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# Fairness- and Cost-Effectiveness-Based Approaches to Effort-Sharing under the Paris Agreement

Im Rahmen des UFOPLAN-Vorhabens

„Implikationen des Pariser Klimaschutzabkommens auf nationale Klimaschutzanstrengungen“

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**Abstract**

The current nationally determined contributions of the Parties to the Paris Agreement are far from being sufficient to achieve the long-term goal to limit global warming. Therefore, the question of how to distribute the global mitigation burden among the Parties in a fair and cost-effective way remains topical. In this paper, approaches based on different fairness criteria and the criterion of cost-effectiveness are applied to a global emission budget compatible with the Paris targets and evaluated for the globally largest emitters including the EU as well as Germany. The results show that domestic mitigation efforts need to be increased in the majority of those countries even more than for the below-2°C limit of the Cancun Agreements. Moreover, even if the cost-effective level is assumed to be reached, there remains a strong need for support by the historical large emitters to others from a fairness perspective.

Die derzeitigen national festgelegten Beiträge der Vertragsparteien des Pariser Abkommens reichen bei weitem nicht aus, um das langfristige Ziel zur Begrenzung der Erderwärmung zu erreichen. Daher bleibt die Frage, wie die globale Minderungslast auf faire und kostengünstige Weise auf die Vertragsparteien verteilt werden kann, aktuell. In diesem Beitrag werden Ansätze, die auf unterschiedlichen Fairnesskriterien und dem Kriterium der Kosteneffizienz basieren, auf ein globales Emissionsbudget angewendet, das mit den Pariser Zielen vereinbar ist, und für die weltweit größten Emittenten einschließlich der EU und Deutschlands ausgewertet. Die Ergebnisse zeigen, dass die inländischen Minderungsmaßnahmen in den meisten dieser Länder noch mehr verstärkt werden müssen als für die in den Cancun-Abkommen festgelegten Grenze von unter 2°C. Selbst wenn davon ausgegangen wird, dass das kosteneffektive Niveau erreicht wird, besteht aus einer Fairnessperspektive darüber hinaus ein großer Bedarf an Unterstützung durch die historischen Großemittenten ggü anderen.

**Disclaimer**

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# 1 Policy brief

In the Paris Agreement (PA), which came into force in November 2016, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) agreed to limit global warming to "well below 2°C above pre-industrial levels" and to make efforts to "limit the temperature rise to 1.5°C above pre-industrial levels". Achieving this temperature goal will depend on sufficient national action by all countries, which will have to be strengthened and accelerated on an ongoing basis, as laid down in the review mechanisms of the PA. **The current reduction commitments of the states[1], including those of Germany and the EU, are not sufficient to achieve the objectives of the Paris Agreement (CAT, 2018).**

In the years prior to the 2009 United Nations Climate Change Conference in Copenhagen (COP15), the international community had an intensive discussion about suitable approaches for the regional allocation of greenhouse gas (GHG) reduction targets. Essential criteria that played a role in this discussion were the historical responsibility of the industrialised countries (in terms of cumulative GHG emissions caused), the mitigation capacity of the states (in terms of the level of development of the states, e. g. on HDI and GDP), the right to development (in terms of per capita emissions of GHG), technical and economic potentials for mitigation, as well as associated cost efficiency/welfare losses. **However, the international community reached neither a consensus nor a compromise how to distribute the mitigation efforts.** The **PA**, which **stresses that contributions from the states[2] have to reflect “the highest possible ambition” and “respective capabilities”,** has shifted the focus to emissions pathways that limit global warming to well below 2 °C, and undertaking effort to not exceed 1.5 °C.

The study underlying this policy brief derives **national GHG emissions reductions for 2030 and 2050** that are **consistent with the Paris Agreements’ long-**

1 so called nationally determined contribution (NDC)

2 While one of the Parties to the Paris Agreement analyzed in this report, namely the European Union, is not a state, for the sake of brevity and simplicity the specific reference to it being a group of states has been avoided throughout the text. Thus, unless specifically mentioned, whenever a reference to “states” is being made in this report, it stands for states and the group of states, namely the EU.

**term temperature goal**[3]**, both based on fairness-based and cost-effectiveness based approaches,** and compares them to emission reductions compatible with temperature goal of the Cancun Agreements (below 2 °C)**.** The range of fair shares is derived from an evaluation of a broad spectrum of fairness-based approaches by the Climate Action Tracker (CAT, 2018). The cost-effective reduction shares are based on recent marginal abatement cost curves (ENERDATA, 2018), which were used to derive globally cost-effective national pathways.

A comparison of those approaches **in this study yields insights how large the efforts in the country domestically should be and indicate need for support to or from other countries**, if there is a mismatch between the cost-effective potentials and the fair share. The study also suggests **whether or not a country can or should increase the ambition of its NDC for 2030**, for example because the NDC is much less ambitious as the mitigation potentials or the fair share of the country. The analysis focuses on countries that are particularly relevant because of their share in global GHG emissions and their role in international climate policy, namely **Brazil, Canada, China, the EU, India, Japan and the United States of America**. In addition, particular emphasis is given to the role of **Germany**.

## 1.1 Global carbon budgets resulting from the Paris Agreements' temperature targets

In the following, global emissions pathways that are consistent with the 2 °C temperature goal of the Cancun Agreements are referred to as 2°C-consistent pathways. Pathways that are consistent with the Paris Agreements' long-term temperature goal will be called 1.5°C-consistent pathways. To identify the emissions reduction goals for 2030 and 2050 compatible with the respective temperature limits, the approach of the Climate Action Tracker (CAT, 2018b) is applied. According to the CAT pathways, **the median global GHG emissions budget of a 2°C-consistent pathway in the period 2016 – 2100 is 1,760 Gt$CO_2$e** and 1,240 Gt$CO_2$e in the period 2016 – 2050 (see Table 5 for ranges). In this case, the annual GHG emissions in 2050 amount to 23.0 Gt $CO_2$e. **For a 1.5°C-consistent**

3 The analysis was carried out before publication of the IPCC's Special Report on Global Warming of 1.5°C. It is based on the global 1.5°C- and 2°C-consistent pathways available before. In particular, among the more recent pathways, there are some that limit warming to 1.5°C with "no or limited overshoot", i.e. reaching a peak warming of less than 1.6°C and returning below 1.5°C before 2100. Earlier 1.5°C pathways have somewhat higher global emissions in the near term (2030) and a somewhat larger warming overshoot of typically 1.65°C. Though an update may result in quantitative changes, the qualitative statements and the associated orders of magnitude can be expected to remain valid.

**pathway, the median global GHG emission budget is 1,080 Gt $CO_2$e in the period 2016 – 2100** and 990 Gt $CO_2$e in the period 2016 – 2050. The annual GHG emissions in 2050 amount to 13.5 Gt $CO_2$e in that case.

The methodology used for the quantification of the cost-effectiveness emissions pathways requires 2°C- and 1.5°C-consistent emissions budgets and pathways for the energy- and process-related GHG emissions only. The resulting median global budget in the period 2016 – 2050 is 790 Gt $CO_2$e and annual GHG emissions of 11.5 Gt $CO_2$e in 2050 for the 2°C-consistent pathway as well as 580 Gt $CO_2$e in the period 2016 – 2050 and annual GHG emissions of 3.5 Gt $CO_2$e in 2050 for the 1.5°C-consistent pathway.

Table 1: Global emissions budgets and pathways applied in this study

| | **Cumulative GHG emissions in 2016 – 2100 [Gt $CO_2$e]** | **Cumulative GHG emissions in 2016 – 2050 [Gt $CO_2$e]** | **Total GHG emissions in 2050 [Gt $CO_2$e]** | **Cum. energy- & process-rel. emissions 2016 – 2050 [Gt $CO_2$e]** | **Energy- & process-rel. emissions in 2050 [Gt $CO_2$e]** |
|---|---|---|---|---|---|
| 2°C-consistent pathway* | 1,760 (range 1,200 – 2,230) | 1,240 (range 970 – 1,460) | 23.0 (range 15.8 – 30.7) | 790 | 11.5 |
| 1.5°C-consistent pathway* | 1,080 (range 730 – 1,390) | 990 (range 970 – 1,460) | 13.5 (range 6.0 – 16.4) | 580 | 3.5 |

* For 2°C-consistency, the associated probability of staying below the temperature limit is 66%, while for 1.5°C-consistency, the associated probability is only 50%. This is in accordance with the majority of the scientific literature.

