CLIMATE ANALYTICS

Supporting science-based policy to prevent dangerous climate change, enabling sustainable development

Report

Setting fair and adequate benchmarks for key countries

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Summary – In this report, we aim to better understand the implications of different effort-sharing criteria and metrics on emission reduction efforts for key countries in the post-2015 agreement.

We defined ten scenarios considering different sets of criteria (amongst historical responsibility, potential to mitigate, capacity and vulnerability) and their proxy metrics (the various possible numerical expressions for each of these criteria) and estimated emissions allowances for 10 parties – Australia, Brazil, Canada, China, European Union, India, Japan, Russian Federation, South Africa and USA.

Our analysis shows that countries are affected in different ways by different criteria. Overall, we observe that metrics related to potential tend to lead to the low end of the range of emissions allowances within Non-Annex I countries and often to the high end of the range within Annex I countries, which is an expression of the generally lower energy efficiency and higher carbon intensity of Non-Annex I countries.

For all Annex I countries (except for Japan), Brazil and South Africa, responsibility metrics define the low end of the range of emissions allowances. The study of scenarios that combine different criteria and metrics deliver quite a wide range of emissions allowances for the countries studied here.

All countries are required to reduce emissions below 2010 levels by as soon as 2020, except for China and India who in some scenarios (and essentially those with focus on historical responsibility) are allowed to increase emissions relative to 2010 levels up to 2050. This analysis also reveals that the choice in criteria is important, but is not the only driver of the variability found in the range of emissions allowances for countries. Choices of metric or the length of cumulative emissions period also play a very important role in determining how much a country must reduce its emissions.

Table of contents

Main Report

Appendix

1 Background

Under the UNFCCC (United Nations Framework Convention for Climate Change), countries have agreed to hold the increase in average global temperature below 2°C relative to pre-industrial levels and to consider a 1.5°C global goal.

The definition of a warming limit allows the estimation of a greenhouse gas budget (or "carbon budget") for global emissions over the 21st century with a certain probability (IPCC 2013; Meinshausen et al. 2009). The time dependent expression of a carbon budget, a constrained emissions pathway, or scenario, can be derived from energy-economic models, achieving a pre-defined goal (e.g. a fixed total emission budget for 2011-2100, or fixed greenhouse gas concentration level by 2100) by spreading costs, technologies and emissions over time such that they represent least-cost pathways, shedding light on current options for mitigation and timing of peaking of emissions.

By adding further constraints, e.g. on regions participating in achieving overall emission reductions, or by limiting the potential of certain technological options (nuclear, carbon-capture and storage-CCS), these models generally show that for mitigation to be achieved at minimal cost, it would need to be stringent and start immediately, and global emissions would need to peak before 2020. Such low emissions levels would require all countries in the world to reduce their greenhouse gases emissions compared to baseline scenarios without mitigation.

How mitigation action and effort are to be distributed among countries across the world remains an important issue for debate that highly impacts the political context for negotiating a solution for climate protection. Efforts made by Parties and the scientific community have often focused on finding formulaic approaches based on different criteria (e.g. historical responsibility or capacity to mitigate), metrics (e.g. cumulative emissions per capita, or GDP per capita, as numerical expressions of these criteria) and algorithms to split future greenhouse gases emissions in an equitable way among parties.

The Equity Analysis Tool developed by Climate Analytics[1] and the PRIMAP[2] group allows for the quantification of equity regimes based on different criteria – historical responsibility, potential to mitigate, capacity, and vulnerability – and their metrics in different weighting schemes (see Appendix for details).

The aim of the present exercise commissioned by Greenpeace is to better understand the implications of the use of these different criteria and metrics on emissions allowances of countries that would be consistent with a global 2 or 1.5 °C temperature increase above pre-industrial levels by 2100.

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A useful step before interpreting complex equity regimes that combine different criteria and metrics is to understand the isolated effect of these individual criteria and metrics on countries' emissions allowances. With that in mind, we conducted our analysis in two steps. First, we analysed emissions allowances delivered by equity regimes considering only a single criterion and metric, in order to understand how each one influences different countries. In a second step, we defined ten scenarios that take into account a different combination of criteria and metrics and calculated countries' emissions allowances.

In our choice of scenarios, we sought to represent the main characteristics of well-known equity proposals currently under discussion. They ranged from scenarios based on only historical responsibility, up to a multi-criteria scenario considering potential to mitigate, historical responsibility, capacity and vulnerability. Using a consistent set of data sources across scenarios (Box 1), we have sought to identify the main source of variability amongst scenarios, and to find potential convergences among them.

Emissions allowances based on these sets of criteria, metrics and their weighting, assuming a 2˚ or 1.5 °C global emissions pathway, were calculated for all countries but analysed in-depth in this report for the following key emitters: Australia, Brazil, Canada, China, European Union, India, Japan, Russian Federation, South Africa and USA. Together, these countries represent 74% of global emissions in 2011 (including or excluding emissions from the LULUCF sector).

Box 1: Data collection

Data availability and quality represents a major challenge for this exercise. Even though the Equity Analysis Tool is embedded in the PRIMAP database (Nabel et al. 2011) that offers a wide range of choices of data sources, a few restrictions prevent a free choice. First, as we are interested in the relative contribution of countries to a certain qualitative metric, top-down data provides a more adequate frame for comparison, as it usually implies that a set of requirements have been met to ensure quality and comparability of data (as opposed to data provided on a national level, following e.g. own – nonstandard – inventory methodologies). Second, for each metric resulting from two single metrics e.g. emissions per GDP, we consistently used data from the same data source. For the current exercise, we have used the following data sources: CRF data, World Development Indicators 2013, CDIAC, United Nations 2012 for population and HDI, and the Climate Vulnerability Indicator. The data used here are from state-of-the-art sources and are regularly updated in the PRIMAP database. We have consistently used the same datasets across all scenario runs, ensuring that the differences between emissions allowances across scenarios arise from criteria/metric choices alone and not by data divergences.

2 Analysis

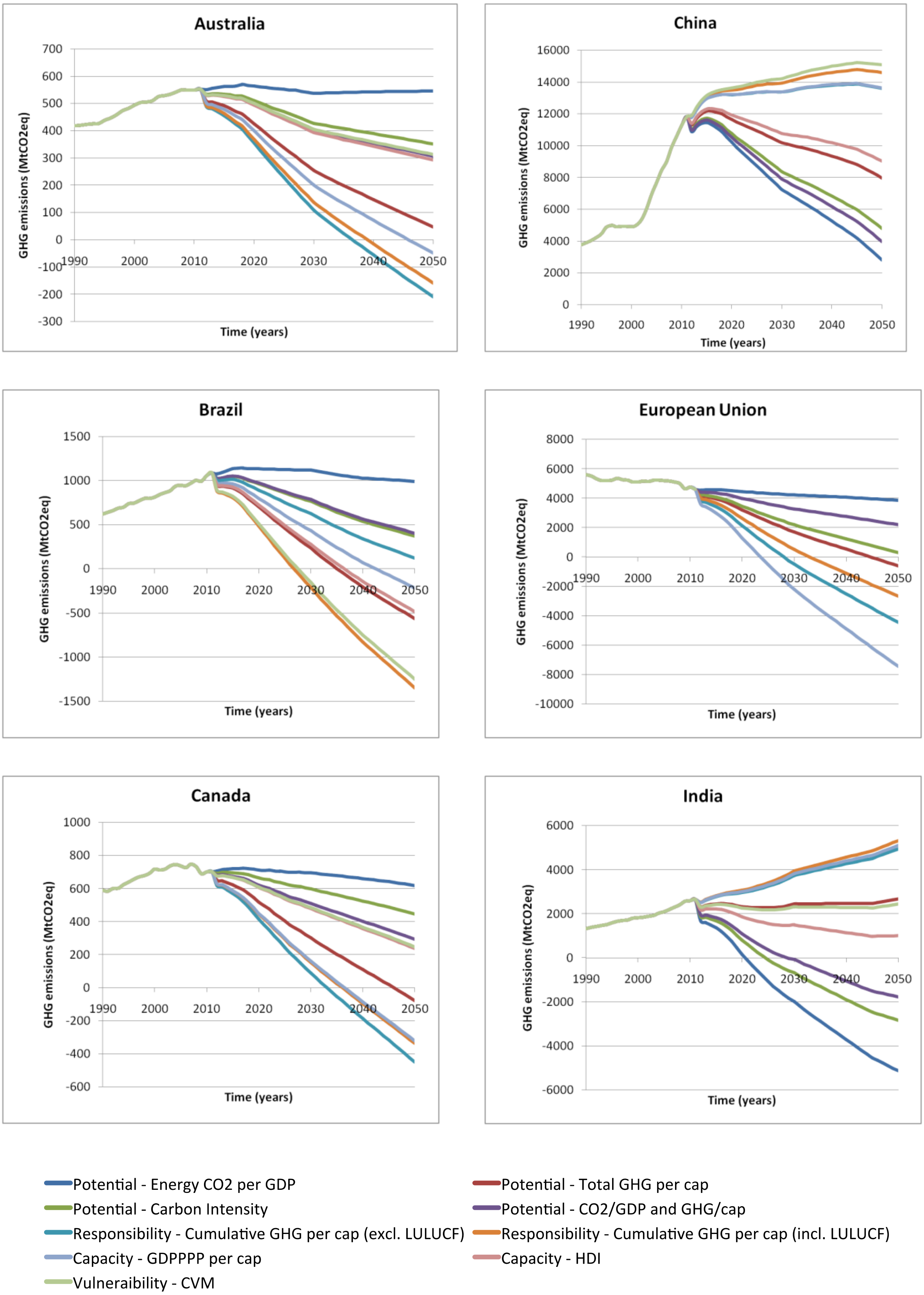
2.1 What is the impact of individual criteria/metrics on country's emissions allowances?

In the following sessions of the main report, we show results for a 2°C world (additional results for 1.5°C are provided in the Appendix). In order to isolate the effect of the multiple factors, we analysed the levels of emissions allowances for each country delivered by each criterion/metric separately. We looked into nine possible emissions allowances for the individual countries, each resulting from one single criterion and one metric for that criterion (unless specified otherwise):

- Only potential
  - Energy CO_2 per unit of GDP purchasing power parity
  - Total GHG per capita
  - Energy CO_2 per unit of energy produced (carbon intensity)
  - Energy CO_2 per unit of GDP and Total GHG per capita (two metrics combined for one criterion).
- Only responsibility
  - Cumulative GHG (1950-2010) excluding emissions from LULUCF
  - Cumulative GHG (1950-2010) including emissions from LULUCF
- Only capacity
  - GDP purchasing power parity per capita
  - Human Development Index
- Only vulnerability
  - Climate Vulnerability Monitor

Box 2: How to read the graphs

Figure 1 shows the emissions allowances for the 10 different countries. Each coloured line corresponds to the emissions allowances delivered by an equity regime considering only one of the criteria and metrics described above. For example, the dark blue line demonstrates that if potential to mitigate measured as 'energy CO_2 per GDP' was the only criterion/metric used to calculate an equity regime, Australia would be allowed to maintain its emissions at today's levels until 2050 (leading to the highest emissions allowances for Australia). For China and India, this metric leads to the lowest emissions allowances relative to the other metrics (zero emissions by as soon as 2020 would be required). Conversely, if only responsibility is considered and the metric 'cumulative emissions excluding LULUCF' is chosen, Australia would need to achieve negative emissions by as soon as 2040 whereas China and India would be allowed to increase their emissions relative to today's levels until 2050. Understanding how each criterion/metric influences final emissions allowances for a country is crucial; final level of emissions allowances for countries are, however, also strongly influenced by the levels of business-as-usual emissions (please refer to section 2.2.3 for a detailed explanation).


