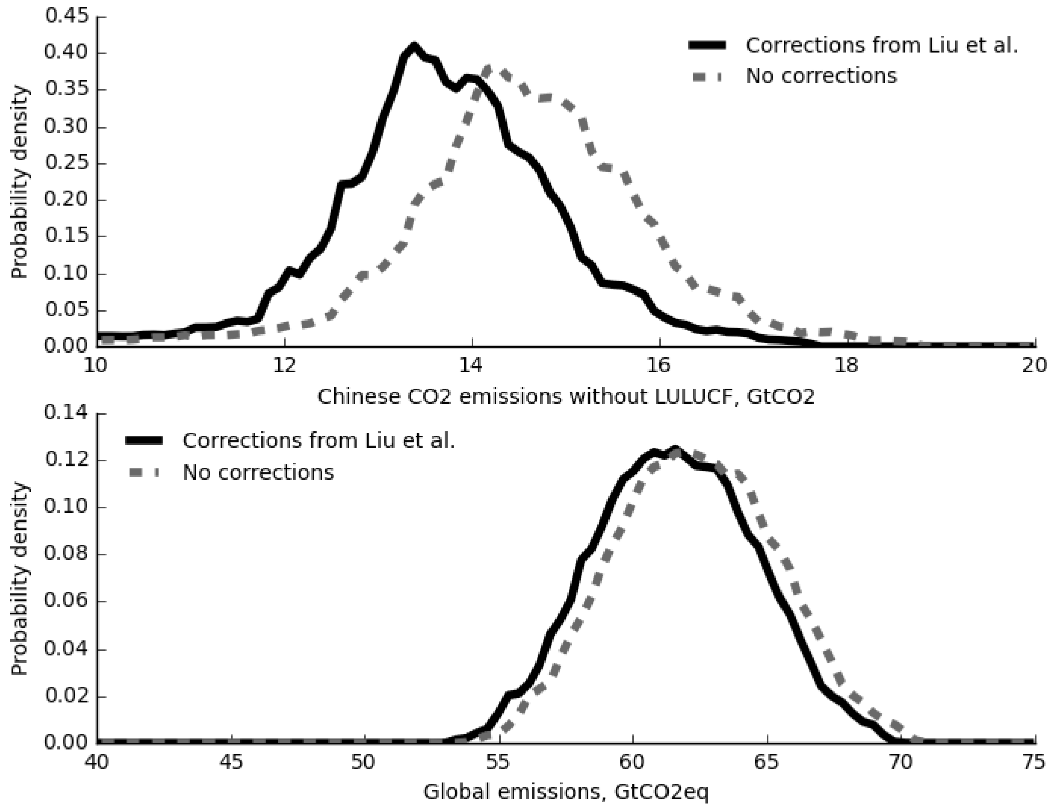


Figure S6: Impacts of the correction applied on historical Chinese emissions of the EDGAR dataset on the Probability distribution functions of a. Chinese CO2 emissions in 2030 and b. global greenhouse gas emissions in 2030 based on full and sole achievement of the NDCs. PDFs illustrate overall distributions for all 20 GDP scenarios**.**

11. Uncertainty drivers of the 2030 global GHG emission level

Figure S7 is a detailed version of Figure 1b. The economic growth drivers are disaggregated into variations due to the choice of GDP data within a given SSP scenario (purple colors) and to the choice of SSP scenario (blue colors). In both cases, Chinese and Indian variances are singled out. The interaction terms arise from (generally positive) covariances between 2030 GDP values for China, India and Other Oil exporting and Rest of World countries. The variance due to Land Use, Land Use Change and Forestry (LULUCF) emissions include both the assumption made for countries from the Rest of World group, and the range given as a target in the Indian NDC.