## 1.2 Effort-sharing based on fairness approaches and cost-effectiveness approaches

The two kinds of approaches applied in this study, **the cost-effectiveness approach and the fairness-based approaches, yield complementary insights into how to distribute the mitigation burden associated with the PA long-term temperature goal.** The former provides knowledge about pathways to be taken by each country domestically. The latter provides knowledge about the range of a fair and equitable distribution of global mitigation efforts based on the criteria brought forward in the climate negotiations and the literature. The fairness-based approaches span a wide range of emissions levels for each country and not all combinations are consistent with the global budget. Via a methodology by the Climate Action Tracker (CAT 2018), combinations of emissions levels that are consistent with the global temperature target can be chosen. The gaps between the emissions levels of the countries under study from the cost-effectiveness approach and the fairness-based approach provide an indication of the different roles of the countries in international cooperation on climate mitigation including climate finance and emissions trading.

**For the majority of countries under study, the cost-effectiveness-based reductions of emissions are lower than it would have to be according to the globally consistent fairness-based distribution in 2030 and 2050** for both, 2°C-consistent and 1.5°C-consistent pathways. The main exceptions here are China and India, for which the consistent choice of the fairness—based GHG emissions allowances that are substantially higher than the emissions based on a cost-effectiveness approach both in 2030 and 2050. It is noteworthy that for the EU, the gap between its fair share and the cost-effective emissions reduction in 2030 for compatibility with the 1.5 °C temperature goal is three times as high as for compatibility with the pre-Paris 2 °C temperature goal. This means an increased need to tackle emissions reductions beyond a cost-effective pathway. For Germany, the increase of the gap is lower (1.7 times higher) with a central reason being its large share in the EU’s gap in 2030.

A look at the sum of the differences reveals that **the cost-effectiveness-based emissions reduction potential within the countries under study is sufficient to achieve 1.5°C- and 2°C-consistency in 2030 but only 2°C-consistency in 2050** (see Table 14), provided that countries not assessed in this report reduce emissions to – on average – similar degree. This does not mean that the global reduction potential is insufficient, but only that from a fairness perspective, the countries under study would be required to support the rest of the world in exploiting emissions reduction potentials in a certain way.

Table 2: The mitigation gap between fairness-based and cost-effectiveness-based effort-sharing distribution by country in absolute terms

| | Mitigation gap between upper fair share and cost-effective share [GtCO2e] | | | |
|---|---|---|---|---|
| | 2030 | | 2050 | |
| Country | 2°C-consistent | 1.5°C-consistent | 2°C-consistent | 1.5°C-consistent |
| **Brazil** | -0.22 | -0.47 | 0.03 | -0.41 |
| **Canada** | 0.10 | 0.04 | -0.07 | -0.26 |
| **China** | 2.78 | 2.33 | 4.05 | 2.99 |
| **Japan** | -0.28 | -0.69 | -1.02 | -1.84 |
| **India** | 4.25 | 2.71 | 4.01 | 2.60 |
| **United States** | 0.23 | -1.04 | -1.48 | -3.33 |
| **EU28** | -0.43 | -1.27 | -2.48 | -4.73 |
| - thereof Germany | -0.27 | -0.44 | -0.61 | -1.13 |
| **TOTAL** | **6.42** | **1.61** | **3.05** | **-4.98** |

Values are positive for countries, where the cost-effectiveness-based reduction requirement is more stringent than its fair share reduction requirement.

## 1.3 Cost-effective effort-sharing in relation to the NDC pledges

In order to relate the findings on appropriate domestic reductions to the current national pledges for 2030, the cost-effectiveness distribution of energy- and process-related emissions reductions can be compared to the development of emissions in a scenario based on the NDC pledges (“NDC scenario”). Table 3 provides the mitigation gaps in absolute terms and relative to the NDC scenario for 2030, as there is no common reference year for all the countries under study. **For 2030, the cost-effective distribution based on the 1.5°C-consistent pathway assumes emissions levels that are – depending on the country - between 42 to 72% lower than in the NDC scenario**. For the 2°C-consistent pathway, the deviation ranges from 24 to 58%. For all countries, the relative emissions reduction of the 1.5°C-consistent pathway compared to the NDC scenario are 12-18%-points higher than the reductions for the 2°C-cosistent pathway in 2030. The sum of gaps of the NDC scenario in the countries under study in 2030 amounts to 13.1 Gt $CO_2$e with regard to 2°C consistency and to 17.5 Gt $CO_2$e with regard to 1.5 °C consistency. This corresponds to 47% and 62% of the energy- and process-related emissions in the current policies scenario in 2030, respectively. **This**

**shows that there is a need to increase the ambition of their emissions reduction goals significantly with regard to 2030.** For the EU (Germany), the gap between the NDC scenario and the cost-effectiveness-based pathway is lower than the global average. Still, the mitigation gap amounts to 1.27 Gt $CO_2$e (0.24 Gt $CO_2$e) for 1.5°C-consistency, which corresponds to an additional GHG emission reduction by 22%-points (14%-points) compared to 1990.

Table 3: The gap between an NDC scenario and cost-effectiveness-based effort-sharing of energy- and process related GHG emission by country in absolute and relative terms

| | **NDC scenario 2030*** | **Gap with regard to 2°C consistency**** | | **Gap with regard to 1.5°C consistency**** | |
|---|---|---|---|---|---|
| **Country** | **[Gt $CO_2$e]** | **[Gt $CO_2$e]** | **[-]** | **[Gt $CO_2$e]** | **[-]** |
| **Brazil** | **0.68** | 0.21 | -31% | 0.29 | -43% |
| **Canada** | **0.46** | 0.16 | -34% | 0.24 | -51% |
| **China** | **13.63** | 7.04 | -52% | 9.02 | -66% |
| **Japan** | **1.01** | 0.41 | -40% | 0.57 | -56% |
| **India** | **4.44** | 2.57 | -58% | 3.19 | -72% |
| **United States** | **4.80** | 1.93 | -40% | 2.68 | -56% |
| **EU28** | **2.81** | 0.79 | -28% | 1.27 | -45% |
| - thereof Germany | 0.57 | 0.14 | -24% | 0.24 | -42% |
| **TOTAL** | **27.84** | **13.10** | **-47%** | **17.26** | **-62%** |

* The NDC scenario translates pledges for total GHG emissions to energy- and process-related emissions based on the NDC.

** Absolute values are positive for countries, where the cost-effectiveness-based reduction requirement is higher than the reduction based on current NDCs. Vice versa for relative values.

## 1.4 Conclusions

In conclusion, for both fairness-based and cost-effectiveness-based approaches to sharing the global GHG emissions budget, the more ambitious long-term temperature goal of the Paris Agreement compared to the former Cancun target results in substantially higher reduction requirements for all countries. Given that there has been a gap between NDCs and the Cancun target of holding global warming below 2 °C, **the Paris goals call for even more ambitious emissions reduction goals in their respective NDCs.** For the effort- and process-related GHG emissions the gaps with regard to cost-effective pathways have increased by 32% on average. **For the EU, the gap between its NDC and a 1.5°-consistent pathway is 61% larger than the gap between its NDC and a pre-Paris 2°-consistent pathway. This shows the clear need to reconsider the EU's long-term targets in light of the Paris Agreement.**

A look at 1.5°C-compatible emissions pathways shows that in the longer term up to 2050, the fairness-based emissions allowances in the major emitting countries considered cannot be met by only redistributing the reductions of a cost-effective pathway among each other. This suggests that **for compatibility with the more ambitious temperature goal of the Paris Agreement, it will also become even more important to engage into a truly global international cooperation on climate change mitigation**.

In spite of the need for international cooperation, it needs to be re-emphasized that the GHG emissions reductions attributed to the domestic targets in the current NDCs for all countries under study here do not meet the level of emissions reductions required for a global cost-effective pathway, even with regard to compatibility with the “old” Cancun 2°C goal. Therefore, **a substantial increase of ambition in all the countries under study is possible without deviating from a global cost-effective pathway**. Even if the high uncertainty about the development of mitigation costs is taken into account, the order of the existing gap justifies no hesitation about moving beyond the ambition of the current NDCs.