Australia
China
Brazil
European Union
Canada
India
GHG emissions (MtCO2eq)
Time (years)
Potential - Energy CO2 per GDP
Potential - Total GHG per cap
Potential - Carbon Intensity
Potential - CO2/GDP and GHG/cap
Responsibility - Cumulative GHG per cap (excl. LULUCF)
Responsibility - Cumulative GHG per cap (incl. LULUCF)
Capacity - GDPPPP per cap
Capacity - HDI
Vulneraibility - CVM

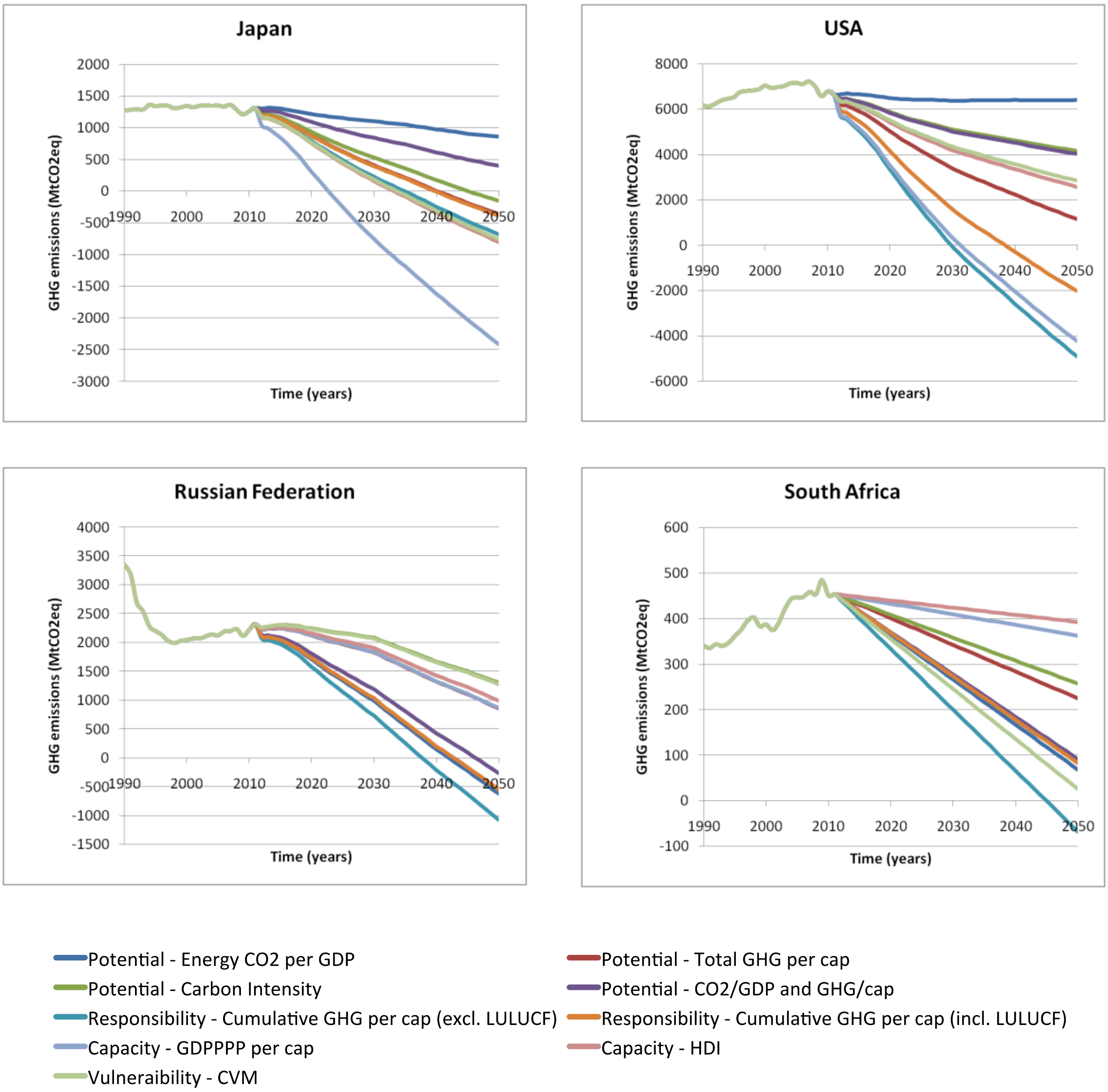


Figure 1: Emissions allowances delivered by single criterion/metric

Figure 1 shows that the level of emissions allowances can be highly variable for a country, depending on the criterion and/or metric selected to estimate this criterion. This imposes a great challenge to the equity debate since equity regimes can be defined to favour certain metrics/criteria and therefore certain countries. To guide the discussions, it is crucial to conduct in-depth studies to analyse such patterns to identify potential convergences between different proposals.

The different criteria and metrics influence countries in very different ways.

For **Australia**, the criterion **potential** delivers the highest allowances (potential: 'energy CO_2 per GDP' and 'energy CO_2 per energy use' – carbon intensity). If 'emissions per capita' are considered, the picture is quite different, and Australia takes on a larger share of the mitigation burden and hence is assigned a lower allowance. **Responsibility** metrics ('cumulative emissions including or excluding LULUCF emissions') lead to the lowest emissions allowances for Australia.

The criterion **potential** also delivers the highest allowances (especially 'energy CO_2 per GDP') for **Brazil**. However, if the metric 'total emissions per capita' is used as a proxy of potential, emissions allowances are considerably lower due to very high levels of emissions in the LULUCF sector (Brazil alone was responsible for roughly 35% of global LULUCF emissions in 2010). Similarly, for **responsibility**, the picture is very different if considering emissions from LULUCF. **Vulnerability** leads to low emissions allowances because, according to the Climate Vulnerability Monitor, Brazil is less vulnerable than other highly populated countries.

Potential delivers the highest allowances ('energy CO_2 per GDP' and 'energy CO_2 per energy use' – carbon intensity) for **Canada**. If total emissions per capita are considered, emissions allowances are significantly lower. **Capacity** ('GDPPPP per capita') and **responsibility** metrics lead to the lowest emissions allowances, requiring Canada to reach negative emissions by as soon as 2035.

Potential metrics lead to the lowest allowances requiring **China** to return to close to 1990 emissions levels by 2050. None of the criteria/metrics lead to negative emissions allowances for China.

The metric for **potential** 'energy CO_2 per unit of GDP' delivers the highest emissions allowances for the **European Union**, which would allow the region to maintain emissions very close to today's levels up to 2050. If 'energy CO_2 per unit of energy' is considered instead, emissions allowances are considerably lower. The lowest allowances are achieved when **capacity** is considered ('GDPPPP per capita', HDI not available for EU) and negative emissions would be required by as soon as 2025. **Responsibility** metrics also lead to low emissions allowances, with negative emissions being required by around 2030.

For **India**, **responsibility** metrics lead to the highest emissions allowances. If one considers the metrics of potential 'emissions per unit of energy use' and 'emissions per unit of GDP' (energy and carbon intensity metrics), very steep emissions reductions would be required as of now. However, this picture is different if 'total emissions per capita' is considered as a metric for potential. This leads to emissions allowances at the upper end of the range, and demonstrates that the choice of metrics of **potential** is of great importance on India's emissions allowances. The two **capacity** metrics also lead to very different emissions allowances, with 'GDPPPP per capita' leading to the high end of the range and 'HDI' leading to considerably lower emissions allowances.

The choice of metrics for the criterion **potential** is also of importance for **Japan**: if 'emissions per unit of GDP' is considered, Japan would need to undertake very low emissions reductions, whereas if 'emissions per unit of energy use' or 'total emissions per capita' are used, Japan needs to become carbon neutral by 2050. **Responsibility** metrics also lead to low emissions allowances, with negative emissions being required from 2025 onwards. It is, however, the criteria **capacity** ('GDPPPP per capita') that leads to the very low end of the range of emissions allowances for Japan.

Responsibility (including or excluding LULUCF) metrics lead to the lowest emissions allowances for **Russia**, despite the sudden decrease in emissions since the fall of the Soviet Union. **Potential** metrics lead to the highest emissions allowances for Russia and **capacity** metrics lead to the intermediate levels.

For **South Africa**, **capacity** metrics lead to the highest emissions allowances, and **responsibility** ('cumulative emissions excluding LULUCF') lead to the lowest. **Potential** metrics lead to intermediate levels of emissions allowances.

Responsibility (cumulative emissions per capita excluding LULUCF) and **capacity** (GDPPPP per capita) lead to the lowest emissions allowances for the **USA**. If the **potential** metric 'energy emissions per GDP' is considered, the USA could maintain today's levels of emissions until 2050. If other metrics of potential ('emissions per unit of energy use' and 'total emissions per capita') are considered, emissions allowances are considerably lower.

Overall, we observe that metrics related to **potential** tend to lead to the lower end of the range of emissions allowances within Non-Annex I countries and to the higher end of the range within Annex I countries, which is an expression of the generally lower energy efficiency and higher carbon intensity of non-Annex I countries.

Our study shows that depending on the metric chosen, responsibility can lead to the very low end of emissions allowances within Non-Annex I countries. This is certainly the case for Brazil when cumulative emissions including LULUCF are considered, and for South Africa when cumulative emissions excluding LULUCF are considered. For China and India, both metrics lead to the high end of the emissions allowances range.

For all Annex I countries, responsibility metrics lead to the very low end of the range (except for Japan, for whom capacity defines the lowest extreme of the range).

Capacity metrics often lead to intermediate levels of emissions allowances within both Annex I and Non Annex I countries studied here. We observe that the two different metrics of capacity can lead to quite divergent levels of emissions allowances for the same country. While ranking countries according to 'GDPPPP per capita' and HDI will lead to quite similar results, the distribution of the indices generated by these two different metrics is very different. For 'GDPPPP per capita', the distribution is skewed (few high values and many low values) whereas HDI has a normal distribution. The consequence is that for GDPPPP, countries with high GDPPPP will take a larger share of the mitigation burden than they do if HDI is considered, so that a smaller share remains to be distributed among countries with lower values of GDPPPP than for HDI.

As far as vulnerability is concerned, the metric used here (the Climate Vulnerability Monitor indicator) consists of discrete values (0.25, 0.5, 0.75, 1). Using solely vulnerability as a criteria/metric leads to comparatively extreme (high/low end of ranges) and unusual results. Using this criterion in combination with the other criteria may still be useful because it adds new information to the calculations. However, the CVM index is, like HDI, a composite indicator in itself and therefore difficult to interpret. At present, a better metric of vulnerability is not available, which places a limit on our ability to evaluate the fairness of equity distributions according to this criterion.

	Potential			Responsibility		Capacity		Vulnerability
	Emissions per GDP	Total emissions per capita	Carbon intensity	Cumulative emissions (excl. LULUCF)	Cumulative emissions (incl. LULUCF)	GDPPPP/cap	HDI	CVM
EU	↗	↘	↘	↘	↘			
China	↘	↗	↘	↗	↗	↗	↘	↗
India	↘	↗	↘	↗	↗	↗	→	→
South Africa	↘	→	→	↘	↘	↗	↗	↘
Brazil	↗	↘	↗	→	↘	→	→	↘
USA	↗	→	↗	↘	↘	↘	→	→
Canada	↗	↘	↗	↘	↘	↘	→	→
Australia	↗	↘	↗	↘	↘	↘	→	→
Russia	↘	↗	↘	↘	↘	↗	↗	↗
Japan	↗	→	↗	↘	↘	↘	↘	↘

↗ Drives emissions allowances towards top of the range ↘ Drives emissions allowances towards bottom of the range → Drives emissions towards middle of the range

Figure 2: Influence of different metrics on countries' emissions allowances

2.2 Range of emissions allowances for countries

2.2.1 Description of scenarios

We defined ten scenarios that differ in their set of criteria and metrics, and their weighting (Figure 3). These scenarios were designed with the goal of capturing the main views contemplated in different effort-sharing proposals put forward by Parties, or the scientific community:

- **Base case**: Multi-criteria indicator (using the following equally weighted criteria: potential to mitigate, capacity and historical responsibility). This would be in line with, for example, the South North Proposal, and considers energy intensity indicators, which have often been supported by developed country Parties (scenarios 1 to 4).
- **Historical responsibility**: reflecting the views of BASIC countries. Considers three different starting years (1950, 1990) and different end years (2010, 2050 and 2100) to account for cumulative emissions (scenarios 5 and 6)
- **Multi-criteria including vulnerability**: considering the views of the most vulnerable countries (scenarios 7 to 10).

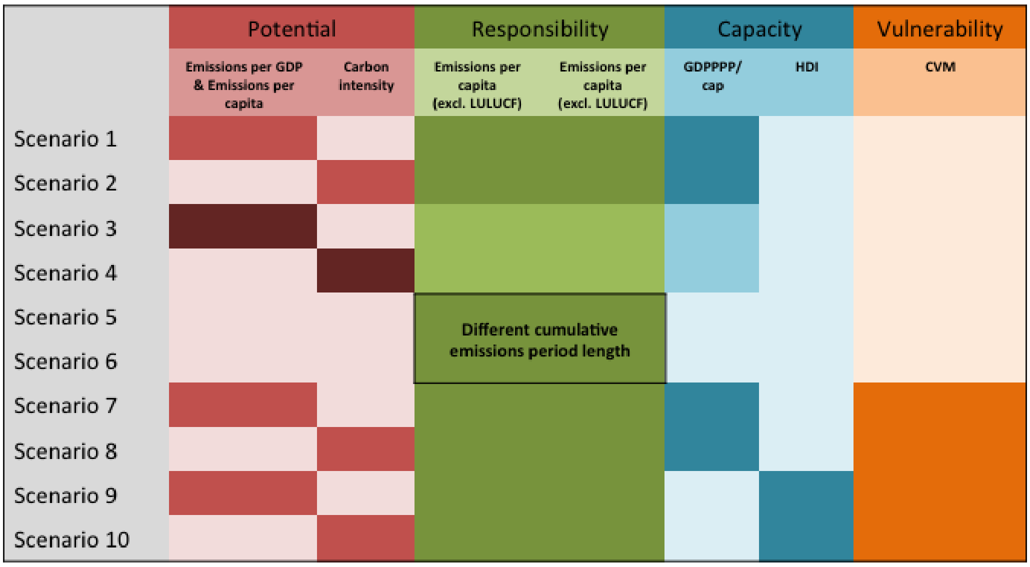


Figure 3: Scenario choices. Ten scenarios were defined, differing in the set of criteria and metrics, and weighting (darker colours indicate that higher weights were attributed to one criterion). All scenarios consider equally-weighted criteria, except for scenarios 3 and 4 which attribute a higher weight to potential criterion (dark red). Scenarios 5 and 6 are based solely on historical responsibility and differ only on the period for accounting for historical responsibility (which can vary between 1950-2010, 1990-2010, 1950-2050, 1990-2050, 1950-2100 and 1990-2100); all other scenarios consider more than one criterion.

2.2.2 What is the overall variability in countries' emissions allowances levels delivered by scenarios?

A wide range of emissions allowances arises from the scenarios studied here. China and India are the only two countries that are allowed to increase their emissions relative to 2010 levels up to 2050 under some scenarios. All other eight countries assessed are required to reduce emissions below 2010 levels by 2020. Detailed results per scenario and emissions allowances ranges expressed as reductions below 1990 and below BAU levels are provided in the Appendix.