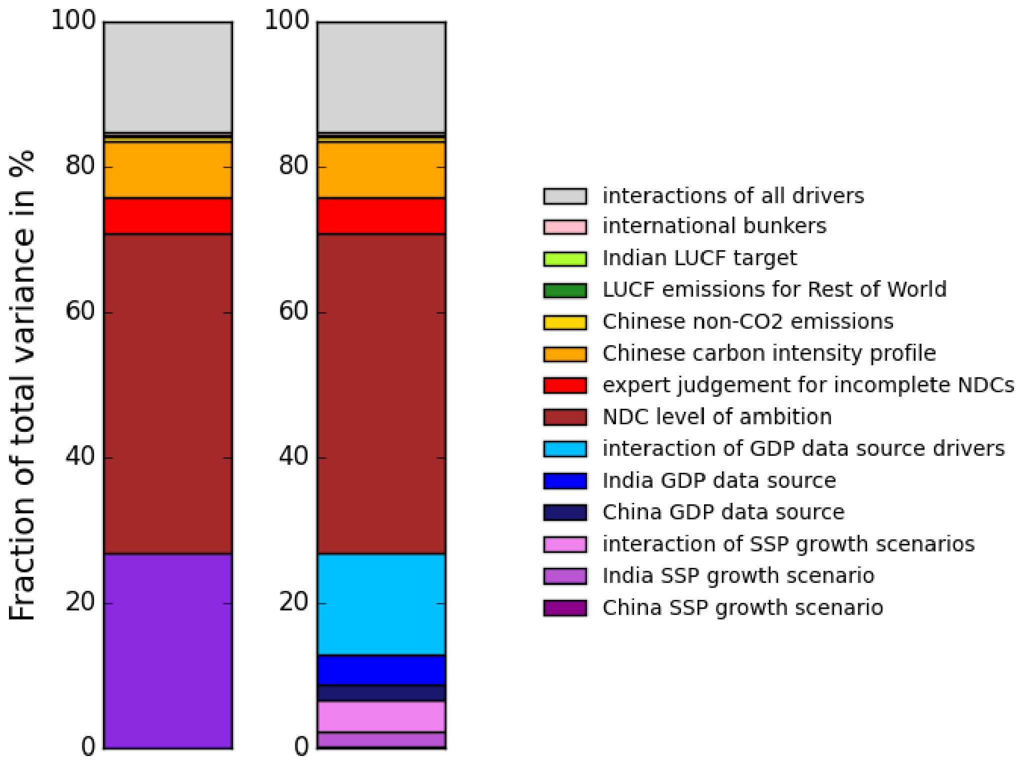


Figure S7: Fraction (%) of the total variance in 2030 global greenhouse gas emissions based on full and sole achievement of the NDCs, explained by the identified set of drivers.

12. Emissions per country / group of countries: uncertainty ranges and comparison with IAM projections

When considering the evolution of emissions per country or country group and their contributions to global emissions, we proceed in the following way. Four of the main emitters (the United States, the European Union, China and India) are singled out; whereas the other 19 large emitters are separated into two groups (see Table S1). Large Emitters with NDCs containing an Absolute reduction with respect to a base year target gather Australia, Brazil, Canada, Japan, Kazakhstan, Russia and Ukraine. Large Emitters with NDCs Not containing an Absolute reduction with respect to a base year target include Egypt, Indonesia, Iran, South Korea, Malaysia, Mexico, Saudi Arabia, South Africa, Taiwan, Thailand, Turkey and the United Arab Emirates. In the following, we refer to these two groups using the acronyms "LEA" and "LENA", respectively. Other countries are gathered in the “World Other” group, itself divided in Other Annex I, Other Emerging, Other Oil exporting countries and Rest of World.

Figure S8 shows the emissions uncertainty ranges for various countries and groups of countries. The largest absolute uncertainties arise from emissions from China, India and countries from Rest of World. For China and India, uncertainties are largely due to the GDP projections, whereas for countries from Rest of World, uncertainties are related to the presence of conditional and unconditional targets in their underlying NDCs.