## 2 Introduction

In December 2015, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) agreed in the Paris Agreement (PA), which came into force in November 2016, to limit global warming to "well below 2°C above pre-industrial levels" and to make efforts to "limit the temperature rise to 1.5°C above pre-industrial levels". Achieving this temperature goal will depend on sufficient national action by all countries, which will have to be strengthened and accelerated on an ongoing basis, as laid down in the review mechanisms of the PA. The Parties should review and adapt their nationally determined contributions (NDC) by 2020 in the light of the Talanoa Call for Action (UNFCCC, 2018). A review process is set to take place every five years, with the first global stocktake in 2023 aiming at review and adjustment of national contributions. The current emissions reduction commitments of the states, including those of Germany and the EU, are not sufficient to achieve the objectives of the Paris climate treaty. According to calculations by the Climate Action Tracker (CAT), the commitments submitted by the parties in their INDC/NDC in 2015, and their subsequent changes (including the USA declaration to withdraw from the agreement) would lead to a global warming of 3.0°C above the pre-industrial level by the end of the century if they are fully implemented (CAT, 2018).

In the years prior to COP 15 in Copenhagen in 2009, the international community had an intensive discussion about suitable approaches for the regional allocation of greenhouse gas (GHG) reduction targets. Essential criteria that played a role in this discussion were the historical responsibility of the industrialised countries (measured in terms of cumulative GHG emissions caused), the mitigation capacity of the states (measured in terms of the level of development of the states, e. g. on HDI and GDP), the right to development (measured in per capita emissions of GHG), technical and economic potentials for mitigation, as well as associated cost efficiency/welfare losses (Duscha, Graichen, Healy, Schleich, & Schumacher, 2010; Höhne, den Elzen, & Escalante, 2014a). However, the international community reached neither a consensus nor a compromise how to distribute the mitigation efforts. The debate on a fair distribution of mitigation efforts has gained a new dimension in the context of the implementation of the Paris Agreement, which stresses that contributions from the states have to reflect “the highest possible ambition” and “respective capabilities”.

However, since Article 2 of the Paris Agreement contains global goal for limiting global warming and since the voluntary contributions of the states are extremely unlikely to be sufficient to achieve it, the question of which national contributions are to be regarded as fairly distributed remains topical. In addition, the debate has also made further progress in the scientific community (see Section 3.1). While the discussions in the run-up to Copenhagen referred to limiting global warming to 2°C, the Paris Agreement has shifted the focus to emissions pathways that limit global warming to well below 2°C, and undertaking efforts to not exceed 1.5°C (Rocha, Sferra, et al., 2016). In addition, the focus of the Paris Agreement is also increasingly on the long-term perspective (mid-century and beyond) and on the implications for the readjustment of mid-term targets.

## 2.1 Goals and structure of the study

This study aims at deriving sets of national emissions reduction targets for 2030 and 2050 that are consistent with the Paris Agreements’ long-term temperature goals.[4] The different sets are meant to cover the different perspectives on a fair

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4 The analysis was carried out before the publication of the IPCC’s Special Report on Global Warming of 1.5°C. It is based on the global 1.5°C- and 2°C-consistent pathways available before. Though a planned update may result in quantitative changes, the qualitative statements and the associated orders of magnitude can be expected to remain valid.

distribution of efforts that most important in the current political and scientific debate, in particular both fairness-based and cost-effectiveness based approaches[5]. The analysis focuses on selected countries that are particularly relevant because of their share in global GHG emissions and their role in international climate policy, namely Brazil, Canada, China, the EU, India, Japan and the United States of America. In addition, particular emphasis is given to the role of Germany.

In Section 2, the various interpretations of the long-term temperature goals are described and the relation to GHG emissions budgets and mitigation pathways is explained. This results in the selection of common global GHG budgets and emissions reduction targets for the fairness-based effort-sharing approaches and the least-cost approach. In Section 3, the different approaches to a fair effort sharing and the resulting ranges of fair national targets are presented. Based on the ranges, fair and consistent national targets are derived for both, the Cancun 2°C and Paris Agreement 1.5°C temperature limits. In Section 4, the methodology for a cost-effectiveness approach is described and applied to the global targets to come up with an effort-sharing that reflects the domestic potentials and costs. In Section 5, the results of the fairness-based approaches and the cost-effectiveness approach are compared and conclusions on the required extent of international cooperation are drawn.

# 3 Carbon budgets and emissions pathways resulting from the Paris Agreement temperature goal

Before unpacking what the Paris Agreement's long-term temperature and emissions goals mean for specific (group of) countries, we need to understand what the agreement means for emissions and energy transition globally. We also need to take a step back and look at the discussion pre-dating the adoption of the PA with a less ambitious temperature goal, to better understand the effort sharing discussion.

5 In this study, we use the following terminology: any approach to the distribution of global emissions reduction targets is called an effort-sharing approach, independent of whether it is based on ethical or economic considerations.

## 3.1 Interpretations of 2°C, "well-below 2°C" and of 1.5°C by the scientific community and policy-makers

In 2009, the goal of limiting warming to below 2°C was ingrained in the Copenhagen Accord (UNFCCC, 2009). This limit was subsequently adopted at the international level in the Cancun Agreements in 2010 where it was expressed as an aim "to hold the increase in global average temperature below 2°C above pre-industrial levels" (UNFCCC, 2011). Recognising concerns of vulnerable countries, in 2010 the UNFCCC established a review process to evaluate whether the long-term global temperature goal of holding warming below 2°C was adequate to avoid dangerous climate change and to consider "strengthening the long-term global goal on the basis of the best available scientific knowledge, including in relation to a global average temperature rise of 1.5°C". This process ended in 2015 with the final report of its scientific arm (Structured Expert Dialogue) concluding that a warming of 2°C cannot be considered safe (UNFCCC, 2015), which ultimately led to the adoption of the Paris Agreement's long-term temperature goal of "holding the increase in the global average temperature to **well below 2 °C** above pre-industrial levels and pursuing efforts **to limit the temperature increase to 1.5 °C** above pre-industrial levels, recognising that this would significantly reduce the risk and impacts of climate change".

The temperature goal is further specified by the long-term emissions goals outlined in Article 4.1. It points out that in order to achieve the long-term temperature goal of the agreement the following three requirements need to be fulfilled:

- GHG emissions need to peak as soon as possible, recognising that peaking will take longer for developing country Parties,
- the global peaking of emissions need to be followed by rapid emissions reductions, and
- a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases needs to be reached in the second half of this century.

The last point means that the global aggregate sum of direct human induced emissions and removals by sinks of greenhouse gases needs to be zero in the second half of the century, with the timing based on the "best available science". It is important to note that this does not mean that the global aggregate sum of sources and sinks needs to be zero at the same time in every region of the world, as some regions may be sinks and other regions sources of emissions.

The old Cancun Agreements' 2°C temperature limit, and the currently binding PA's temperature goal, have quite different implications for long-term emissions levels and for the implementation of the long-term emissions goals in Article 4.1. The Cancun Agreement's 2°C temperature limit has generally been assessed in the scientific community as holding global mean temperature rise to below 2°C during the 21st century with a likely (more than 66%) chance (see e.g. scenarios in IPCC's AR5 and UNEP's Emissions Gap report series and see Schleussner et al 2016). This implied that GHG emissions need to be reduced by 40-70% in 2050 below 2010 (35-55% below 1990) levels and reach globally aggregated zero emissions by 2080-2100 (IPCC, 2014c). Globally, energy- and industry-related $CO_2$ emissions would need to be reduced by 2050 by 35-80% below 2010 (10-70% below 1990) levels, reaching zero around 2060-2075 (IPCC, 2014a).

Based on the up-to-date scientific literature and available energy-economic scenarios, the PA's long-term temperature goal can be represented by pathways that hold warming to below 2°C with at least 80% probability and below 1.5°C by 2100 with a more than 50% chance (Schleussner et al 2016). Achieving this goal requires that global emissions are reduced by 70-95% below 2010 (65-90% below 1990) levels by 2050, and reach globally aggregated zero emissions by 2060-2080. Emissions from global energy and industry will need to be reduced by 2050 by at least 95% in comparison to 2010 (Rogelj, Schaeffer & Hare, 2015).

The respective temperature limits have often been associated with a specific carbon budget. Just before the 2°C limit was engrained in the Copenhagen Accord, a paper by Meinshausen, et al. estimated that in order not to exceed that temperature goal, the combined emissions in the period 2000-2050 should not exceed 1,437 $GtCO_2$ (Meinshausen et al., 2009).