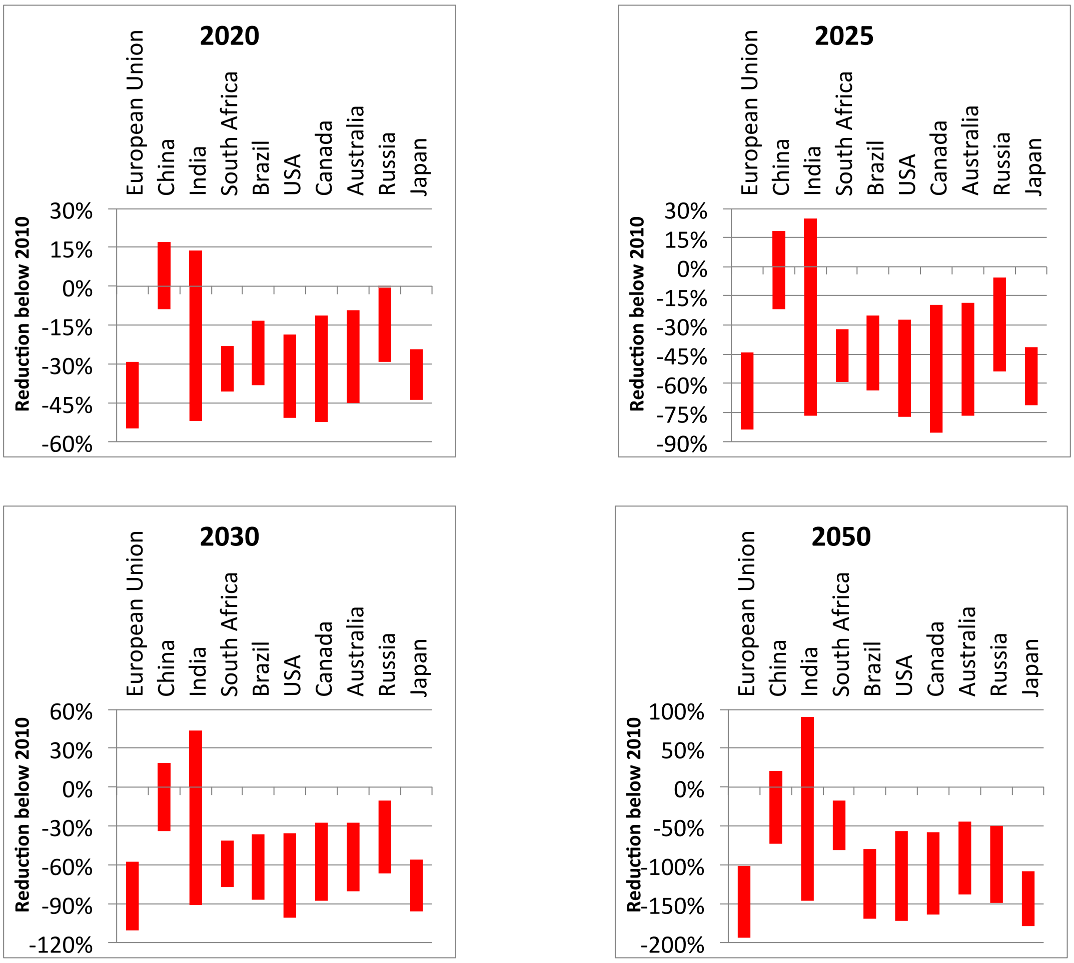


Figure 4: Emissions allowance ranges delivered by the ten scenarios (each scenario considering 2 different cumulative emissions period lengths: 1950-2010 and 1990-2010) for the ten key emitters, expressed as reductions below 2010 levels in 2020, 2025, 2030 and 2050.

2.2.3 What determines a country's emissions allowances level?

A country's final levels of emissions allowances will be determined by the two main factors: business-as-usual (BAU) projection levels and the values of the allowance-determining criteria/metrics calculated for that country.

First, because a country's emissions allowances level consists of the difference between its BAU emissions and the mitigation burden share, final emissions allowances levels will be strongly dependent on that country's BAU levels. It is therefore important to understand how much BAU projections vary.

This is probably not problematic for all countries but needs to be carefully assessed for countries like China and India. In order to ensure consistency across the BAU emissions trajectories used here, a thorough methodology to generate BAU emissions at a country level has been developed based on the composite of high quality data.

A next step, a follow-up to the study presented here, would be to study a range of BAU projections and include the effects of accounting for that range within the emissions allowances range shown in Figure 4.

The second factor influencing a country's level of emissions allowances level is the actual share of the global mitigation burden attributed to it. This will vary according to the criteria/metrics chosen in the equity regime in question and is actually the number that informs us as to the stringency each country is required to mitigate by (contrary to BAU level, which determines the starting point from which to reduce emissions, but does not inform us on the differential duties of countries).

It is crucial to consider how these two factors play together to understand final emissions allowances. For example, according to our calculations, the European Union needs to reduce more than the USA if we consider an equity regime based solely on a metric of total emissions per capita (final emissions allowances levels are -112% and -83% in 2050 below 2010 levels for the EU and the USA respectively). However, the USA has a higher level of total emissions per capita (the final normalised indicator level calculated based on total emissions per capita is 0.3 and 0.55 for the EU and the USA respectively), indicating that if we consider this metric alone, the USA would need to take on a considerably larger share of the mitigation burden when compared to the EU. This is indeed the case. However, because the USA's BAU emissions are expected to grow faster than the EU's, this results in a higher final level of emissions allowances for the USA, even though the reduction below BAU is stronger.

2.2.4 Why do countries' relative levels of reduction vary over time?

As we define a base year (2010) for calculating the index, the share of the global mitigation burden attributed to a country will be the same over time. Because the total mitigation burden increases over time, the actual amount of mitigation burden for each country will also increase over time, even if the share stays unchanged. The changes we observe in the relative emissions allowances among countries as we progress through 2020, 2025, 2030 and 2050, are mainly due to differences in BAU projections for each country rather than any changes in that countries' share of the global mitigation burden. For example, the emissions growth rate in Russia is expected to be higher than in Australia in the near-term. Therefore, in 2020 Russia would need to take on a smaller reduction relative to 2010 levels than Australia, but that reduction amount comparatively increases through 2050 as the BAU emissions growth in Russia stabilises.

2.2.5 Can we find common ground amongst scenarios assessed?

On very general lines, our assessment shows that while we may change criteria, metrics or length of cumulative emissions period, different equity regimes may lead to the same stringency of emissions reductions in a country (see Appendix for detailed reductions required of countries per scenario).

For example, the **EU**, **China**, **Russia**, the **USA** and **Canada** need to reduce as strongly in a multi-criteria scenario considering potential, capacity and responsibility as in a scenario based uniquely on responsibility which accounts not only for past emissions (from 1950 on) but also for future emissions (up to 2050 or 2100).

If we consider only historical responsibility (cumulative emissions up to 2010), this picture changes and China takes on a considerably smaller share of the burden, whereas the remaining countries need to reduce considerably more.

South Africa and **Australia** are both favoured by multi-criteria scenarios that take into account potential, capacity and responsibility when compared to scenarios that consider solely responsibility, regardless of cumulative period length.

The same applies for **Japan**, but as we prolong the cumulative emissions period length into the future, stringency decreases due to the expected weak growth of business-as-usual emissions for Japan.

Brazil's emissions allowances range delivered by the scenarios studied here are considerably narrower than those encountered for all other countries, suggesting that the different indicators influence Brazil similarly.

The opposite is observed for **India** and very little consensus has been found among scenarios. In fact, India shows a very large range of emissions allowances, suggesting that the indicators delivered by the selected criteria and metrics determining those allowances also vary greatly. This is the direct translation of the intrinsic diversity of circumstances in India: where it has the lowest emissions per capita or cumulative emissions amongst countries studied here, it has one of the highest carbon intensity and emissions intensity per unit of GDP.

2.3 What determines the overall variability in the range of emissions allowances?

Our analysis reveals that the choice in criteria is important - but not the only driver of the variability found in the range of emissions allowances for countries[1]. In this session, we study the range in emissions allowances delivered by scenarios that differ in:

- The choice of **criteria**. For example, the difference between scenarios 1 and 5: the first considers potential, capacity and responsibility, whereas the latter is based on responsibility alone.
- The **metrics** used to estimate the criteria. For example, the difference between scenarios 1 and 2, which differ only in the potential metric they use – emissions intensity and emissions per capita vs. carbon intensity.
- The **length of the cumulative emissions period** considered in determining historical responsibility. Examples include scenarios 5 and 6 that consider 1990-2010 or 1950-2050 as cumulative emissions period respectively.

This analysis will allow us to understand how the variability of the different sources contributes to the overall variability in the emissions allowances ranges. It is important to note that these sources of variability do not add up to the overall variability as they may vary in different directions.

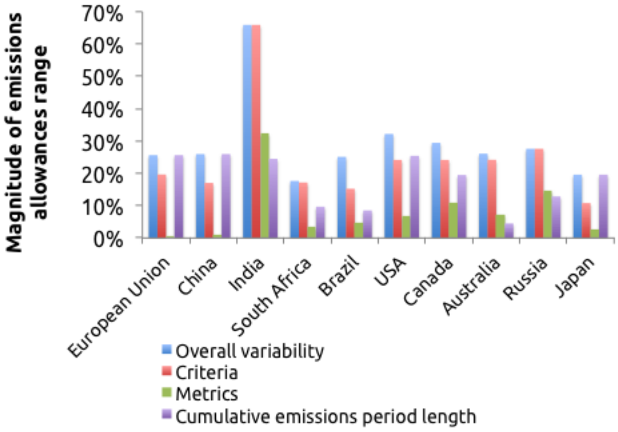


Figure 5: Magnitude of ranges in emissions allowances expressed in terms reductions below 2010 levels in 2020 (which are proportionally the same for 2030 and 2050 – see Appendix). The overall variability (blue bar) is a result of the variability in choices of criteria (red bar), metrics (green bar) and of cumulative emissions period length (purple bar). Note that the different sources of variability do not add up to total variability because they do not necessarily vary in the same direction

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[1] Note that if we had studied the emissions allowances ranges delivered by *single criteria/metric* instead of the *ranges* delivered by the scenarios, the results would be different. We opted to study the variability within the scenarios as they better represent proposals being debated today and are closer to an actual fair outcome. Emissions allowances delivered by single metrics/criteria - while helping us to understand the mechanisms behind these more complex scenarios - are conceptually poor and unlikely to deliver a fair/realistic outcome for countries.

Figure 5 shows that often, the largest difference between emissions allocations are delivered by scenarios that differ in their **criteria**. This is the case for Australia, Brazil, India, Russia and South Africa. However, choices of **metric** or the **length of cumulative emissions period** can also play an important role. For example, the choice in metrics matters most for Japan and considerably for the European Union, India and Russia, yet matters very little for China, South Africa, Brazil, USA, Canada and Australia. The choice of the **length of cumulative emissions period** contributed more to the variability than the varying criteria for EU, China, USA and Canada, and remains an important game-changer for most countries.

Equity discussions have traditionally focused on the conceptual consequences of choosing different criteria and/or length of cumulative emissions period. Our findings suggest that, beyond conceptual discussions, the equity debate could benefit highly from, on the one hand, defining a list of acceptable indicators covering a wide range of criteria and metrics, and on the other hand, from the thorough assessment of the impact of these indicators on countries' emissions allowances. This will allow a concrete framework for comparison among proposals and a better understanding of the possible convergences among them.

Some other studies have also examined the sensitivity of results to methodological options. Den Elzen et al. 2013 examined the sensitivity of cumulative per capita emissions proposals to the choices made for quantification. They found that inclusion or exclusion of time periods (2000-2010), gases (non-CO2), or sectors (LULUCF) could significantly impact the results. In addition, they show that (1) consideration of technological progress, that is technology with lower emissions intensity was not available in the past, or (2) deducting emissions for 'basic needs' (by allowing 1.2tCO2/capita), can make a significant difference if considered. Finally, assumptions regarding the rate of mitigation in the near-term (up to 2020) have implications for the period beyond that. For example, if pre-2020 mitigation does not exceed the unconditional reduction pledges for 2020, stronger and more rapid reductions will be needed post-2020 to meet the same temperature goal. The extent to which a factor can affect the final result varies by country, but factors between 0.15 and 1.5 were found across the different methodological choices. Some of these methodological choices are based on clearly defined principles, others are more practical, but there are many options to choose from.

3 Comparison to recently published AR5

In this section, we compare the results obtained in this report to the results of Höhne et al. 2013, which was also used in the WG III section of the IPCC AR5 report. The Höhne et al. 2013 study provides a comparison of more than 40 scientific effort-sharing studies and establishes ranges of emissions reductions other studies for 2020, 2030 and 2050 for 10 regions. Data from several different studies were processed so that a comparison could be made. First, data were harmonised to common historical data, then it was aggregated by region, and finally any missing LULUCF and non-CO_2 emissions were added to the results. Studies were categorised according to the target stabilisation pathway (400, 450, 500, 550, and 650 ppm) and the equity criteria considered (responsibility, capability/need, equality, and cost-effectiveness). This harmonization process improves comparability between the studies included in Höhne et al. 2013, but does not allow a perfect comparison. One advantage of the Equity Analysis Tool is that exactly the same data and assumptions underlie the different scenarios.