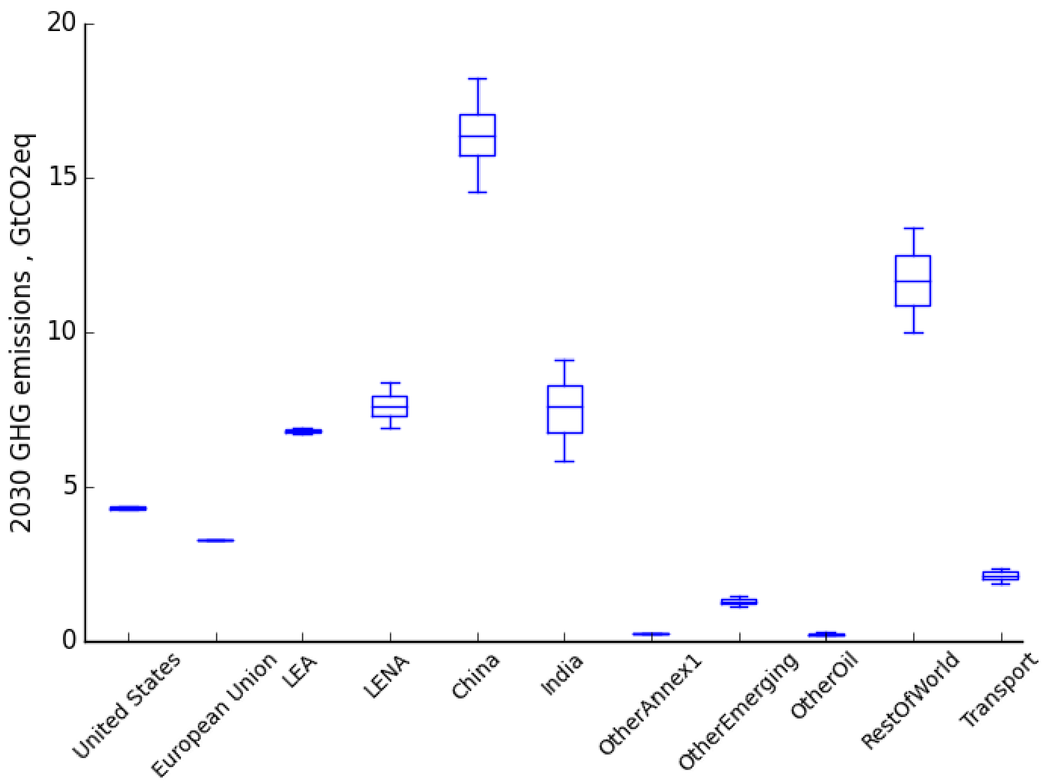


Figure S8: Emissions uncertainty ranges per country or group of countries based on full and sole achievement of the NDCs. Uncertainty ranges are shown for 2030 in the form of box-and-whisker plots representing the 5th percentile, 1st quartile, median, 3rd quartile and 95th percentile values, and include all 20 GDP scenarios considered in this study. Countries from **LEA** (Large Emitters with

Absolute reduction) provided an NDC with an absolute reduction with respect to a base year target; **LENA** countries (Large Emitters with Non Absolute reduction) provided other types of targets in their NDC. See Table S1 for a full description of country groupings.

Figure S9 shows our results aggregated into the five meta-regions used in IAMs (OECD=countries of Organisation for Economic Co-operation and Development including Turkey, REF= Countries from the Reforming Economies of Eastern Europe and the Former Soviet Union, LAM= countries of Latin America and the Caribbean, MAF= countries of the Middle East and Africa, and ASIA= most Asian countries with the exception of the Middle East, Japan and Former Soviet Union states) and compared with the results from five different IAMs (AIM/CGE, IMAGE, WITCH-GLOBIOM, MESSAGE-GLOBIOM, REMIND-MAGPIE) projections.

The projection of the countries onto the five meta-regions of the IAMs is straightforward but small differences may arise in the treatment of Overseas Territories of OECD countries. We handle the emissions from 'International Aviation' and 'International Shipping' separately, while IAMs generally apportion these emissions to the regions. For the sake of this comparison, we apportion these emissions to the five meta-regions in proportion to their total GDP. We note that GHG emissions for 2005 and 2010 differ among the IAMs and differ from ours, but we do not attempt to renormalize these emissions. Results are shown for the five SSP but are stratified by the radiative forcing levels reached in 2100 (2.6, 3.4, 4.5, 6.0 W.m-2 and Baseline) [15].

We find, not surprisingly, that our projected emissions for the ASIA region are in the high end of those projected in IAMs, while our projected emissions for the OECD region are in the low end of those projected by IAMs. The reason is twofold. First, our emissions in 2005/2010 are already on the low end for OECD and on the high end for ASIA, probably because we include terrestrial carbon sinks for some of the OECD countries as per UNFCCC accounting rules. Second, climate policies are usually enforced in IAMs through a global carbon price, which shifts the emissions reductions from developed to developing countries. Our estimated emissions are more in line with mid-way scenarios for the other three meta-regions.