Table 4: Characterization of emissions reductions scenarios in the scientific literature that at the time informed the temperature limits adopted in Cancun (2010) and Paris (2015).

| | **Cancun Agreements** | **Paris Agreement** |
|---|---|---|
| Probability of staying below 2°C | >66% | >80%* |
| Probability of staying below 1.5°C | (>25%)** | >50%* |
| Global GHG emissions reduction in 2050 in comparison to 1990 | By 35-55% | By 65-90% |
| Global GHG emissions reduction in 2050 in comparison to 2010 | By 40-70% | By 70-95% |
| Global energy and industry emissions reduction in 2050 in comparison to 1990 | By 10-70% | By 95-125% |
| Global energy and industry emissions reduction in 2050 in comparison to 2010 | By 35-80% | By 95-120% |
| Global energy and industry emissions reach zero | Around 2060-2075 | Around 2045-2055 |

* Emissions scenarios that fully achieve the long-term temperature goal of the Paris Agreement need to provide a perspective on both its warming limits ("well below" 2°C and 1.5°C). Scenarios that achieve a 50% probability to drop warming below 1.5°C by 2100 in general simultaneously achieve a probability of 80% to hold warming below 2°C during the 21st century – see Schleussner et al (2016).

** The brackets symbolize the fact that the 1.5°C warming limit was not part of the global temperature goal formulated in the Cancun Agreements. The emissions scenarios informing the "below 2°C" temperature limit adopted in Cancun hold warming below 2°C with more than 66% probability, which is typically associated with a simultaneous probability to limit warming to 1.5°C by 2100 with a probability of 25% or more – see Schleussner et al (2016).

As there is a close to linear relationship between the carbon emissions and the magnitude of warming, associating the respective temperature limits with a carbon budget is possible up to approximately 2000 $GtCO_2$ (MacDougall & Friedlingstein, 2014). However, the distribution of the emissions over time does also play an important role. A significant temperature overshoot, even if followed by a massive application of negative emissions, could trigger some positive feedbacks that may accelerate the warming (MacDougall, Zickfeld, Knutti, & Matthews, 2015). Hence, a distribution of efforts should take into account not only the emissions budget but also its realisation over time in the form of an emissions pathway.

The currently available global scenarios that would keep warming at below 1.5°C in 2100 with 66% probability or more result in peak warming between 1.5°C and 1.8°C in the course of the century. The higher the peak warming level, the more these scenarios require implementation of negative emissions on a large scale in the second half of the century (Rogelj et al., 2018). While so called "negative emissions technologies" (NETs) that reduce the $CO_2$ concentration in the atmosphere are needed due to insufficient action thus far, they cannot be allowed to slow down mitigation effort: rapid and deep GHG emissions reduction is needed to not exceed the Paris Agreement temperature limit. In addition to the lower efficiency of taking out carbon from the atmosphere in comparison to emissions reduction described above, insecurity about the possible scale up of the negative emissions technology (Muri, 2018) as well as the numerous co-benefits of ambitions emissions reductions (UNDP, 2016) also support the call for more ambitious emissions reductions in spite of NETs. Nevertheless, there are tradeoffs between climate mitigation and other Sustainable Development Goals (SDGs). E.g. increasing the access to energy can lead to higher emissions if achieved through increased utilization of the fossil fuels. At the same time, climate mitigation, which itself constitutes one of the SDGs, can facilitate the achievement of other SDG, e.g. SDG 3 “Good Health and Well Being for People” can be supported by decreasing pollution resulting from the combustion of fossil fuels.

While reaching the PA’s temperature goal without relying on negative emissions will be challenging, there are some scenarios, which investigate such developments. What they have in common is a significant decrease in energy consumption resulting from a substantial improvements in energy efficiency, major acceleration in the development of renewable sources of energy, and electrification of the other sectors of energy (Kriegler et al., 2018; Vuuren et al., 2018).

## 3.2 Global emissions budgets and pathways used in this report

Here and in the following, we refer to global emissions pathways that are consistent with the 2 °C temperature goal of the Cancun Agreements as 2°C-consistent pathways or pre-Paris 2 °C pathways. Pathways that are consistent with the PA’s temperature goal of “well-below 2 °C” and 1.5 °C will be called 1.5°C-consistent pathways or PA-compatible pathways.[6]

To identify the emissions reduction goals for 2030 and 2050 compatible with the respective temperature limits we used the approach developed in the framework of the Climate Action Tracker (CAT, 2018b). It develops a global emissions pathway based on the energy-economic models GCAM, IMAGE, MESSAGE, REMIND, and WITCH. This global pathway is then used as input to a carbon-cycle / climate model (MAGICC), which is run multiple times in order to obtain a

6 The analysis was carried out before the publication of the IPCC’s Special Report on Global Warming of 1.5°C. A planned update may result in quantitative changes to the pathways, but the associated orders of magnitude can be expected to remain valid.

probability distribution of outcomes such as global mean temperature, $CO_2$ concentration, and total greenhouse gas concentration, reflecting fundamental uncertainties in climate physics and the carbon cycle. The detailed methodology of the climate model is outlined in (M. Meinshausen, Raper, & Wigley, 2011; Malte Meinshausen et al., 2009). Methodology for the version used is based on Schaeffer et al (2015). According to the CAT pathways, the global GHG emissions budget for a meeting *2°C* goal with 66% probability in the period 2016 – 2100 is 1,760 $GtCO_2e$ (full range 1,200 – 2,230 $GtCO_2e$) and 1,240 $GtCO_2e$ (full range 970 – 1 460 $GtCO_2e$) in the period 2016 – 2050. In this case, the annual GHG emissions in 2050 amount to 23.0 $GtCO_2e$ (full range 15.8 – 30.7 $GtCO_2e$). The global GHG emission budget in the period 2016 – 2100 for not exceeding *1.5°C* temperature limit with 50% probability is 1,080 $GtCO_2e$ (full range 730 – 1,390 $GtCO_2e$) and 990 $GtCO_2e$ (full range 840 – 1,160 $GtCO_2e$) in the period 2016 – 2050. The annual GHG emissions in 2050 amount to 13.5 $GtCO_2e$/a (full range 6.0 – 16.4 $GtCO_2e$) for a 1.5°C-consistent pathway (see Table 5).

The methodology used for the quantification of the cost-effectiveness emissions pathways for the selected countries in Section 4 requires 2°C- and 1.5°C-consistent emissions budgets and pathways for the energy- and process-related GHG emissions only. Since the IMAGE and MESSAGE models generate pathways that include all sectors, the pathways reflecting only energy- and process-related emissions are generated by subtracting agriculture and forestry emissions from the pathways generated by the IMAGE and MESSAGE models (own calculations based on Rogelj et al. 2015 and van Vuuren et al. 2018). Due to this approach, we cannot provide meaningful ranges for the energy- and process-related emissions but only the median. To compensate for this, we compare the results of the cost-effectiveness approach to the full ranges coming from the equity-based approaches in Section 5. The resulting global budget in the period 2016 – 2050 is 790 $GtCO_2e$ and annual GHG emissions of 11.5 $GtCO_2e$ in 2050 for the 2°C-consistent pathway as well as 580 $GtCO_2e$ in the period 2016 – 2050 and annual GHG emissions of 3.5 $GtCO_2e$ in 2050 for the 1.5°C-consistent pathway.

Table 5: Global emissions budgets and pathways used in this report in Gt $CO_2e$

| | Cumulative GHG emissions in 2016 – 2100 [Gt CO2e] | Total GHG emissions in 2016 – 2050 [Gt CO2e] | Total GHG emissions in 2050 [Gt CO2e] | Cumulative energy- and process-related GHG emissions 2016 – 2050 [Gt CO2e] | Energy- and process-related GHG emissions in 2050 [Gt CO2e] |
|---|---|---|---|---|---|
| 2°C-consistent pathway | 1,760 (range 1,200 – 2,230) | 1,240 (range 970 – 1,460)e | 23.0 (range 15.8 – 30.7) | 790 | 11.5 |
| 1.5°C-consistent pathway | 1,080 (range 730 - 1,390) | 990 (range 970 – 1,460)e | 13.5 (range 6.0 – 16.4) | 580 | 3.5 |

# 4 Effort sharing based on equity approaches

As mentioned above, there has already been a great deal of effort by the scientific community to develop approaches to split global mitigation efforts to the country/regional level. These approaches can be divided into two groups. The first group is looking into ***equity indicators***, such as a country's historical responsibility for global climate changes, or capability to contribute to global emissions reduction efforts. Many equity proposals, based on different criteria and metrics, have been put forward by the scientific community and by the governments.