Equity Analysis Tool			*Höhne et al. 2013*		
Party	***Min***	***Max***	**Region**	***Min***	***Max***
European Union	-110	-58	**Western Europe and EIT**	-130	-15
China	-34	19	**East Asia**	-70	25
India	-91	44	**South Asia**	-50	>100
Brazil	-87	-36	**Latin America and Caribbean**	-80	10
USA	-101	-35	**North America**	-140	-15
Canada	-87	-27			
Russia	-67	-10	**EIT**	-85	-15
Australia	-80	-27	**Japan, Australia, New Zealand**	-130	-10
Japan	-96	-56			

Table 1 Emissions allowance ranges in 2030 for ten scenarios for the nine key emitters, expressed as percentage reductions below 2010 levels delivered by the Equity Analysis Tool compared with the full range over all studies included in the Höhne et al., 2013 study. Ranges shown for Höhne et al., 2013 are for the entire region to which the country belongs. Sufficient data for South Africa is not available for a comparison.

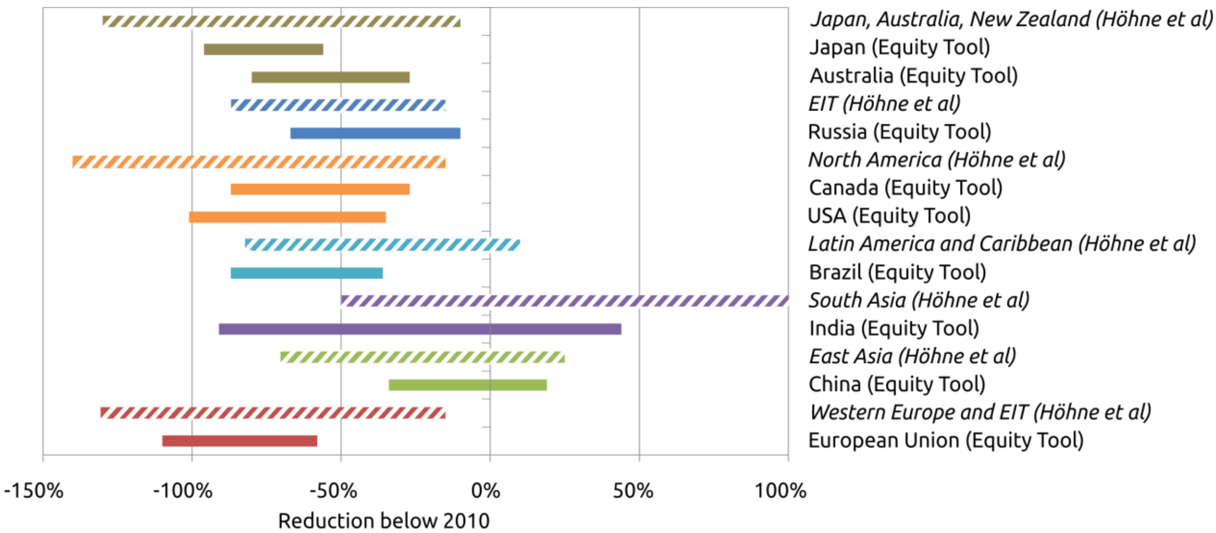

Figure 6: Emissions allowance ranges in 2030 for ten scenarios for the nine key emitters, expressed as percentage reductions below 2010 levels delivered by the Equity Analysis Tool (solid bars) compared with the full range over all studies included in the Höhne et al., 2013 study (hatched bars). Ranges shown for Höhne et al., 2013 are for the entire region to which the country belongs. Sufficient data for South Africa is not available for a comparison.

Table 1 shows that for nine of the key emitters, the ranges identified over all ten different scenarios by the Equity Analysis Tool are broadly comparable with ranges found in Höhne et al. 2013. The ranges identified by the Equity Analysis Tool are often narrower than those found in Höhne et al. 2013. This is in part due to the fact that the Höhne et al. 2013 exercise comprises more equity principles than the ones considered here, e.g. cost-effectiveness. In addition, Höhne et al. 2013 take a regional approach and two individual countries within one region, such as Japan and Australia, may have significantly different ranges within the entire range for that region. This second reason highlights a key advantage of the Equity Analysis Tool; that it calculates ranges for individual countries and therefore reveals nuances within a region that are not shown in Höhne et al. 2013.

Consistent with the Equity Analysis Tool results, Höhne et al. 2013 show that the outcome for a country is, to a large extent, determined by the way the equity principle is implemented (parameters, data and methods assumed) rather than the equity principle itself.

The Höhne et al. 2013 study includes a 'combined indicators (responsibility, capacity and need)' category of equity principles. This does not correspond exactly to what we refer to in our analysis as 'multi-criteria'. Instead, the 'combined indicators' category comprises the Greenhouse Development Rights (GDR) approach studies. The GDR approach is based on a principle of preserving the right to development, implicitly equating this right to develop with a right to emit. The mitigation burden share is based on an indicator that excludes all individuals in a country with an income below a 'development threshold'. It therefore considers not only differentiation of income between countries, but also within countries, so that a country with extreme in-country income inequality is assigned a relatively lower emission-reductions obligation (linked to the lower fraction of wealthy individuals in that country). The GDR approach achieves very different mitigation obligations to the Equity Analysis Tool approach and to the other principles considered in the Höhne et al. 2013 study. In part, this is because of the methodology used in the GDR approach. Although an average between responsibility and capacity is taken to determine the mitigation share, the responsibility index also includes a measurement of capacity (the wealth of citizens above an income threshold). The GDR method therefore results in strong mitigation requirements from wealthier countries in comparison to other effort-sharing proposals, and vice versa: weak mitigation requirements from poorer countries.

Overall, emissions allowances calculated for India by the Equity Analysis Tool are considerably lower than those calculated by Höhne et al. 2013. The GDR approach considered in Höhne et al. 2013 (and not in the Equity Analysis Tool) explains the high allowed increase in emissions at the high end of the range (>100%) in Table 1 for South Asia for Höhne et al. 2013 (with a high fraction of people below the threshold income level). The low end of the range delivered by the Equity Analysis Tool is lower than the one found in Höhne et al. 2013 for India (-91% and -50% below 2010 emissions levels respectively). In the Equity Analysis Tool, these low levels of emissions allowances are delivered in a scenario with emphasis on potential and using 'carbon intensity' as proxy metric. There are no comparable scenarios in Höhne et al. 2013.

Höhne et al. 2013 further conclude that for many regions, the choice of target stabilisation level (400, 450, 500, 550, or 650 ppm CO_2eq) was of equal or larger importance for the resulting emissions allowances than the choice of effort-sharing approach (particularly in 2050). Because the mitigation burden to be distributed among countries is determined by the target stabilisation level, increasing the stabilisation level will necessarily lead to a shift upwards of countries' emissions allowances and this is also observed in the results delivered by the Equity Analysis Tool (see Appendix for differences between 2 and 1.5°C pathways).

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Appendix

1 Methodology

1.1 Description of Equity Analysis Tool

The PRIMAP group at the Potsdam Institute for Climate Impact Research (PIK) developed the Potsdam Real-time Integrated Model for the probabilistic Assessment of emission Paths (PRIMAP model)[1]. The Emissions Module[2] has been developed as part of this model and allows for the flexible combination of data sources into composite datasets, and the calculation of national, regional and global emission pathways following various emission allocation schemes. At the core of the Emissions Module is a custom-built emissions database, the so-called PRIMAPDB.

Climate Analytics and the PRIMAP group developed an Equity Analysis Tool for the assessment of equity principles and indicators, embedded in the Emissions Module. This tool allows the user to choose from various equity criteria - and for each criterion a range of possible empirical metrics to quantify them is available - promoting the better understanding of the consequences of these different choices in terms of emissions allocations for the Parties.

1.1.1 Criteria and empirical metrics

The equity criteria selected and the different empirical metrics available to evaluate them in the Equity Tool are:

Historical Responsibility: this remains the main argument used by developing countries that claim that the greenhouse gas problem is essentially a problem of industrialized countries. The rationale behind this it that "[...] the developed countries bear responsibility for the degradation of the global environment. Ever since the Industrial Revolution, the developed countries have over-exploited the world's natural resources through unsustainable patterns of production and consumption, causing damage to the global environment, to the detriment of the developing countries."[3] Developing countries argue that accounting for past emissions is crucial in understanding how much a country can still emit, and parties such as China and India have put forward proposals that are based solely on the concept of historical responsibility. Most, if not all, effort-sharing proposals discussed today integrate the idea of historical responsibility. The metrics used as a proxy for historical responsibility in this exercise are based on per capita cumulative emissions i.e. the quotient of cumulative emissions for each country and its cumulative population within the pre-set time frame:

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[1] https://sites.google.com/a/primap.org/www/the-primap-model

[2] Nabel et al. (2011). "Decision support for international climate policy - The PRIMAP emission module." Environmental Modelling and Software Vol. 26 Issue 12, p.1419-1433.

[3] 1991 Beijing declaration on Environment and Development

- Cumulative greenhouse gases emissions per capita, excluding deforestation emissions: starting and end years for accounting cumulative emissions are flexible
- Cumulative greenhouse gases emissions per capita, including deforestation emissions: starting and end years for accounting cumulative emissions are flexible

Capacity to mitigate: the overall capacity to mitigate in a country is often related to a country's wealth or degree of development, as these relate to the country's ability to pay for measures to reduce greenhouse gases emissions. The concept of capacity to mitigate appears in the effort-sharing proposals: South African proposal, Greenhouse Development Rights, and South-North Proposal, among others. Metrics available to evaluate this criterion are:

- GDP Purchasing Power Parity (PPP) per capita
- Human Development Index (HDI) at a certain year

Potential to mitigate is a measure of the actual room for improvement existing in a country. Among proposals that consider potential as a criteria are the Triptych methodology and the South North Proposal. The following intensities can be used to estimate a country's potential to mitigate:

- Emissions intensity: Energy related greenhouse gas emissions per unit of GDP
- Emissions per capita: Total national greenhouse gas emissions per capita, including deforestation emissions.
- Carbon intensity: greenhouse gas emissions per unit of energy production

Vulnerability: The Climate Convention recalls that States have "the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."[1] Hence, the needs and circumstances of the most vulnerable countries that are subject to strong effects of climate change need to be fully taken into account. These parties have therefore often called for the integration of the concept of vulnerability in effort-sharing proposals and allocation schemes. Because measuring the vulnerability of countries can be an extremely complex task, until now vulnerability has not been put into practice in effort-sharing approaches. Given the recent development of a vulnerability Index, the Climate Vulnerability Monitor[2], this is now possible and we have considered this metric in this exercise.

- Climate Vulnerability Monitor aggregate indicator, with discrete values (0.25, 0.5, 0.75, 1) of vulnerability

[1] 1771 UNTS 107; S. Treaty Doc No. 102-38; U.N. Doc. A/AC.237/18 (Part II)/Add.1; 31 ILM 849 (1992)

[2] Climate Vulnerability Monitor, Dara. The Climate Vulnerability Monitor synthesizes the latest research and scientific information on the global impact of 34 indicators within 4 Impact areas for climate change and climate economy: Environmental Disasters, Habitat Change, Health Impact and Industry Stress.

1.1.2 Weighting

Weights or coefficients can be attributed to each one of the criteria selected. This means that allocation regimes based on only one of the criteria, e.g. responsibility, or based on more than one criterion, and assuming either equal or different weighting among the different criteria can be studied. For each criterion, one or a set of empirical measures to evaluate them can be selected, also with different weights. Such an approach allows for full flexibility of assumptions in regard to criteria and metrics.

1.1.3 Index calculation

The selected quantitative measures are weighted, normalized and added, to obtain an interim index. The split of the mitigation burden is calculated proportionally to a final index, which is obtained by normalizing and weighting the interim index by the population share of each country. To avoid using projections, we calculated the index based on the last common historical year shared between all selected metrics, which was 2010. The index is calculated for as many countries as possible, which is the number of common countries available for all selected metrics (for details, refer to Table A1).

Because the index is the result of the normalization of variables, we investigate the presence of extreme countries in each one of the metrics and exclude those to avoid the over or under-estimation of countries' share of responsibility. The method used to identify extreme countries is based on the interquartile range, which is the difference between the upper and lower quartiles (Q3 and Q1 respectively). We considered extremes to be all values that were below or above the lower or upper fences, which are defined as $Q1-k_l*(Q3-Q1)$ and $Q3+k_u*(Q3-Q1)$ respectively (with k_l and k_u constants for the lower and the upper fence constants). Note that for skewed distributions, the lower and upper control limits are asymmetrically placed with respect to the centre and the lower and upper fence constants k_l and k_u are allowed to be different. We conducted a post-hoc analysis of the extreme countries excluded at each scenario run to ensure that these only took on a small share of global emissions and that their exclusion would have a low impact on final allowances results (e.g., if China was considered an outlier and excluded from the analysis, this would have a major impact on countries' final emissions allowances. For details, refer to Table A1).