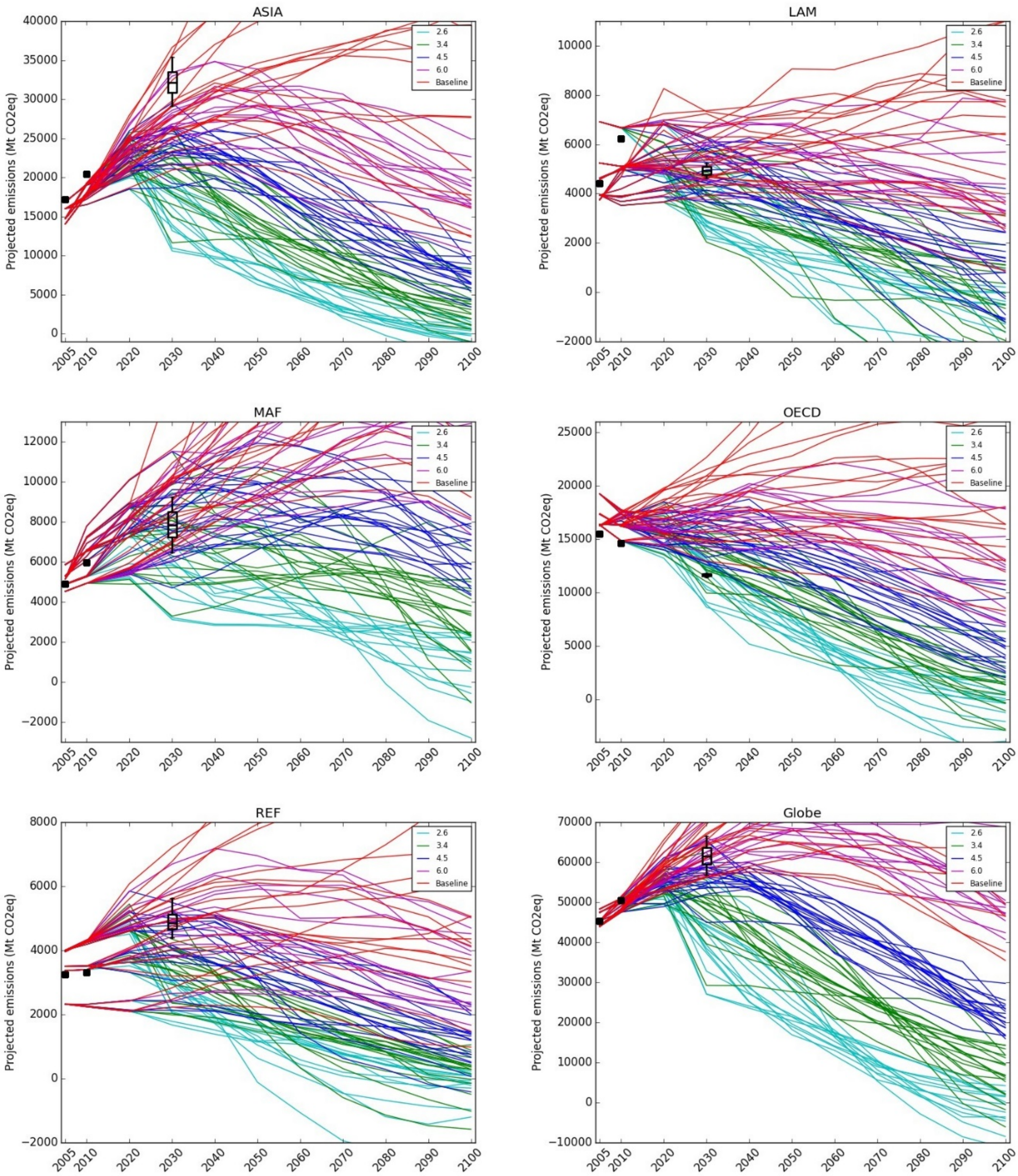


Figure S9: Comparison of estimated emissions based on full and sole achievement of the NDCs with IAM regional projections. GHG emission trajectories for five meta-regions and the globe, for five IAMs (AIM/CGE, IMAGE, WITCH-GLOBIOM, MESSAGE-GLOBIOM, REMIND-MAGPIE) and stratified by radiative forcing levels reached in 2100 (2.6, 3.4, 4.5, 6.0 Wm^{-2} and Baseline), from the SSP database. Our estimated emissions levels for years 2005, 2010 and 2030 are superimposed to those trajectories; 2005 and 2010 are displayed with black squares, whereas 2030 uncertainty ranges are displayed with box-and-whisker plots representing the 5th percentile, 1st quartile, median, 3rd quartile and 95th percentile values.