The second group of approaches is using ***energy-economy models*** to assess emissions reductions using the mitigation costs as the main determinant. These models combine the current knowledge of energy systems and climate-model projections to identify economically and technologically feasible emissions pathways consistent with a temperature limit, while minimising global costs. These are the so-called optimal **"**cost-effective**" pathways.**

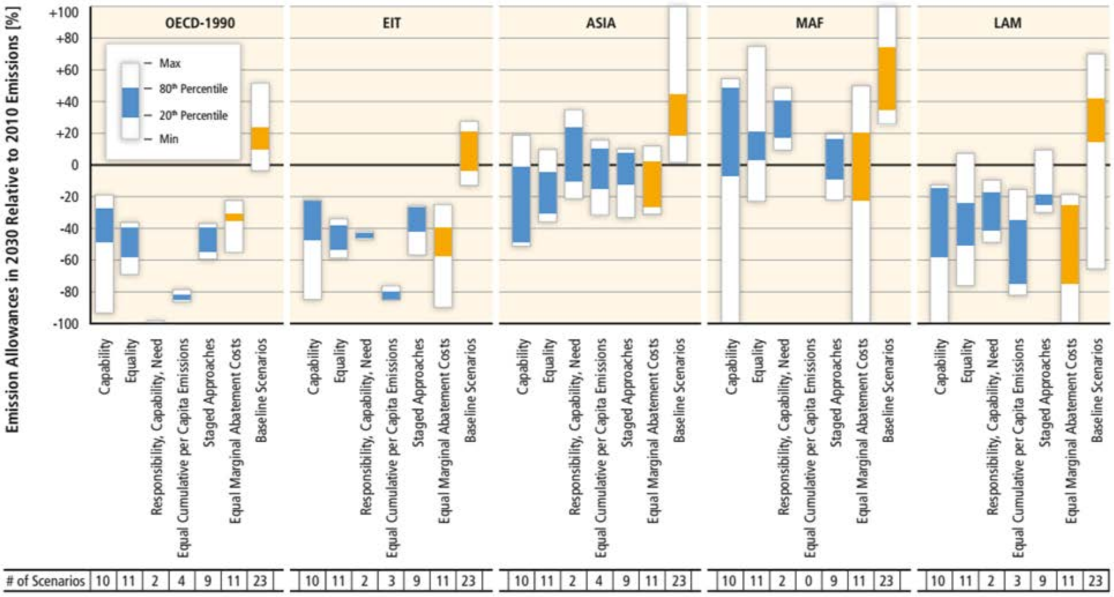
An important point here is the following distinction. Effort-sharing approaches result in levels or emissions reductions that do not have to correspond to domestic emissions and maybe even cannot due to physical limitations, but can be linked via certain mechanisms for compensation; we thus refer to these as emissions allowances, rather than as emissions. Least-cost pathways, on the other hand, provide information on the splitting of domestic reduction potentials among countries, which has no immediate implication with regard to emissions allowances. While this section focuses on the first group of approaches, also referred to as “equity approaches”, the following section 4 describes the repercussions of applying the “cost-effective” approaches to effort distribution.

## 4.1 Introduction of the main approaches and summary of the recent literature

Since the 1990s, policy makers and researchers have suggested numerous approaches, how the effort of mitigation of climate change could be distributed among countries in an equitable manner. The International Panel on Climate Change (IPCC) picked up and synthesized those suggestions in its reports. The Fourth Assessment Report (AR4) quantified emissions reduction for Annex I countries (USA, EU, Belarus, Ukraine, Kazakhstan, Norway, Switzerland and Iceland) and non-Annex I countries to not exceed the $CO_2$ concentration levels of 450 ppm understood as equivalent to the 2°C limit. According to this quantification Annex I countries should reduce emissions in 2020 by between 25% and 40% in comparison to 1990 levels. By 2050 emissions should be reduced by between 80% and 95%. For the non-Annex I countries the AR4 stressed that “substantial deviation from baseline in Latin America, Middle East, East Asia and Centrally-Planned Asia” should take place for 2020, and “substantial deviation from baseline in all regions” for 2050 (IPCC, 2007).

The Fifth Assessment Report (IPCC, 2014b) synthesized results from more than 40 studies across five regions, split up by effort sharing category (compare Figure 2), based on (Höhne, den Elzen, & Escalante, 2014b). Annex 1: Studies included in the analysis of the Climate Action Tracker contains a complete list of publications included in the research underlying the IPCC analysis.

Figure 1: Emissions allocation in 2030 relative to 2010 emissions by effort sharing category for 2°C compatible mitigation scenarios (reaching 430 – 480 ppm $CO_2$eq. in 2100).




Source: IPCC AR5 WGIII, Figure 6.28, Chapter 6, adapted from (Höhne et al., 2014b). Notes: EIT: Economies in Transition, MAF: Middle East and Africa, LAM: Latin America. For the OECD90 list, please refer to the IPCC definition. The different effort sharing categories are described in detail in (Höhne et al., 2014b)

In most cases, the overall results give an indication of the direction of where emissions in 2030 should be headed on average for the region. Scenarios reaching concentration levels between 430 ppm and 480 ppm $CO_2$e in 2100 require reductions of roughly 50% below 2010 for OECD countries with a large range and a third below 2010 for Economies in Transition (EIT). Asian countries should be at 2010 levels in 2030, and Latin America well below 2010 levels (Clarke, Jiang, Akimoto, Babiker, Blanford, Fisher-Vanden, et al., 2014; Höhne et al., 2014b). According to those results, only the region "Middle East and Africa" has increasing emissions allowances compared to 2010, given their very low responsibility (understood as low historic emissions) and capability of reducing emissions due to the low economic development. However, the choice of effort sharing category makes a large difference for some regions. This is critical to consider for the choice of approaches for this analysis (compare Section3.2 ).

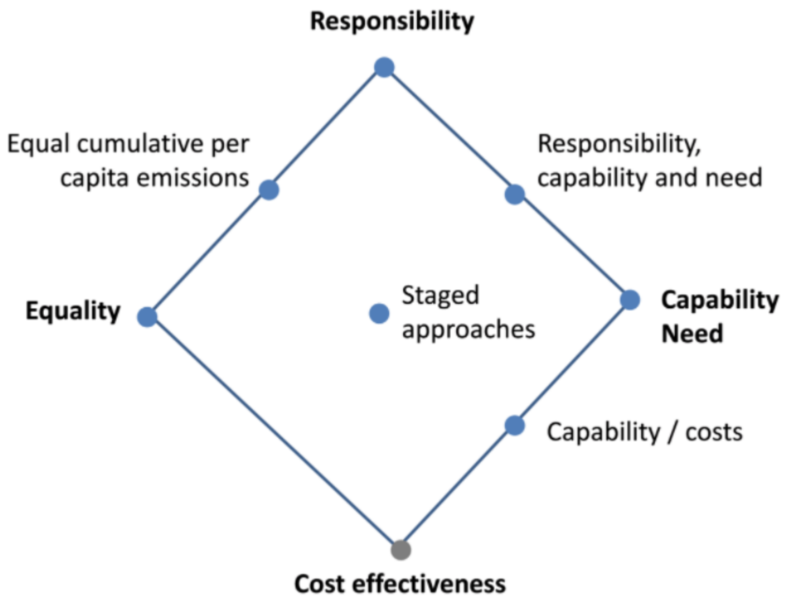
Since the publication of AR5 which synthesised all literature available up to that point (Clarke, Jiang, Akimoto, Babiker, Blanford, Fisher-Vanden, et al., 2014), various studies have emerged, mostly to reflect a move to 1.5°C scenarios. Relevant studies not included in AR5 are Pan, Teng, & Wang (2013), Pan, Teng, & Wang (2014), Robiou du Pont et al. (2016) and Holz, Kartha, & Athanasiou

(2017). The Climate Action Tracker finds that, on aggregate, moving from 2°C scenarios to 1.5°C scenarios leads to a modest decrease of allowances for most countries in the short- and midterm, but to substantial differences in 2050 (Parra et al., 2017, CAT, 2018a).

### 4.1.1 Overview of existing effort sharing approaches

Höhne et al. introduce the grouping of effort sharing along various categories (Höhne et al., 2014b). This categorization goes beyond pure equity considerations as it also includes cost effectiveness, which – as explained at the beginning of this section - is not an equity principle, but a way to share mitigation according to a global cost-based approach.