1.1.4 Calculation of countries' emissions allowances

1.1.4.1 Low-carbon scenarios

Equity methodologies often fit global emissions to levels that are in line with temperature targets. The scientific literature contains many different emission scenarios computed by integrated assessment models that limit global temperature rise to 1.5° C or 2° C above preindustrial levels, with a certain probability. The differences in shapes of emissions mitigation pathways arise from the range of assumptions made about inputs such as costs, potential and performance of different mitigation technologies, as well as driving forces of emissions such as economic and population growth. The two scenarios chosen here are consistent with maintaining temperatures (1) below 2°C with a likely probability (34% probability of exceeding 2°C within the 21st century) and (2) below 1.5°C with medium probability (50% chance of exceeding 1.5°C in 2100). For the time-span we analyze here (2020-2050), the two scenarios require similar levels of reduction for Parties as the two pathways assume similar carbon budgets until 2050 (see Box A1). However, if other types of scenarios are chosen e.g. later-action scenarios (UNEP 2012) instead of least-cost scenarios, efforts in 2020 would be relieved whereas actions in 2030 and 2050 would need to be enhanced.

Box A1: 2 and 1.5°C pathways and AR5

The IPCC's Working Group III contribution to the Fifth Assessment Report assesses the scientific literature on energy-economic emission scenarios. This includes hundreds of scenarios that keep warming below 2°C. In figure A1 we show the 80% ranges of emissions for scenarios that keep warming below 2°C with over 66% probability ('*likely*'), as well as a higher probability (85%) that also leads to below 1.5°C by 2100 with more than 50% probability. These scenarios assume there is still full potential for immediate and concerted global reduction efforts, leading to emissions peaking before 2020 and overall lowest economic costs over the 21st century. As an illustration of the early-versus-late reductions trade-off, we also show a median estimate of emissions in scenarios that reach 2020 levels only a bit below 2020 levels implied by Cancun reduction pledges. That pathway by necessity reaches much faster and deeper reductions than other 2°C pathways, at a higher overall economic cost and higher technological feasibility risks. The illustrative pathways of the Climate Action Tracker (CAT) shown in Figure A1 were based on UNEP's Emissions Gap report 2013 and are mostly within the emission ranges of the more recent WGIII scenarios.

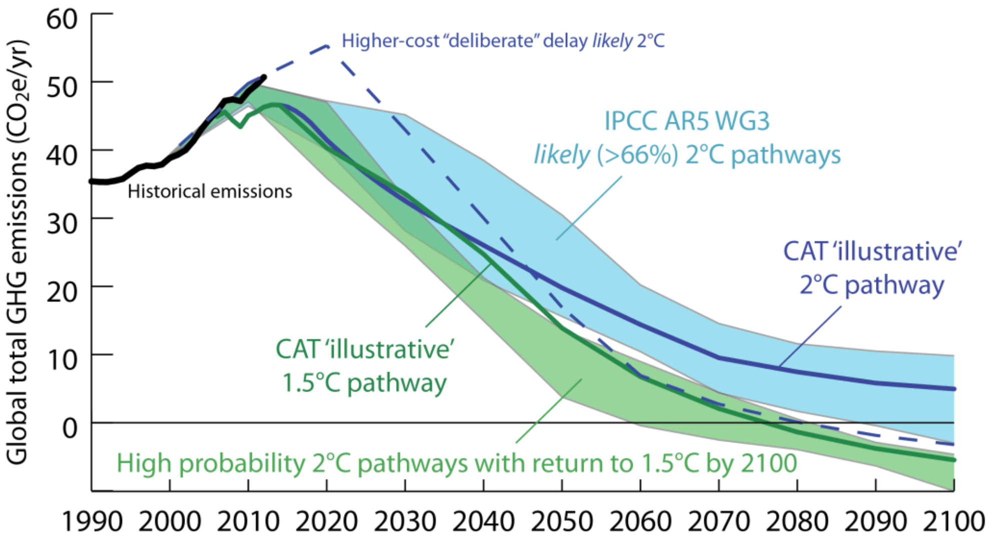

Figure A1 Emission scenario ranges (10 to 90 percentile) for IPCC AR5 Working Group III scenarios compared to CAT illustrative scenarios and a representative pathway of delayed-action scenarios.

Figure A2 depicts emissions for CO_2 from energy and industry, showing that these need to decline more rapidly than total GHG emissions in 1.5 and 2°C pathways, and also pass through zero earlier, reaching deep net-negative values by the end of the century in most scenarios.

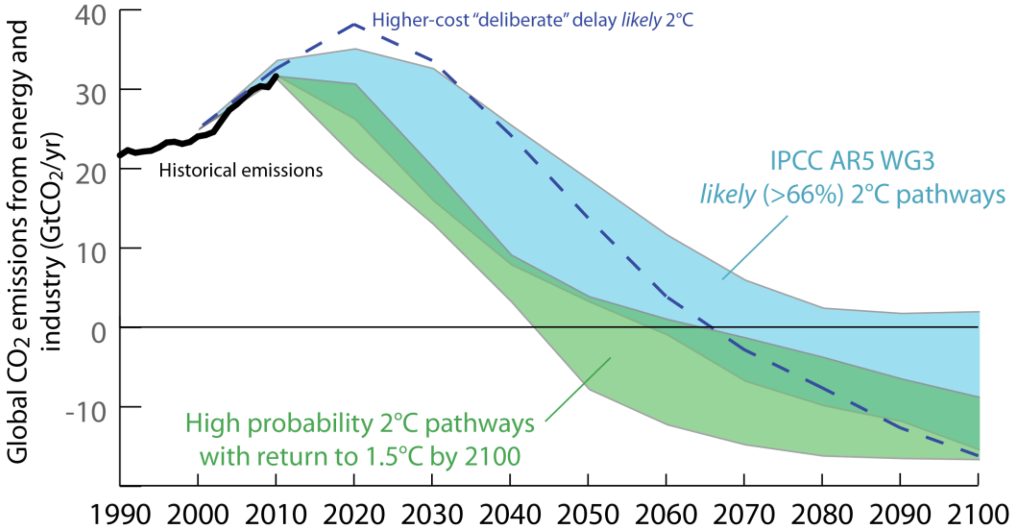

Figure A2 As Figure A1 for CO_2 emissions from energy and industry.

1.1.4.2 Treatment of emissions from international aviation and marine shipping and from deforestation

Since the 2 and 1.5°C scenarios comprise total global emissions, they take into account efforts in all sectors, including international aviation and marine shipping and the land-use and land-use change (LULUCF) sectors. Here, we have opted to treat these two sectors separately from all other sectors for the following reasons. First, addressing emissions from international aviation and marine shipping is challenging, because they are produced along routes where no single nation has regulatory authority. Internationally, the Kyoto Protocol excludes international emissions from aviation and marine transport from developed countries' national targets, unlike all other sources of emissions. Secondly, emissions from the LULUCF sector add a very high level of uncertainty to the overall results of individual countries. For both international aviation and marine shipping and the LULUCF sectors, we have built global policy pathways, using the following methodology:

- **International aviation and marine shipping policy pathway:** According to IMO, 2011, the abatement potential of measures in the marine shipping sector are 20% and 46% below business-as-usual in 2020 and 2030 respectively. Considering SRESA1 business-as-usual for that sector, we built policy pathways considering those reductions in 2020 and 2030 and then SRESA1 growth rates up to 2050. For the aviation sector, we employ the methodology described in the UNEP 2011 which considers potential emissions in 2020 according to (MODTF/FESG, 2009) scenario 'S6' with reductions through technological, operational means, and additional reductions of 5% uptake of low-CO_2 biofuels. Both pathways are harmonized to most recent historical data and added to create one global bunkers policy pathway.

- **LULUCF policy pathway:** Since Brazil and Indonesia take by far the largest share of deforestation emissions globally, a LULUCF policy pathway is built assuming that these two countries will meet their pledge to reduce emissions in that sector. Because those pledges are formulated as reductions below BAU, we assume regional BAU emissions from RCP8.5 and apply the reduction in Brazil and Indonesia to their respective regions. A final global policy pathway is obtained by aggregating the regional data and harmonizing with most recent historical data for the sector.

The obtained policy pathways are then deducted from the global emissions scenarios consistent with 2 or 1.5°C. This approach implies that emissions reductions in these two sectors will be achieved. Such an assumption can be questioned and the option to deduct other pathways for these sectors (e.g. business-as-usual for bunker emissions, assuming no emission reductions in this sector) from the global emissions scenario is also available in the tool. Because achieving low temperature targets would require strong reductions in all sectors, in this report we only show results using policy pathways for the international bunkers and LULUCF sectors.

1.1.4.3 Global mitigation burden

Based on the selected low-carbon scenario, an emissions mitigation burden (Figure A3) is calculated as the difference between global business-as-usual emissions and an emissions trajectory that avoids the worst effects of global warming (here consistent with a 2 or 1.5°C temperature target).

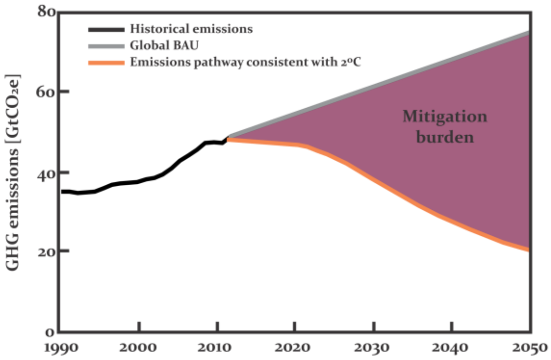

Figure A3 Mitigation burden

1.1.4.4 Calculation of emissions allowances

The index calculated using the methodology described in section c (above) is then used to split the mitigation burden across countries, in such way that the country's index share of the sum of all indices will be proportional to its share of the mitigation burden. Countries with high indices will be attributed a high share of the mitigation burden and vice-versa. The share of the global mitigation burden of a country is subsequently subtracted from this country's business-as-usual emissions to obtain its final emissions allocations. Such an approach allows for attribution of negative emissions allocations.

As previously mentioned, the final number of countries for which we calculate the index depends on the availability of data and on the number of outlier countries and represents therefore a subset of all countries in the world. The mitigation burden will be split among this subset of countries only, which implies that countries for which the index was not calculated (due to unavailability of data) will not take part in mitigation and are allowed to follow business-as-usual. For each scenario run, we have also recorded the final number of countries assessed and the percentage of global emissions that they represent in 2011 in order to evaluate the effect of not taking them into account in our calculations (Table A1).

Table A1: Number of countries considered in each scenario and amount of global emissions they represent

Scenario	Percentage of global emissions	Number of countries
1	97,1%	144
2	95,9%	95
3	97,1%	144
4	95,9%	95
5	98,8%	189
6	98,6%	178
7	97,4%	166*
8	96,2%	120 *
9	97,2%	170 *
10	96,2%	123*

*Members states of the European Union are considered separately due to lack of aggregate data for the European Union (HDI and CVM)

As shown in Table A1, the minimum percentage of global emissions considered by the countries for which data is available is of 95.9% (meaning that all countries that will follow BAU do not represent more than 4% of global emissions). This is within the range of uncertainty in the data and scenarios and therefore has a very small influence on the results.

An alternative methodology that allocates the emissions space (carbon budget under the selected mitigation target scenario instead of the difference between BAU emissions and target scenario) is appealing because it would not rely on BAU development assumptions. However, it has not been employed here because it would require politically sensitive assumptions to be made. Emissions levels consistent with a 2° or 1.5°C world can only realistically be reached if some parts of the world continue to emit whilst others cease and/or start to have negative emissions or participate in a carbon market mechanism that allows for the sum of emissions allowances to be equal to emissions levels consistent with the required stabilisation level. Establishing a methodology to split the carbon budget would require defining a threshold to split the world between countries that still have the right to emit and countries that do not, and is therefore highly political.

2 Additional results

2.1 Emissions allowances in a 2°C world

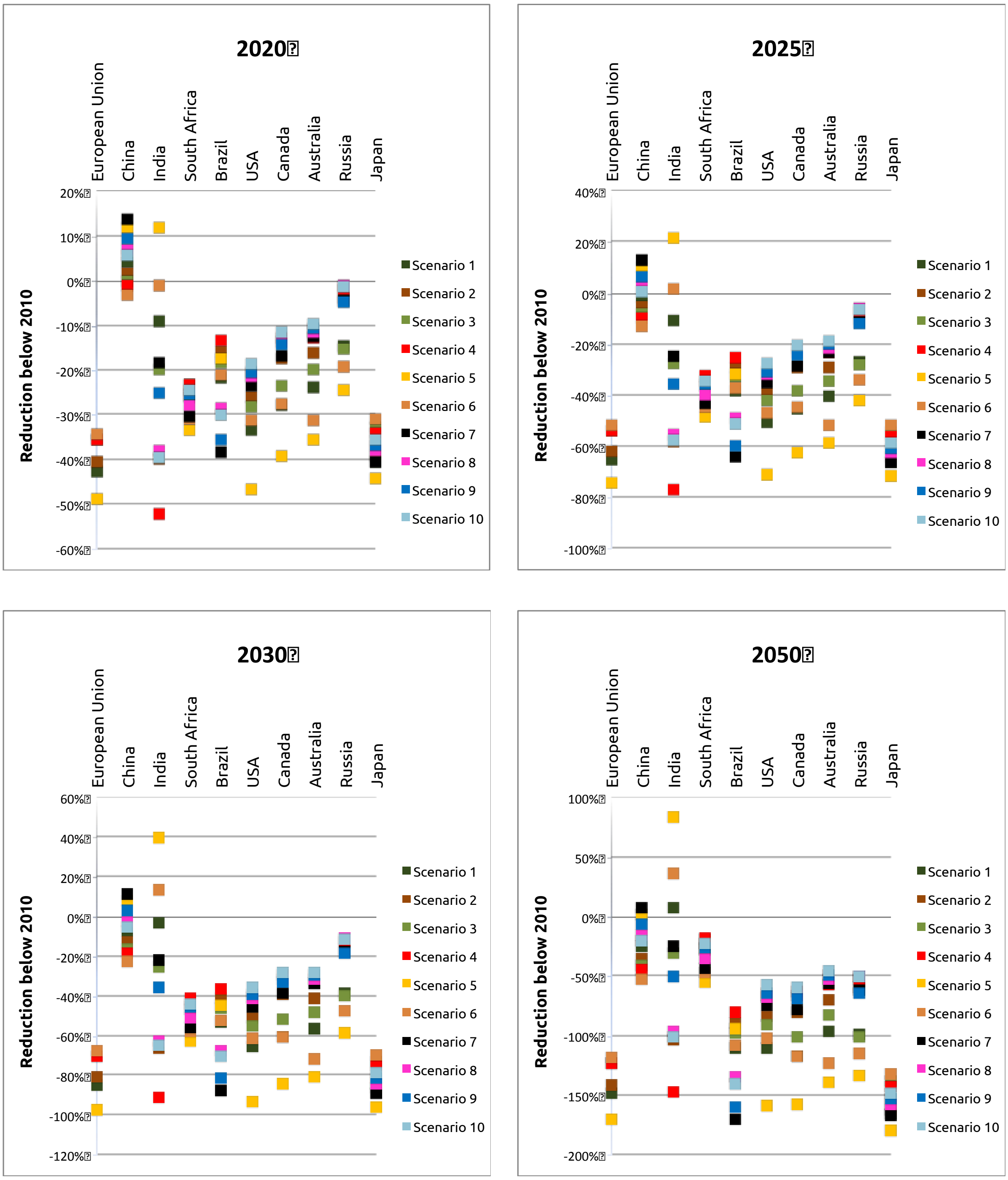

Figure A4 Emissions allowance delivered by the ten scenarios for the ten key emitters, expressed as reductions below 2010 levels in 2020, 2025, 2030 and 2050. To ease graphical readability, we only show emissions allowance levels for one cumulative emissions period length: 1990-2010.