13. Per capita emissions inequalities between countries

Our framework allows to estimate per capita emissions for each country, using population scenarios from the SSP. For this indicator, there is a striking change of distribution between countries. Per capita emissions are expected to decrease between 2010 and 2030 in the United States, the European Union and LEA and LENA countries, and increase in China and India (Figure S10). Depending on the GDP scenarios considered, per capita emissions could either increase or decrease in the less emitting countries. Per capita emissions would become larger in China than in the European Union in 2030, whichever growth and population scenarios are considered. Chinese per capita emissions could even exceed those of the United States. Depending on the growth and population scenarios considered, Indian per capita emissions could also exceed European ones in 2030.

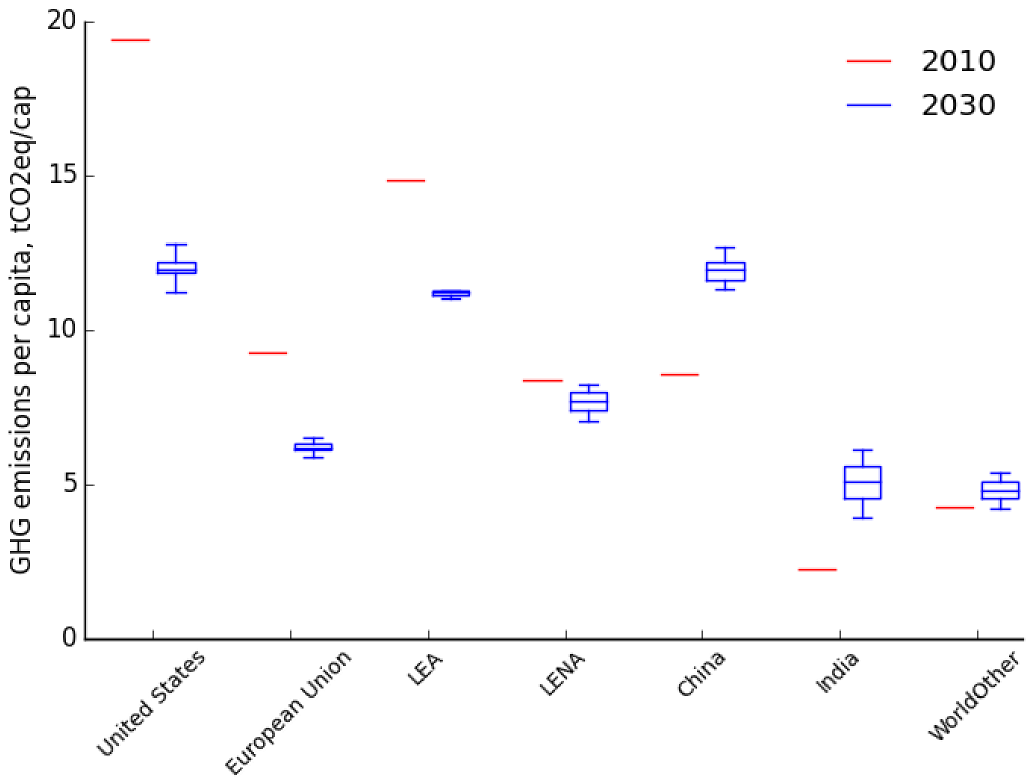


Figure S10 - Evolution of greenhouse gas emissions per capita (in ton CO2eq per capita) between 2010 (in red) and 2030 based on full and sole achievement of the NDCs (in blue) for various countries and groups of countries. Uncertainty ranges are shown for 2030 in the form of box-and-whisker plots representing the 5th percentile, 1st quartile, median, 3rd quartile and 95th percentile values, and include all 20 GDP scenarios considered in this study. LEA stands for Large Emitters with NDCs containing an Absolute reduction with respect to a base year target (gathering Australia, Brazil, Canada, Japan, Kazakhstan, Russia and Ukraine). LENA stands for Large Emitters with NDCs Not containing an Absolute reduction with respect to a base year target (including Egypt, Indonesia, Iran, South Korea, Malaysia, Mexico, Saudi Arabia, South Africa, Taiwan, Thailand, Turkey and the United Arab Emirates).