Figure 2: Categorisation of effort sharing approaches according to Höhne et al




Source: Höhne et al., 2014

Höhne et al. describe the categories as follows:

- Responsibility: This concerns the historical contribution to global emissions or warming. It is included in many approaches as one element, and its origin is often taken to be Article 3 of the UNFCCC which states that countries should take action on the basis of ‘common but differentiated responsibilities and respective capabilities’ (CBDR-RC).
- Capability: This is sometimes also called ‘capacity’ or ‘ability to pay for mitigation’. Its origin is also often taken to be the reference in Article 3 of the UNFCCC to CBDR-RC. The ‘basic needs’ principle, also known as the ‘right

to development', was also considered in this category because it could be considered a special expression of the capability principle – the least capable countries could have a less ambitious reduction effort to secure their basic needs.

- Equality: Many approaches are based on equal rights per person, which translates into equal emissions allowances per person, immediately or over time.
- Cost effectiveness: Some approaches allocate emissions reduction targets (in part) based on mitigation potential or costs–effectiveness. For example, emissions could be reduced in each country to the extent that the marginal costs of further reductions are the same everywhere (applying an equal carbon tax in an economic model). The triptych approach (den Elzen, Höhne, & Moltmann, 2008; Phylipsen, Bode, Blok, Merkus, & Metz, 1998) contains elements of cost–effectiveness in that those with high specific emissions (i.e. high potential for emissions reductions) have to reduce more. It was used as a basis to share the emissions reduction of the first commitment period for the Kyoto Protocol within the EU.

Some approaches combine those main categories. Table 2 in the paper lists the publications by category or mix of categories. Table 6 lists approaches typically assigned to the categories.

Table 6: Overview of effort sharing approaches by categories and main publications.

| **Category** | **Examples for approaches covered** | **Selected publications (no complete list)** |
|---|---|---|
| Responsibility | Brazilian proposal in run-up to Kyoto | |
| Capability | Ability to pay approach | (Berk & den Elzen, 2001; den Elzen, Lucas, & van Vuuren, 2005; den Elzen, Schaeffer, & Lucas, 2005),… |
| Equality | Converging per capita emissions, Emissions intensity convergence | (Agarwal & Narain, 1998; Chakravarty et al., 2009), |
| Responsibility, capability, need | Greenhouse Development Rights (GDR), Responsibility, capability and sustainable development | (Baer, Athanasiou, Kartha, & Kemp-Benedict, 2008; Höhne & Moltmann, 2008; Winkler, Jayaraman, et al., 2011),… |
| Equal cumulative per capita emissions | Equal cumulative per capita rights | (Bode, 2004; Pan, Teng, & Wang, 2013b),… |

| Category | Examples for approaches covered | Selected publications (no complete list) |
|---|---|---|
| Staged approaches | Tryptich appraoch, Common but Differentiated Convergence, Multistage, South North Proposal | (Berk & den Elzen, 2001; Böhringer & Welsch, 2006; Criqui et al., 2003; den Elzen, Höhne, van Vliet, & Ellermann, 2008; den Elzen, Meinshausen, & van Vuuren, 2006; Groenenberg, Phylipsen, & Blok, 2001; Hof & Den Elzen, 2010; Knopf, Kowarsch, Lüken, Edenhofer, & Luderer, 2012; Phylipsen et al., 1998),… |

Source: Authors, adapted from (CAT, 2017; Höhne et al., 2014). For a full overview of all literature, please refer to Höhne et al. 2014b.

While the literature described above provides a general direction of where countries should be headed in terms of their emissions reduction, the results still lead to large ranges of emissions allowances for many countries. This is particularly the case for those countries with extreme indicator values (e.g. particularly high or low per capita income). The choice of the effort sharing approach is one variable, however even within one approach, the assumptions on how exactly the approach is implemented, as well as the underlying data sources can play a major role in determining the resulting emissions allowances.

When speaking about effort sharing in the context of international negotiations, it becomes clear that many interpretations exist, and that most countries favour those approaches, that are most convenient for themselves. They usually do not consider (at least not in official communications) what the choice of their approach would mean for others (Winkler et al., 2017). To discuss what is the most equitable, it is thus not possible to rely on one approach only, but to look at the full range of what countries might consider equitable for themselves.

## 4.2 Translating equity criteria into emissions allowances

Given that there are no agreed guidelines on what would constitute a fair level of contribution to the global effort, beyond the general understanding of it to reflect the “highest possible ambition” and “common but differentiated responsibilities and respective capabilities, in the light of different national circumstances” (Paris Agreement, Article 4.3), for this study we will include a wide range of literature estimates for what is an equitable contribution for each of the countries analysed.

For this purpose we will use the methodology developed by the Climate Action Tracker (CAT) to assess effort sharing, which consists of a compilation of a wide range of literature on what different researchers from many perspectives would consider a “fair” contribution to greenhouse gas reductions.

The effort-sharing studies in the CAT’s database include over 40 studies used by the IPCC (chapter 6 of WG III and Höhne et al. (2013)) plus additional analyses the CAT has performed to complete the dataset (see Annex 1 for full list). They cover very different viewpoints of what could be fair, including considerations of equity such as historical responsibility, capability, and equality. The CAT takes into account results from studies that are compatible with the former 2°C goal, as well as the 1.5°C limit in the Paris Agreement, to cover the full range of perspectives and historical developments of the long-term temperature goals.

The different studies have different underlying assumptions and often use different data sources for historical emissions. These differences can be substantial, especially for countries where the share of non-$CO_2$ emissions is high. To account for these differences, we apply the same methodology of the CAT:

- First, we scale the whole time series of each study and scenario upwards or downwards by one factor, so that the emissions in the study’s base year have the same emissions value as the standard CAT dataset. For countries not covered by the CAT, historical data from the PRIMAP database serves as a common base level.
- Where this option leads to drastic absolute differences between the original and the harmonised value of over 100%, we scale the whole time series by an absolute amount of emissions, rather than by a multiplicative factor. This happens mostly for developing countries with large data uncertainty in the historical data. For the large majority of studies for the countries included in this analysis the differences are not very large and we do not use this method. Brazil is the main exception with 4 out of 27 studies for 2°C and 7 out of 17 studies for 1.5°C limit being harmonised by an absolute factor.

While each of the allocations (emissions levels) within the fair share range guarantees that the target emissions scenario is met if all countries were to follow the same approach, in reality there is no guarantee that all the countries will choose the same equity approach. Quite the opposite, the most likely scenario is that each country will tend to choose the categories and metrics that favour them the most. Given the large variability of equity proposals, criteria and metrics, each country has a wide equity range, and if all countries would reach emissions levels in line with the top of their equity ranges, the resulting global emissions would be far higher than the emissions levels in line with the target global emissions scenario. It is therefore crucial to determine the maximum level of emissions within countries' equity ranges, which when aggregated, wouldn't exceed the temperature limit.

Following again the methodology of the CAT[7], this level is determined as follows:

- Calculate emissions levels consistent with:
    - a global equity best-case scenario: where all countries choose to reduce emissions to the very bottom of their range, which is numerically equivalent to the total of the minima of all countries' equity ranges, and necessarily below the target scenario,
    - a global equity worst-case scenario: where all countries choose to reduce emissions only to the top of their equity range, which is numerically equivalent to the total of the maxima of all countries' equity ranges, and necessarily below the target scenario,
    - given that equity-based allocations are rarely available after 2050, the CAT applies its standard pathway extension methodology for determining emissions levels in the second half of the century that are consistent with the effort level in each underlying pathway. The global equity best-case scenario and the global equity worst-case scenario points result in a global equity range
    - In a next step, using a climate model, a large number of simulations is run, looking at the resulting temperature outcome if all countries were to reduce emissions at a level consistent with each of the percentiles within their equity range.
    - Once the temperature outcome is consistent with the global warming targets, that relative level is applied to all countries' equity ranges proportionally to determine the minimum level of effort within the full equity range that would be consistent with each global temperature target, without relying on other countries to do proportionally more effort.

The result of the methodology described above is the division of the fair share range for each country into three categories:

- **Consistent with the 1.5°C** temperature limit as defined in Section 2, namely keeping the average warming at the end of the century at or below 1.5°C with 50% probability, and corresponding to remaining below 2°C with around 80% probability.

7 For further details on the CAT methodology see webpage: https://climateactiontracker.org/methodology/comparability-of-effort/).

- **Consistent with the 2°C** limit as defined in Section 2, namely keeping the average warming at the end of the century at or below 2°C with at least 66% probability
- **Exceeding 2°C** warming with more than 34% probability and thus insufficient effort distribution according to even the Cancun Agreements, let alone the PA temperature limit

Each section corresponds to the temperature outcomes that would result if all other governments were to put forward emissions reduction commitments with the same relative ambition level.