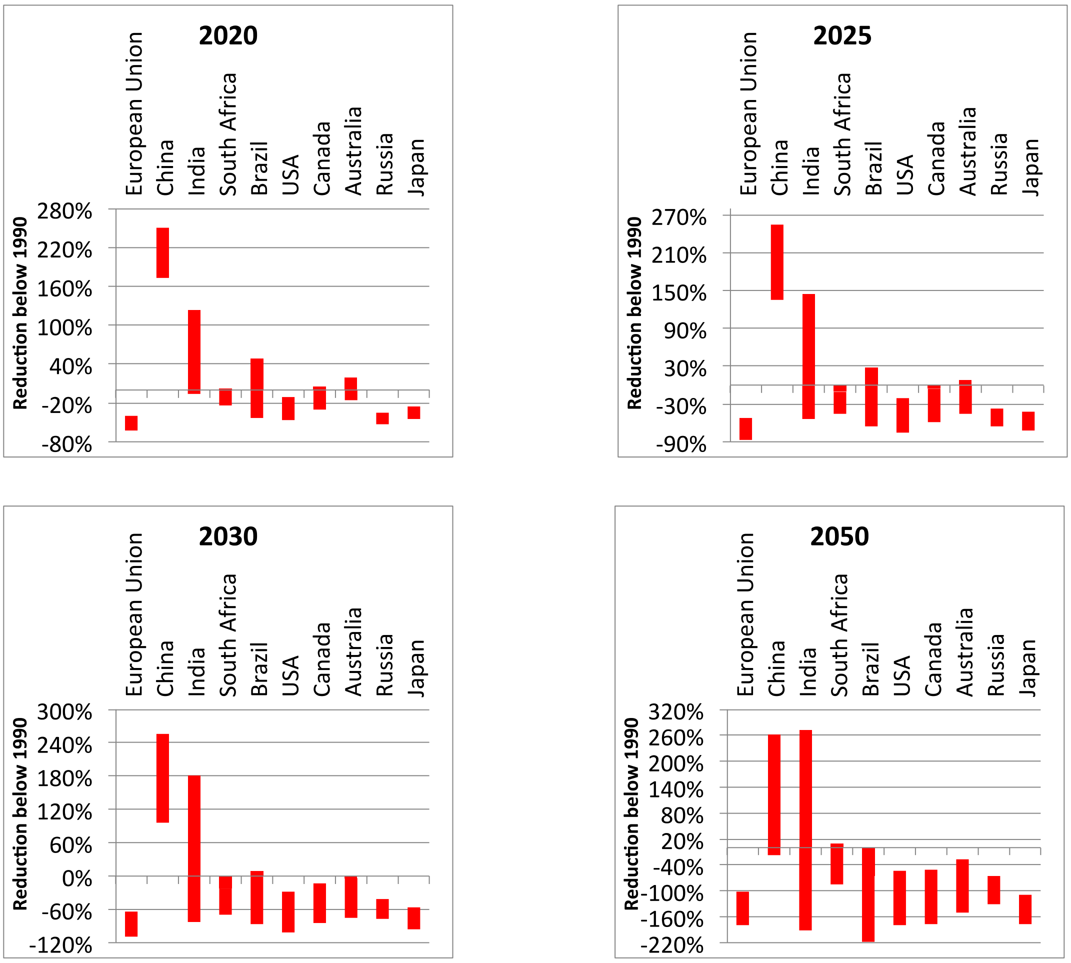

Figure A5 Emissions allowance ranges delivered by the ten scenarios for the ten key emitters, expressed as reductions below 1990 levels in 2020, 2025, 2030 and 2050.

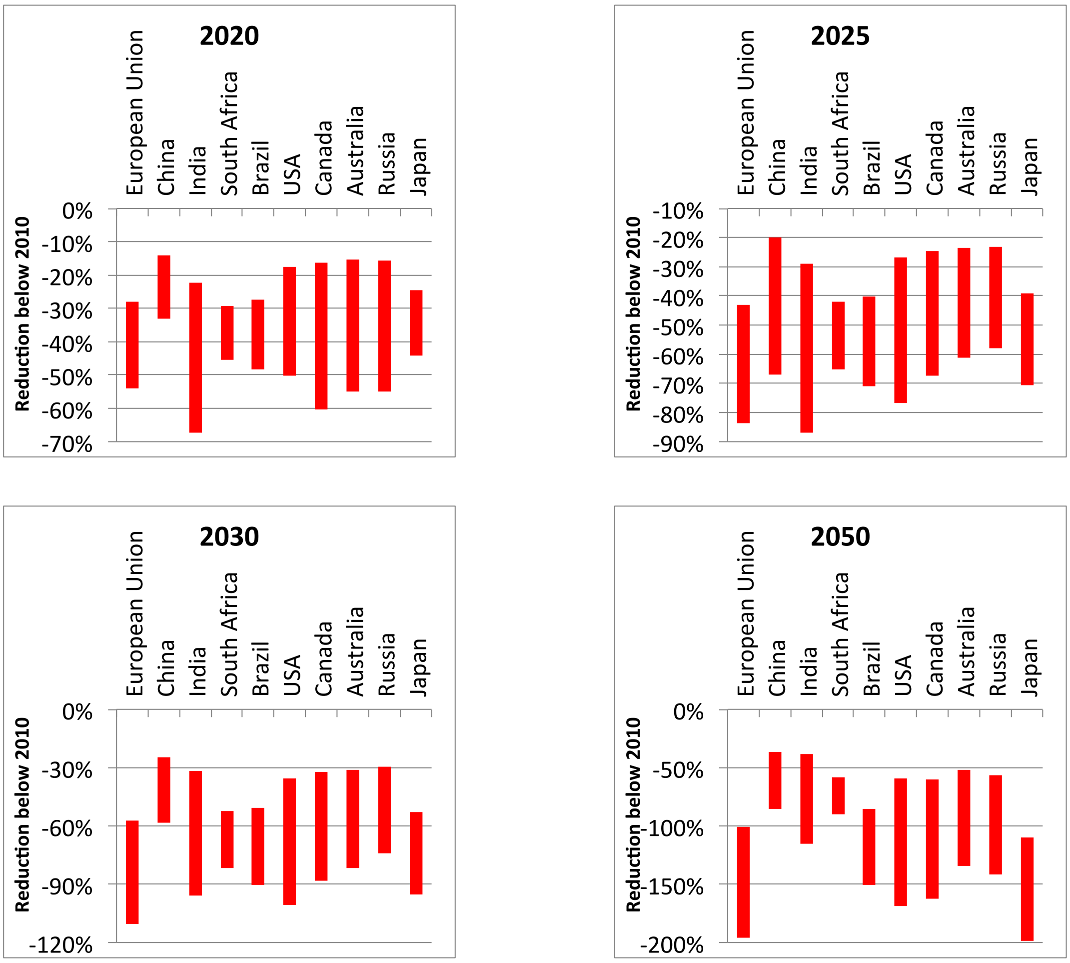

Figure A6 Emissions allowance ranges delivered by the ten scenarios for the ten key emitters, expressed as reductions below business-as-usual levels in 2020, 2025, 2030 and 2050.

As indicated in the Main report, final levels of emissions allowances are strongly influenced by the starting level of business-as-usual emissions of the countries. When the results are expressed as reductions below 1990 levels, emissions allowances for China in 2020 are much higher than in the other countries analysed here. This is because Chinese emissions have grown and are expected to grow much faster than in any other country. If emissions are instead expressed as reductions below BAU, the reduction ranges among all countries are in fact much more similar to each other. The choice of reference level for comparison can significantly change the perceived equality between countries emissions allowances, and several reference levels should be considered to give a complete picture.

Table A2 Percentage reduction below 2010 levels per equity regime scenario and Party for 2020, 2030 and 2020 in a 2°C world.

	Cumulative emissions period length	Scenario 1			Scenario 2		
		2020	2030	2050	2020	2030	2050
EU28	1950-2010	-44%	-87%	-153%	-41%	-82%	-144%
	1990-2010	-43%	-85%	-148%	-40%	-81%	-141%
China	1950-2010	5%	-6%	-23%	3%	-11%	-31%
	1990-2010	4%	-7%	-25%	2%	-12%	-34%
India	1950-2010	-10%	-5%	4%	-40%	-66%	-103%
	1990-2010	-9%	-3%	8%	-40%	-66%	-103%
South Africa	1950-2010	-26%	-48%	-30%	-24%	-43%	-21%
	1990-2010	-26%	-46%	-27%	-23%	-41%	-18%
Brazil	1950-2010	-20%	-51%	-105%	-16%	-42%	-91%
	1990-2010	-21%	-53%	-110%	-16%	-41%	-89%
USA	1950-2010	-34%	-66%	-111%	-26%	-51%	-85%
	1990-2010	-33%	-65%	-110%	-26%	-50%	-83%
Canada	1950-2010	-27%	-60%	-115%	-17%	-39%	-79%
	1990-2010	-28%	-60%	-117%	-17%	-39%	-79%
Australia	1950-2010	-22%	-54%	-91%	-16%	-40%	-68%
	1990-2010	-24%	-56%	-96%	-16%	-41%	-69%
Russia	1950-2010	-16%	-41%	-103%	-4%	-18%	-62%
	1990-2010	-14%	-38%	-98%	-4%	-16%	-59%
Japan	1950-2010	-39%	-85%	-160%	-38%	-84%	-157%
	1990-2010	-40%	-88%	-166%	-39%	-86%	-161%

CLIMATE ANALYTICS

Cumulative emissions period length		Scenario 3			Scenario 4		
		2020	2030	2050	2020	2030	2050
EU28	1950-2010	-36%	-71%	-124%	-36%	-71%	-124%
	1990-2010	-35%	-70%	-123%	-35%	-70%	-123%
China	1950-2010	0%	-16%	-40%	0%	-17%	-43%
	1990-2010	0%	-16%	-41%	-1%	-18%	-44%
India	1950-2010	-21%	-27%	-35%	-52%	-91%	-147%
	1990-2010	-20%	-25%	-31%	-52%	-91%	-147%
South Africa	1950-2010	-26%	-48%	-30%	-23%	-42%	-19%
	1990-2010	-26%	-47%	-27%	-23%	-41%	-17%
Brazil	1950-2010	-17%	-44%	-93%	-14%	-37%	-81%
	1990-2010	-18%	-46%	-97%	-13%	-36%	-80%
USA	1950-2010	-28%	-54%	-91%	-21%	-41%	-67%
	1990-2010	-28%	-54%	-91%	-21%	-40%	-66%
Canada	1950-2010	-23%	-51%	-100%	-13%	-30%	-62%
	1990-2010	-23%	-51%	-101%	-13%	-29%	-62%
Australia	1950-2010	-19%	-46%	-78%	-12%	-33%	-56%
	1990-2010	-20%	-48%	-82%	-13%	-34%	-56%
Russia	1950-2010	-16%	-42%	-105%	-2%	-13%	-54%
	1990-2010	-15%	-40%	-101%	-2%	-12%	-52%
Japan	1950-2010	-31%	-69%	-132%	-33%	-74%	-140%
	1990-2010	-33%	-73%	-138%	-34%	-75%	-142%