Although the convergence of per capita emissions towards a single value does not encompass all possible dimensions of international equity [16, 17], it is sometimes considered a criterion for a "just climate action" [18, 19]. Therefore, we analyze the evolution of disparities between countries in terms of per capita emissions, as implied by NDCs. An indicator commonly used to measure income inequalities is the Gini coefficient [20], which varies between 0 (perfect equality) and 1 (complete inequality). Here, we calculate both the usual Gini coefficient, measuring inequalities between countries and groups of countries in terms of per capita GDP, and an adapted version of the Gini coefficient, measuring inequalities in terms of per capita GHG emissions [21].

Calculations on inequality using the Gini coefficient are carried out as follows. First, the United States, the European Union, Large Emitters with Absolute target (LEA) and Large Emitters with Non Absolute target (LENA) (see Table S1), and groups Other Annex I, Other Emerging, Other Oil exporting countries and Rest of World are ordered by growing per capita emissions and GDP, for years 2010 and 2030 and for the 20 GDP scenarios, using population datasets of the corresponding SSP from the IIASA projections. Then Lorenz curves are computed by cumulating global emissions or GDP and global population, by country or country grouping with growing per capita emissions or GDP. The un-normalized Lorenz curves for 2010 and 2030 emissions are shown in Figure S11. Gini coefficients for both emissions and GDP are computed as twice the area between the normalized Lorenz curves and the first bisector.

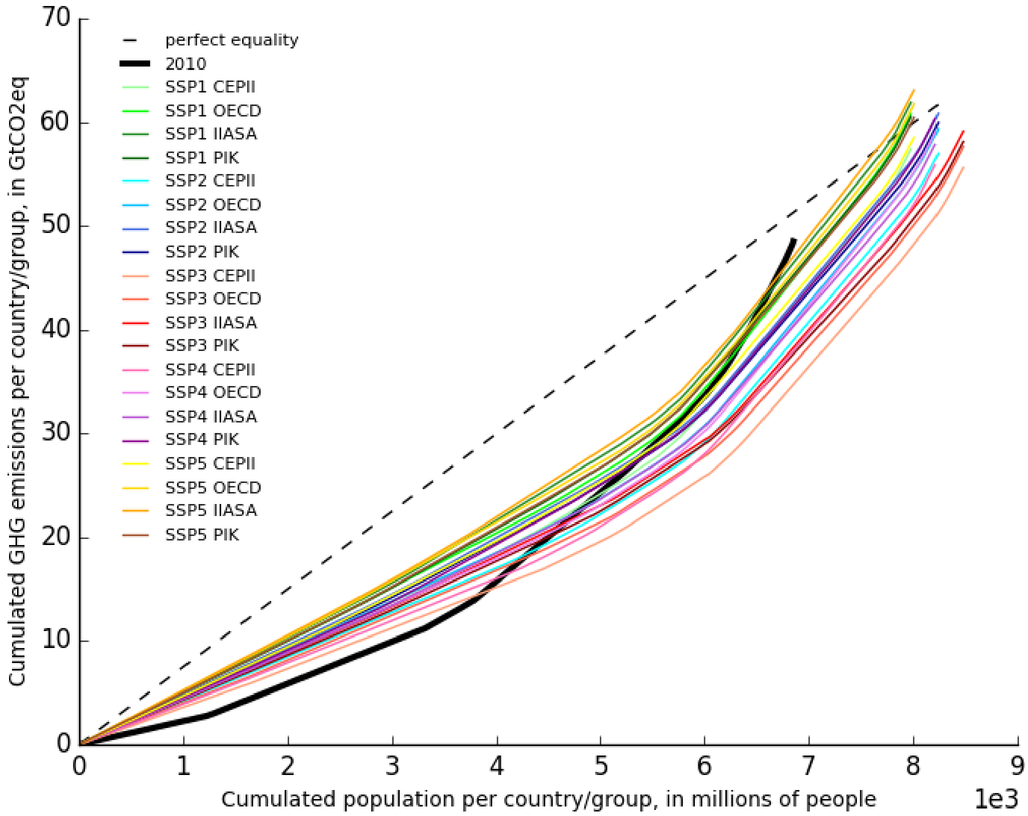


Figure S11: Emissions inequalities between countries. Unnormalized Lorenz curves showing emissions inequalities between countries and groups of countries for 2010 (thick solid line) and 2030 (coloured lines) based on full and sole achievement of the NDCs under 20 GDP scenarios based on the five Shared Socioeconomic Pathways (SSP) and the four different data sources (CEPII, OECD, IIASA, PIK). The dashed line represents a perfect equality for average population and greenhouse gas emissions across the GDP scenarios.