## 4.3 Ranges from the equity approaches and results of the equity approaches

This section shows the results from the fairness-based effort-sharing approaches for 2030 and 2050. The calculations are based on the global GHG emissions pathways specified in Section 2.2. For reasons outlined in Annex 3 emissions from land use, land-use change and forestry (LULUCF) are not included in the analysis.

Given the large variability of equity proposals, criteria and metrics, each country has a wide equity range, as shown in Figure 3 and Figure 4. For simplicity, we only use the lower and upper end of the part of the range that is consistent globally with either 1.5°C or 2°C as a benchmark in the main tables in this report. The emissions allowances compatible with the 1.5°C and 2°C temperature limits for year 2030 (Table 7) and year 2050 (Table 8) are compared to the historical values from 2005 and 2015.

Figure 3: Effort sharing range of total GHG emissions in 2030

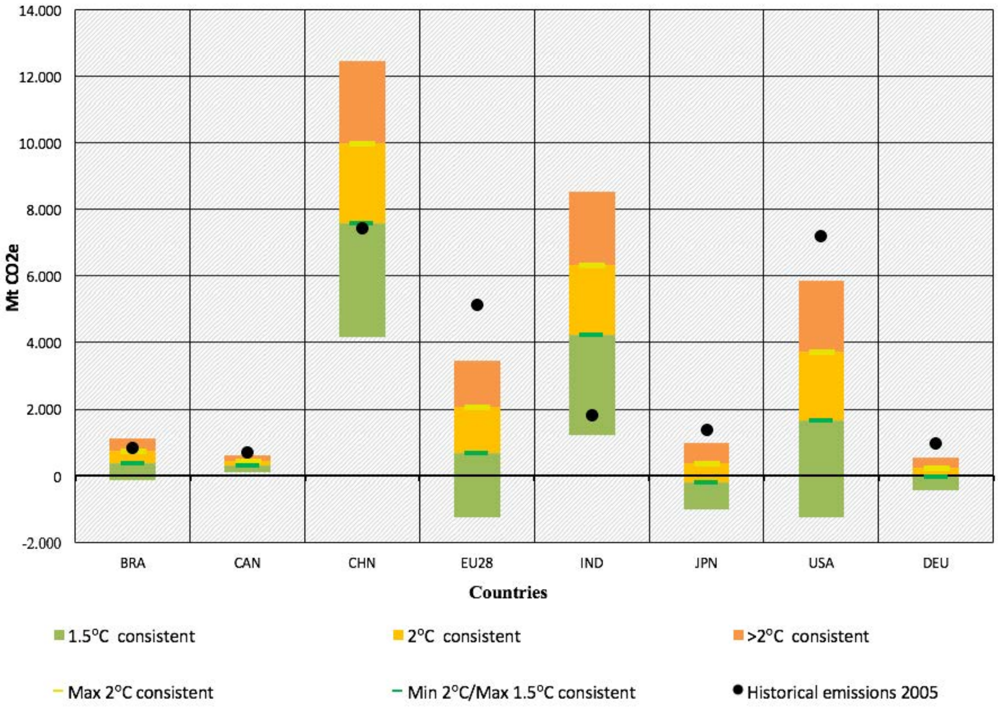



Table 7: Absolute and relative comparison of GHG emissions excluding LULUCF in 2030 against equity-based allowances for selected countries, EU28 and world

| | CAT AGGREGATION OF FAIRNESS-BASED APPROACHES | | | | | |
|---|---|---|---|---|---|---|
| **Country** | **Histori-cal 2005 [GtCO2e]** | **Histori-cal 2015 [GtCO2e]** | **Maximum emissions in 2030 to remain compat-ible with the respective temperature limit [GtCO2e]** | | **Minimum emissions reduction compared to 2015 required to not exceed the re-spective limit** | |
| | | | **1.5°C** | **2°C** | **1.5°C** | **2°C** |
| **Brazil** | 0.83 | 1.04 | 0.38 | 0.75 | -63% | -28% |
| **Canada** | 0.72 | 0.71 | 0.32 | 0.46 | -55% | -35% |
| **China** | 7.42 | 11.54 | 7.57 | 9.98 | -34% | -14% |
| **Japan** | 1.38 | 1.29 | -0.19 | 0.39 | -115% | -70% |
| **India** | 1.83 | 2.63 | 4.22 | 6.34 | 61% | 141% |
| **Germany** | 0.98 | 0.90 | -0.03 | 0.26 | -104% | -71% |
| **United States** | 7.20 | 6.46 | 1.67 | 3.73 | -74% | -42% |
| **EU28** | 5.13 | 4.24 | 0.70 | 2.06 | -84% | -51% |
| **World** | 43.32 | 48.78 | 30.89 | 37.74 | -37% | -23% |

* For the world, emissions allowances are not derived from equity approaches, they are consistent with the benchmark pathways from the CAT pathways for 1.5°C and 2°C

The comparison between equity-based emissions allowances and historical emissions levels shows broadly two categories of countries. On the one hand, countries like China and India, which based solely on fairness considerations, could increase their emissions levels by 2030. On the other hand, all the other countries covered in this study would need to reduce substantially their emissions in 2030, compared with historical emissions levels. Indeed, fairness-based ranges show that if the most stringent fairness-based considerations were taken into account (lower end of the effort sharing range) the European Union, the United States, Germany, Japan would even need to reach negative emissions levels in 2030.

For 2050 (see Table 8), fairness-based emissions allowances compatible with the 1.5°C and 2°C temperature limits have still wide ranges across the countries, even wider than in 2030 in absolute terms. However, (as expected) all the emissions levels for all countries are smaller in 2050 than in 2030. When compared to 2015 levels, for the 2°C-compatible emissions levels, the deviation ranges from -155% (Japan) to +101% (India), while for 1.5°C compatible allowances, the deviation ranges from -233% (Japan) to +25% (India). Based solely on equity considerations, by mid-century all the countries covered in this study (except for India and China) would need to reach negative emissions levels under the Paris Agreement fairness-based considerations (green in Figure 4).

Figure 4: Effort sharing range of total GHG emissions in 2050

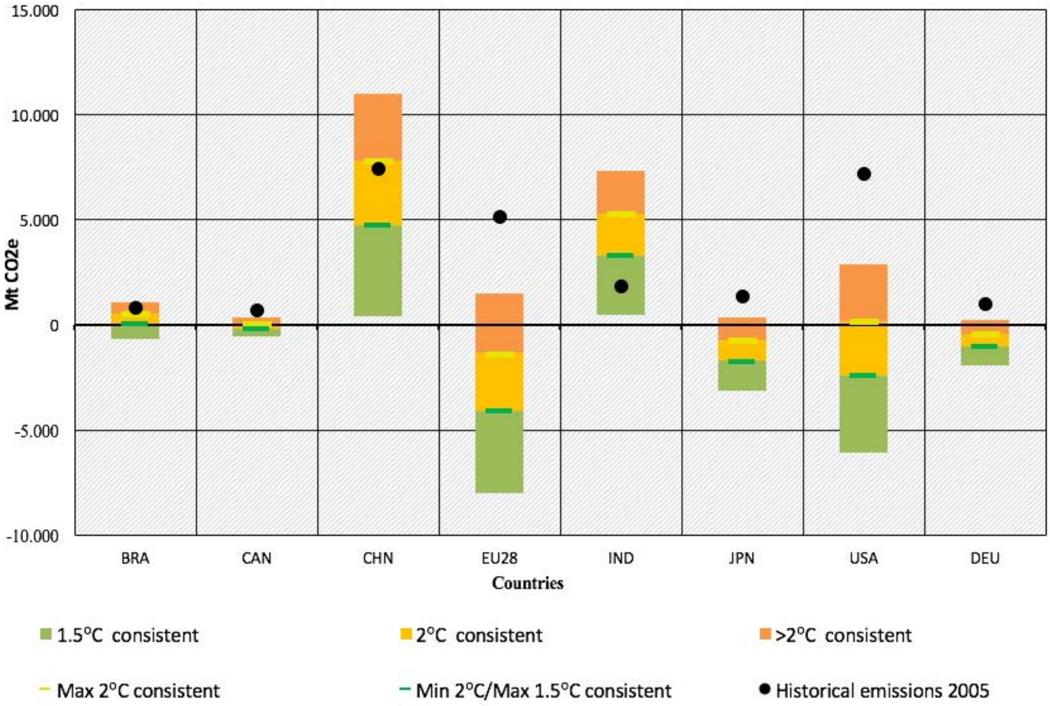



Table 8: Absolute and relative comparison of GHG emissions excluding LULUCF in 2050 against equity-based allowances for selected countries, EU28 and world