	Start year for cumulative emissions	Scenario 5(end year for cumulative emissions 2010)			Scenario 6 (end year for cumulative emissions 2050)			Scenario 6 (end year for cumulative emissions 2100)		
		2020	2030	2050	2050	2030	2050	2020	2030	2050
EU28	1950	-55%	-110%	-193%	-39%	-78%	-136%	-33%	-65%	-114%
	1990	-49%	-97%	-170%	-34%	-68%	-118%	-29%	-58%	-101%
China	1950	17%	19%	21%	3%	-10%	-30%	-4%	-25%	-56%
	1990	12%	8%	2%	-3%	-23%	-52%	-9%	-34%	-73%
India	1950	14%	44%	90%	2%	20%	49%	-8%	-2%	10%
	1990	12%	40%	84%	-1%	14%	37%	-11%	-6%	2%
South Africa	1950	-40%	-76%	-79%	-33%	-62%	-55%	-41%	-77%	-81%
	1990	-33%	-62%	-55%	-31%	-57%	-46%	-40%	-75%	-78%
Brazil	1950	-16%	-41%	-89%	-24%	-58%	-119%	-19%	-48%	-101%
	1990	-17%	-44%	-94%	-21%	-52%	-108%	-17%	-43%	-92%
USA	1950	-51%	-101%	-172%	-35%	-69%	-116%	-28%	-55%	-91%
	1990	-47%	-93%	-158%	-31%	-61%	-102%	-25%	-49%	-81%
Canada	1950	-41%	-87%	-164%	-30%	-66%	-126%	-24%	-52%	-102%
	1990	-39%	-84%	-158%	-28%	-60%	-116%	-21%	-48%	-94%
Australia	1950	-35%	-80%	-138%	-32%	-72%	-124%	-31%	-72%	-124%
	1990	-36%	-80%	-139%	-31%	-71%	-122%	-31%	-71%	-123%
Russia	1950	-28%	-67%	-148%	-21%	-52%	-123%	-18%	-44%	-109%
	1990	-24%	-58%	-133%	-19%	-47%	-114%	-16%	-41%	-102%
Japan	1950	-37%	-82%	-154%	-30%	-67%	-128%	-25%	-57%	-110%
	1990	-44%	-96%	-179%	-31%	-69%	-132%	-24%	-56%	-108%

	Cumulative emissions period length	Scenario 7			Scenario 8		
		2020	2030	2050	2020	2030	2050
EU28	1950-2010	-	-	-	-	-	-
	1990-2010	-	-	-	-	-	-
China	1950-2010	14%	13%	10%	7%	-2%	-15%
	1990-2010	14%	12%	8%	7%	-2%	-16%
India	1950-2010	-16%	-17%	-16%	-38%	-62%	-97%
	1990-2010	-18%	-22%	-25%	-38%	-62%	-96%
South Africa	1950-2010	-31%	-58%	-48%	-28%	-51%	-35%
	1990-2010	-30%	-55%	-43%	-28%	-51%	-35%
Brazil	1950-2010	-36%	-83%	-163%	-28%	-67%	-134%
	1990-2010	-38%	-87%	-170%	-28%	-67%	-134%
USA	1950-2010	-25%	-49%	-81%	-21%	-41%	-67%
	1990-2010	-23%	-45%	-74%	-21%	-41%	-67%
Canada	1950-2010	-18%	-41%	-82%	-13%	-31%	-65%
	1990-2010	-17%	-38%	-78%	-13%	-31%	-66%
Australia	1950-2010	-13%	-35%	-59%	-11%	-31%	-52%
	1990-2010	-12%	-33%	-55%	-11%	-31%	-52%
Russia	1950-2010	-6%	-21%	-68%	-1%	-10%	-49%
	1990-2010	-4%	-17%	-62%	-1%	-10%	-49%
Japan	1950-2010	-41%	-90%	-168%	-38%	-83%	-156%
	1990-2010	-40%	-89%	-166%	-38%	-84%	-157%

Cumulative emissions period length		Scenario 9 2020	Scenario 9 2030	Scenario 9 2050	Scenario 10 2020	Scenario 10 2030	Scenario 10 2050
EU28	1950-2010	-	-	-	-	-	-
	1990-2010	-	-	-	-	-	-
China	1950-2010	10%	4%	-5%	6%	-4%	-20%
	1990-2010	10%	3%	-6%	6%	-5%	-20%
India	1950-2010	-25%	-37%	-51%	-39%	-65%	-101%
	1990-2010	-25%	-36%	-50%	-39%	-65%	-101%
South Africa	1950-2010	-25%	-46%	-26%	-24%	-44%	-22%
	1990-2010	-25%	-45%	-25%	-24%	-44%	-22%
Brazil	1950-2010	-35%	-82%	-160%	-30%	-70%	-140%
	1990-2010	-35%	-81%	-159%	-30%	-70%	-140%
USA	1950-2010	-20%	-38%	-62%	-19%	-35%	-57%
	1990-2010	-20%	-39%	-63%	-19%	-35%	-57%
Canada	1950-2010	-14%	-32%	-67%	-11%	-27%	-59%
	1990-2010	-14%	-33%	-68%	-12%	-27%	-59%
Australia	1950-2010	-10%	-28%	-47%	-9%	-27%	-45%
	1990-2010	-10%	-29%	-49%	-10%	-27%	-45%
Russia	1950-2010	-5%	-18%	-63%	-1%	-11%	-50%
	1990-2010	-5%	-18%	-63%	-1%	-11%	-50%
Japan	1950-2010	-36%	-80%	-151%	-35%	-78%	-147%
	1990-2010	-37%	-81%	-153%	-35%	-78%	-148%

2.2 Emissions allowances in a 1.5°C world

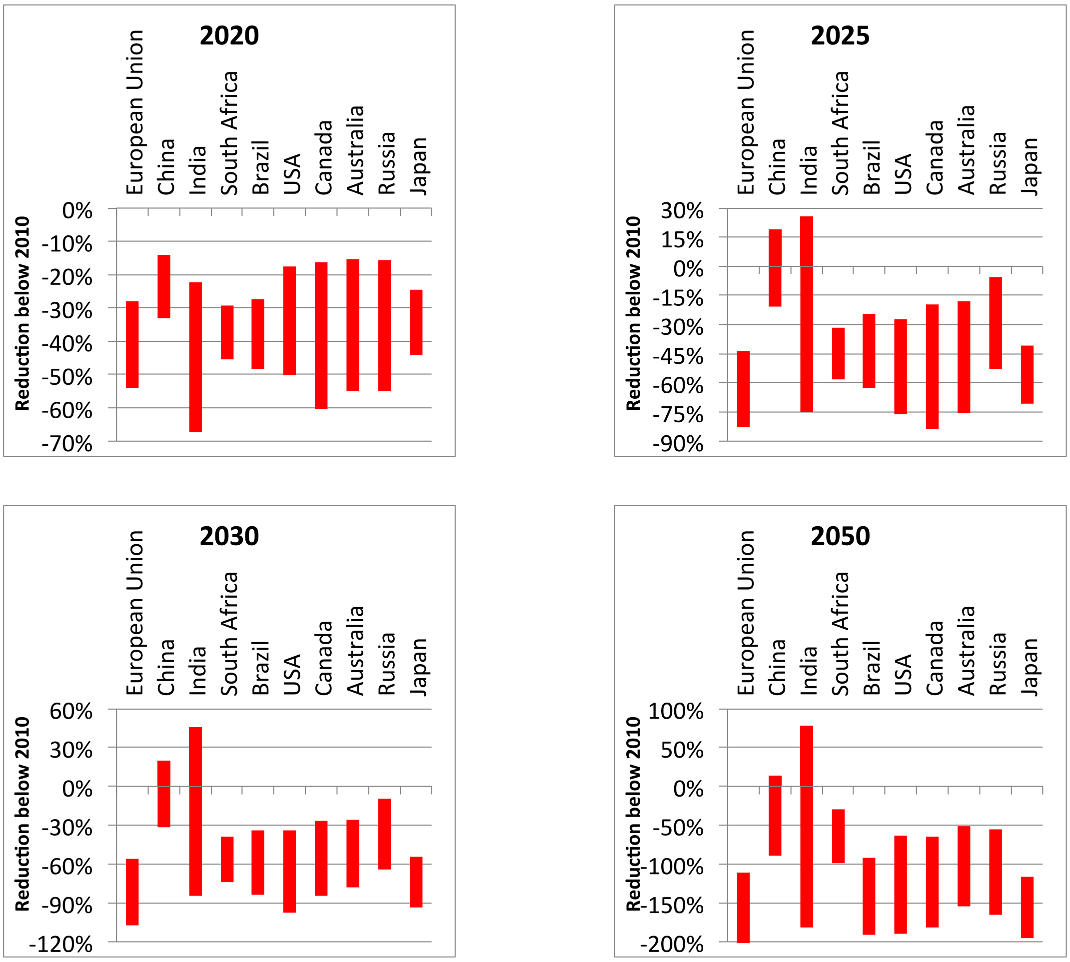

Figure A7 Emissions allowance ranges delivered by the ten scenarios for the ten key emitters, expressed as reductions below 2010 levels in 2020, 2025, 2030 and 2050.

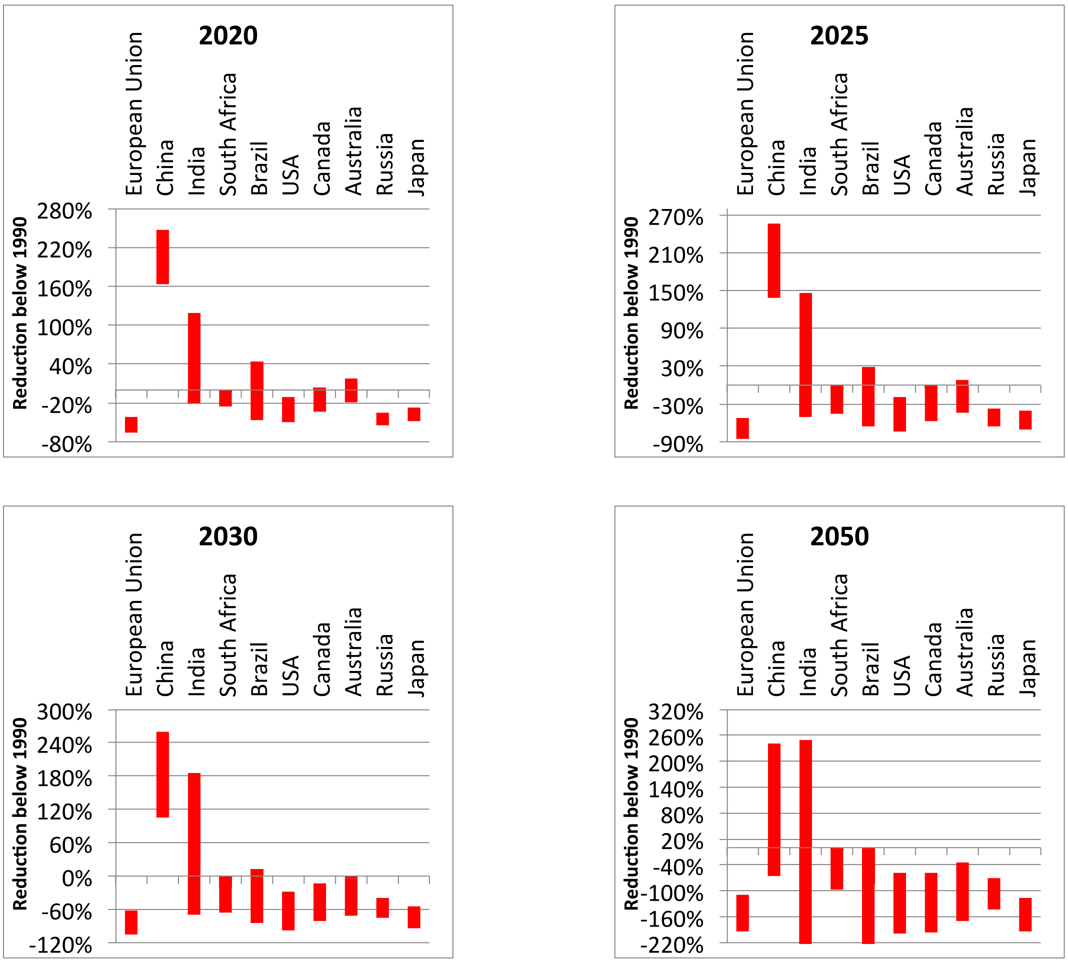

Figure A8 Emissions allowance ranges delivered by the ten scenarios for the ten key emitters, expressed as reductions below 1990 levels in 2020, 2025, 2030 and 2050.