As shown in Figure S12, there is a higher inequality related to GDP than to emissions at the aggregation level considered here, both in 2010 and in 2030. Between those dates, both emissions- and GDP-related inequalities decrease, whatever the GDP scenario considered (except for one SSP4, described as "Inequality" and where GDP inequalities increase). Furthermore, in all GDP scenarios, emissions-related inequalities decrease faster than GDP-related inequalities, illustrating the decoupling of GHG emissions from economic growth.

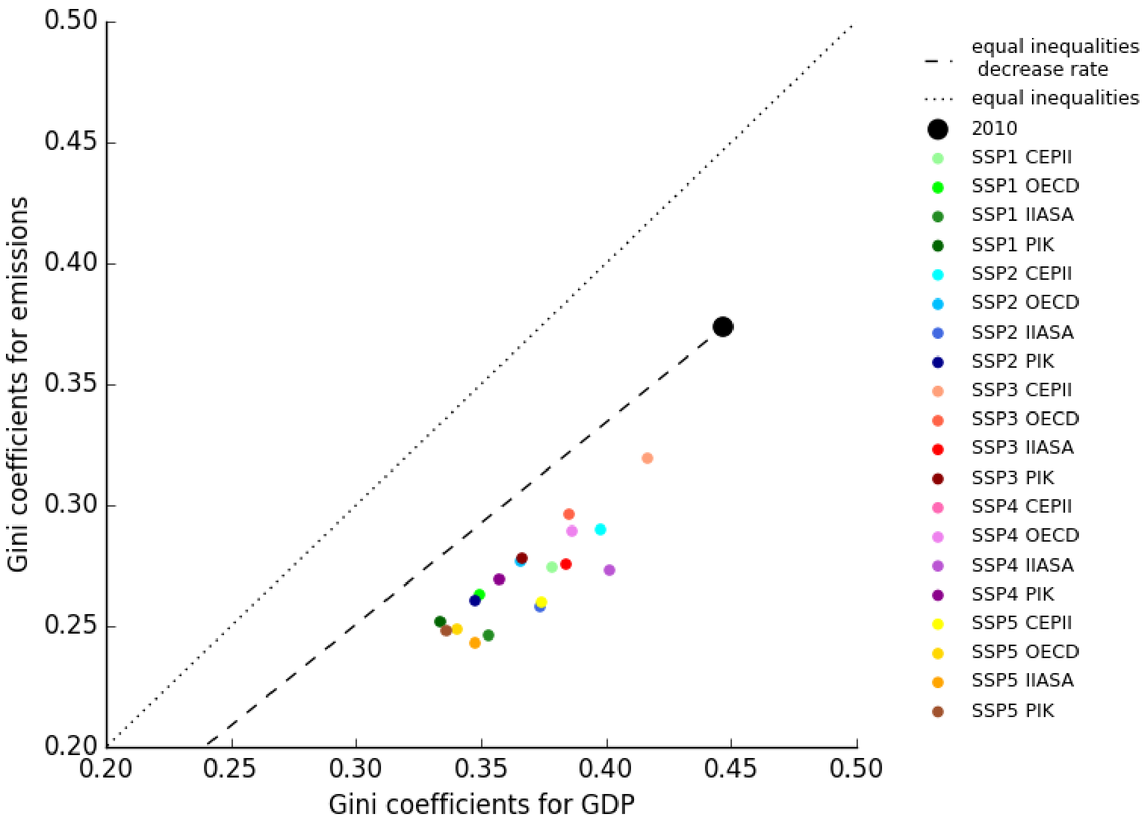


Figure S12 – Gini coefficients for emissions and GDP. Scatter plot of Gini coefficients for greenhouse gas emissions per capita (y-axis) against Gini coefficients for GDP per capita (x-axis) in 2010 (large black filled circle) and 2030 for full and sole achievement of the NDCs (small colored filled circles) for 20 GDP scenarios based on the five Shared Socioeconomic Pathways (SSP) and the four different data sources (CEPII, OECD, IIASA, PIK). The dashed line indicates an equal decrease rate between inequalities related to emissions and inequalities related to GDP. The dotted line represents equal inequalities related to emissions and to GDP.

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