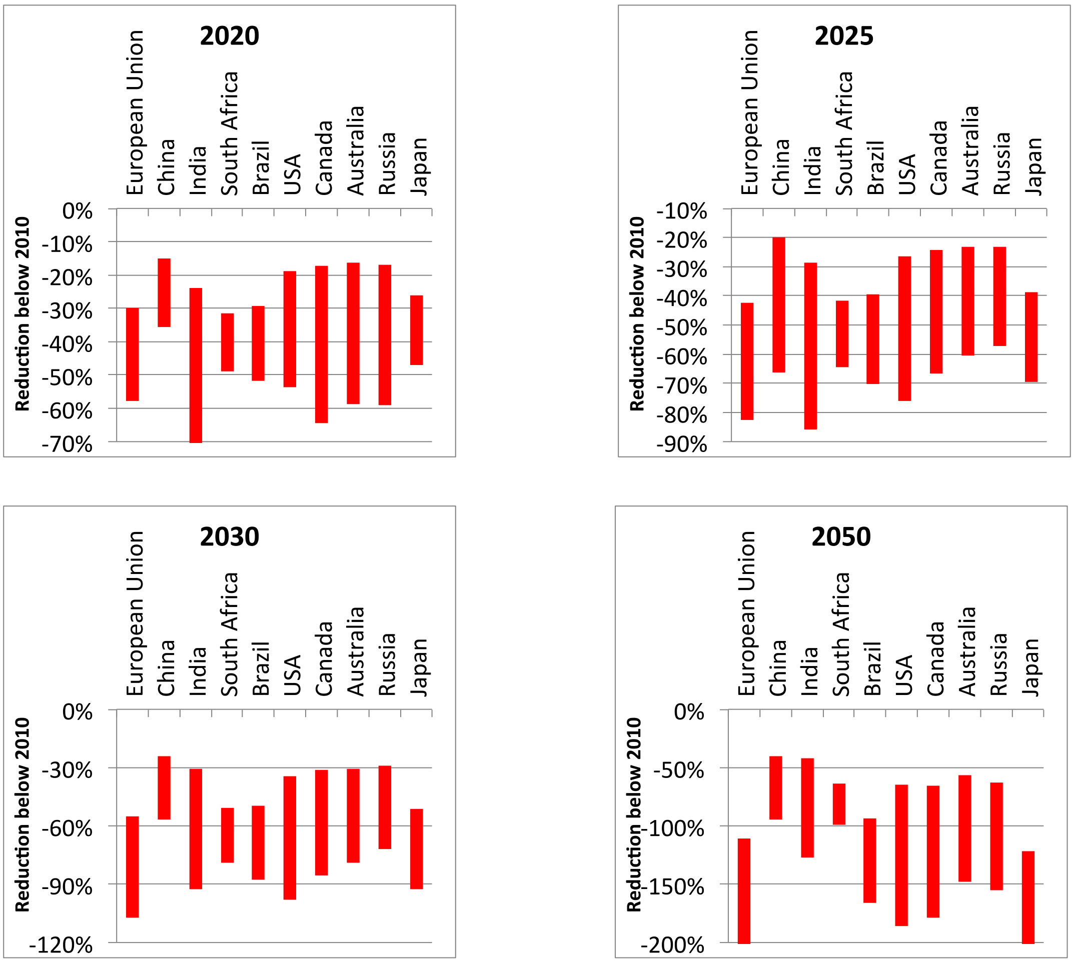

Figure A9: Emissions allowance ranges delivered by the ten scenarios for the ten key emitters, expressed as reductions below 1990 levels in 2020, 2025, 2030 and 2050.

As indicated in Box A1, the 1.5 and 2°C mitigation pathways do not differ substantially from each other until 2050, the period of time studied here, and hence emissions allowances in a. 1.5°C world are very similar to those in a 2°C.

Table A2 Percentage reduction below 2010 levels per equity regime scenario and Party for 2020, 2030 and 2020 in a 1.5°C world.

	Cumulative emissions period length	Scenario 1			Scenario 2		
		2020	2030	2050	2020	2030	2050
EU28	1950-2010	-47%	-85%	-168%	-44%	-80%	-158%
	1990-2010	-45%	-82%	-163%	-43%	-78%	-155%
China	1950-2010	3%	-4%	-34%	0%	-9%	-44%
	1990-2010	2%	-5%	-36%	-1%	-10%	-47%
India	1950-2010	-14%	-2%	-16%	-46%	-60%	-134%
	1990-2010	-13%	0%	-12%	-46%	-61%	-134%
South Africa	1950-2010	-29%	-46%	-42%	-26%	-41%	-32%
	1990-2010	-28%	-44%	-39%	-25%	-39%	-30%
Brazil	1950-2010	-23%	-48%	-120%	-19%	-40%	-104%
	1990-2010	-24%	-51%	-124%	-18%	-39%	-101%
USA	1950-2010	-36%	-64%	-123%	-28%	-49%	-94%
	1990-2010	-36%	-63%	-122%	-28%	-49%	-92%
Canada	1950-2010	-30%	-58%	-127%	-19%	-38%	-88%
	1990-2010	-30%	-58%	-129%	-19%	-38%	-87%
Australia	1950-2010	-24%	-52%	-102%	-18%	-39%	-76%
	1990-2010	-26%	-54%	-107%	-18%	-39%	-77%
Russia	1950-2010	-18%	-39%	-116%	-6%	-16%	-70%
	1990-2010	-17%	-36%	-109%	-5%	-15%	-67%
Japan	1950-2010	-41%	-83%	-174%	-41%	-81%	-171%
	1990-2010	-43%	-86%	-180%	-42%	-83%	-175%

Cumulative emissions period length		Scenario 3 2020	Scenario 3 2030	Scenario 3 2050	Scenario 4 2020	Scenario 4 2030	Scenario 4 2050
EU28	1950-2010	-38%	-69%	-136%	-38%	-69%	-136%
	1990-2010	-38%	-68%	-134%	-38%	-68%	-135%
China	1950-2010	-2%	-14%	-53%	-3%	-15%	-56%
	1990-2010	-3%	-14%	-54%	-4%	-16%	-58%
India	1950-2010	-26%	-23%	-59%	-59%	-85%	-182%
	1990-2010	-24%	-21%	-54%	-59%	-85%	-182%
South Africa	1950-2010	-29%	-46%	-43%	-26%	-40%	-31%
	1990-2010	-28%	-45%	-40%	-25%	-39%	-29%
Brazil	1950-2010	-19%	-41%	-106%	-16%	-35%	-93%
	1990-2010	-21%	-44%	-111%	-15%	-34%	-91%
USA	1950-2010	-30%	-53%	-100%	-23%	-40%	-74%
	1990-2010	-30%	-53%	-100%	-22%	-39%	-73%
Canada	1950-2010	-25%	-49%	-110%	-14%	-28%	-69%
	1990-2010	-25%	-50%	-111%	-14%	-28%	-69%
Australia	1950-2010	-21%	-45%	-88%	-14%	-32%	-62%
	1990-2010	-22%	-47%	-91%	-14%	-32%	-63%
Russia	1950-2010	-19%	-40%	-118%	-4%	-12%	-61%
	1990-2010	-18%	-38%	-113%	-3%	-11%	-59%
Japan	1950-2010	-33%	-68%	-143%	-35%	-72%	-152%
	1990-2010	-35%	-71%	-150%	-36%	-73%	-154%

Start year for cumulative emissions		Scenario 5(end year for cumulative emissions 2010) 2020	2030	2050	Scenario 6 (end year for cumulative emissions 2050) 2050	2030	2050	Scenario 6 (end year for cumulative emissions 2100) 2020	2030	2050
EU28	1950	-59%	-107%	-212%	-42%	-76%	-149%	-35%	-64%	-125%
	1990	-52%	-94%	-187%	-36%	-66%	-129%	-31%	-56%	-111%
China	1950	16%	20%	14%	1%	-8%	-42%	-7%	-23%	-71%
	1990	10%	10%	-7%	-6%	-20%	-66%	-12%	-32%	-89%
India	1950	11%	46%	78%	-1%	23%	33%	-12%	2%	-10%
	1990	10%	42%	71%	-4%	16%	20%	-15%	-3%	-18%
South Africa	1950	-44%	-73%	-97%	-36%	-60%	-70%	-44%	-74%	-99%
	1990	-36%	-59%	-70%	-34%	-55%	-60%	-43%	-72%	-96%
Brazil	1950	-18%	-39%	-101%	-27%	-56%	-135%	-22%	-46%	-115%
	1990	-20%	-42%	-107%	-24%	-49%	-122%	-19%	-41%	-105%
USA	1950	-54%	-98%	-190%	-37%	-67%	-128%	-30%	-53%	-101%
	1990	-50%	-90%	-174%	-33%	-59%	-113%	-27%	-48%	-90%
Canada	1950	-44%	-84%	-181%	-33%	-64%	-139%	-26%	-50%	-113%
	1990	-42%	-81%	-174%	-30%	-58%	-128%	-23%	-46%	-104%
Australia	1950	-38%	-78%	-153%	-34%	-70%	-138%	-34%	-70%	-137%
	1990	-39%	-78%	-154%	-34%	-69%	-136%	-34%	-69%	-137%
Russia	1950	-32%	-64%	-165%	-24%	-50%	-137%	-20%	-42%	-122%
	1990	-27%	-55%	-148%	-22%	-45%	-127%	-18%	-38%	-114%
Japan	1950	-40%	-80%	-168%	-32%	-65%	-139%	-27%	-55%	-119%
	1990	-47%	-93%	-194%	-33%	-67%	-143%	-26%	-54%	-117%

	Cumulative emissions period length	Scenario 7			Scenario 8		
		2020	2030	2050	2020	2030	2050
EU28	1950-2010	-	-	-	-	-	-
	1990-2010	-	-	-	-	-	-
China	1950-2010	13%	14%	2%	5%	0%	-25%
	1990-2010	12%	13%	0%	5%	0%	-26%
India	1950-2010	-20%	-13%	-38%	-44%	-57%	-127%
	1990-2010	-23%	-18%	-48%	-44%	-57%	-127%
South Africa	1950-2010	-34%	-56%	-62%	-31%	-49%	-49%
	1990-2010	-33%	-53%	-57%	-30%	-49%	-48%
Brazil	1950-2010	-40%	-80%	-182%	-32%	-64%	-152%
	1990-2010	-42%	-84%	-191%	-32%	-64%	-152%
USA	1950-2010	-27%	-47%	-90%	-23%	-40%	-74%
	1990-2010	-25%	-44%	-82%	-23%	-40%	-74%
Canada	1950-2010	-20%	-39%	-91%	-15%	-30%	-72%
	1990-2010	-18%	-37%	-86%	-15%	-30%	-72%
Australia	1950-2010	-15%	-34%	-66%	-13%	-30%	-58%
	1990-2010	-14%	-32%	-62%	-13%	-30%	-59%
Russia	1950-2010	-8%	-20%	-76%	-2%	-9%	-56%
	1990-2010	-6%	-16%	-69%	-2%	-9%	-56%
Japan	1950-2010	-44%	-87%	-183%	-40%	-81%	-170%
	1990-2010	-43%	-86%	-181%	-41%	-81%	-171%

	Cumulative emissions period length	Scenario 9 2020	Scenario 9 2030	Scenario 9 2050	Scenario 10 2020	Scenario 10 2030	Scenario 10 2050
EU28	1950-2010	-	-	-	-	-	-
	1990-2010	-	-	-	-	-	-
China	1950-2010	8%	5%	-15%	4%	-2%	-31%
	1990-2010	8%	5%	-16%	4%	-3%	-31%
India	1950-2010	-31%	-32%	-77%	-46%	-60%	-132%
	1990-2010	-30%	-31%	-75%	-45%	-59%	-132%
South Africa	1950-2010	-28%	-44%	-38%	-27%	-42%	-34%
	1990-2010	-28%	-43%	-37%	-27%	-42%	-34%
Brazil	1950-2010	-39%	-78%	-180%	-33%	-67%	-157%
	1990-2010	-39%	-78%	-179%	-33%	-67%	-157%
USA	1950-2010	-21%	-37%	-69%	-20%	-34%	-63%
	1990-2010	-22%	-38%	-70%	-20%	-34%	-63%
Canada	1950-2010	-15%	-31%	-74%	-13%	-26%	-65%
	1990-2010	-16%	-32%	-75%	-13%	-26%	-65%
Australia	1950-2010	-11%	-27%	-53%	-11%	-26%	-51%
	1990-2010	-12%	-28%	-55%	-11%	-26%	-51%
Russia	1950-2010	-6%	-17%	-71%	-3%	-10%	-57%
	1990-2010	-6%	-17%	-71%	-3%	-10%	-57%
Japan	1950-2010	-39%	-78%	-164%	-38%	-76%	-160%
	1990-2010	-39%	-79%	-166%	-38%	-76%	-161%

2.3 Main drivers of variability in the range of emissions allowances

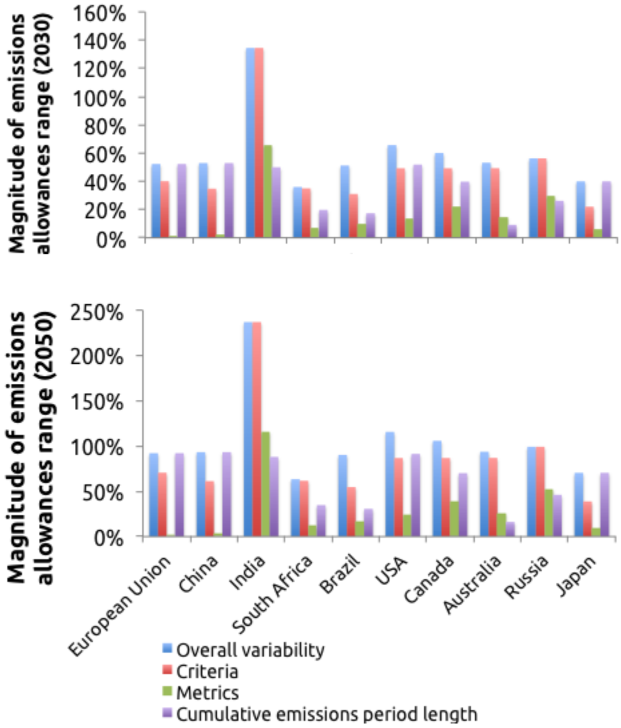

Figure A10: Magnitude of ranges in emissions allowances expressed in terms reductions below 2010 levels in 2030 (upper panel) and 2050 (bottom panel). The overall variability (blue bar) is a result of the variability in choices of criteria (red bar), metrics (green bar) and of cumulative emissions period length (purple bar). Note that the different sources of variability do not add up to total variability because they do not necessarily vary in the same direction

3 References

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