| | CAT AGGREGATION OF FAIRNESS-BASED APPROACHES | | | | | |
|---|---|---|---|---|---|---|
| **Country** | **Histori-cal 2005 [GtCO2e]** | **Histori-cal 2015 [GtCO2e]** | **Maximum emissions in 2050 to remain compati-ble with the respective temperature limit [GtCO2e]** | | **Minimum emissions reduction compared to 2015 required to not exceed the re-spective limit** | |
| | | | **1.5°C** | **2°C** | **1.5°C** | **2°C** |
| **Brazil** | 0.83 | 1.04 | 0.06 | 0.57 | -94% | -45% |
| **Canada** | 0.72 | 0.71 | -0.17 | 0.08 | -124% | -88% |
| **China** | 7.42 | 11.54 | 4.74 | 7.80 | -59% | -32% |
| **Japan** | 1.38 | 1.29 | -1.17 | -0.70 | -233% | -155% |
| **India** | 1.83 | 2.63 | 3.28 | 5.28 | 25% | 101% |
| **Germany** | 0.98 | 0.90 | -1.03 | -0.42 | -215% | -146% |
| **United States** | 7.20 | 6.46 | -2.41 | 0.20 | -137% | -97% |
| **EU28** | 5.13 | 4.24 | -4.09 | -1.35 | -197% | -132% |
| **World** | 43.32 | 48.78 | 13.49 | 23.00 | -72% | -53% |

* For the world, emissions allowances are not derived from equity approaches, they are consistent with the benchmark pathways from the CAT pathways for 1.5°C and 2°C

A more detailed analysis of the fairness-based allowances for the countries selected shows that while the ranges are wide and differ substantially across countries, there are some general patterns that can be observed:

- Overall, the lower end of emissions allowances (more stringent end of the fair share range) under the 1.5°C-compatible scenarios tends to be lower, sometimes significantly lower, than the lower end of 2°C compatible scenarios for most countries as would be expected. For 2030, the lower end of the fair share range is on average 96% lower for 1.5°C compatible scenarios, and for 2050 they are on average 55% lower.
- Some of the difference in the width of the fairness-based ranges can be explained by the number of data points (studies & scenarios) available for each country (see Annex 2). In general, much more data points (65 on average) are available for 2°C compatible scenarios than for 1.5°C compatible ones. In particular, the capability-cost category is the only one for which there are not studies in the literature for the 1.5°C. Coverage is also limited fir the equal cumulative per capita emissions category. This means that the results for 2°C compatible scenarios are more robust and more literature on the equitable allowances under the Paris Agreement would allow a better understanding of the implications of the different criteria for specific countries.
- The studies in the literature have different geographic scopes, with the EU and Germany being the regions with the least coverage. The ranges for those regions therefore have much less observations (20 less on average) than the other countries covered in this study. This means that the results for these countries are less robust than for the other countries as they are more effected by outliers (extreme categories). Therefore, careful interpretation of the ranges presented in this study for those two regions is advised.

# 5 Cost-effectiveness approach to distribute the global carbon budget

As discussed at the beginning of Section 3, fairness-based effort-sharing approaches are used to distribute emissions allowances according to ethical criteria such as responsibility and equity. Contrary to that, the distribution of physical emissions (not allowances) is based on cost-based approaches. In these approaches, the techno-economic potentials of countries and regions as well as the corresponding costs are used to distribute the mitigation burden for a certain temperature limit in a cost-effective way. As fairness-based approaches and cost-effectiveness approaches represent different perspectives and apply different criteria, their results usually deviate substantially. This deviation can be interpreted as an indication for the amount of international cooperation in mitigation required to realize a cost-effective pathway (Röser et al 2015). While this section focuses on the application of a cost-effectiveness approach to the budgets and pathways from Section 2.2, the subsequent Section 5 will deal with the comparison of the results from the different approaches.

In the literature, there are different cost-based approaches to construct mitigation pathways that are cost-optimal in a certain sense. Optimal welfare approaches distribute mitigation efforts among countries based on the optimization of the global gross domestic product. This requires a macroeconomic analysis of the global economy, which is a rather complex endeavor and therefore bound to high uncertainties. There are similar approaches based on the optimization of additional energy system costs or total energy expenditures that cover only the energy system instead of the full economy.

A more direct cost-based approach to distribute the global mitigation requirement to the countries or regions is the cost-effectiveness approach**.** In this approach, the mitigation effort is divided among countries based on marginal abatement cost curves (MACCs) that measure the total additional cost of reducing emissions.

In this section, we pursue the cost-effectiveness approach based on MACCs, as it can be realized without setting up of additional complex models and also enables to distribute the mitigation costs not only to countries but also to sectors in a simple way. On the other hand, MACCs do not reflect interrelations and feedbacks between sectors (see Section 4.3 for details on the resulting limitations).

## 5.1 Details of data and methodology

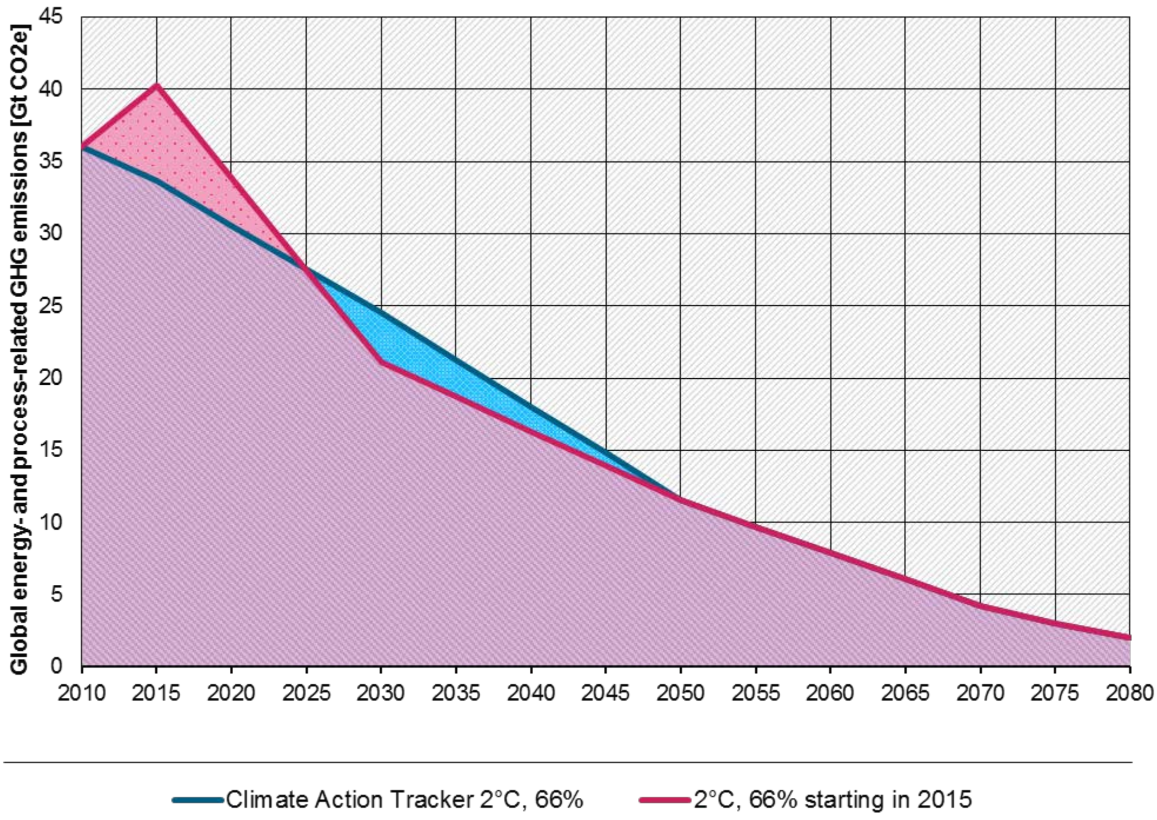
In our assessment of the cost-effectiveness approach, we distribute total emissions based on global economic efficiency. MACCs underpin our analysis on effort sharing according to the cost-effectiveness approach. MACCs measure the total economic cost of reducing emissions based on econometric demand functions for final demand sectors and fuel price simulations for different countries. Thus, MACCs represent the emissions reduction amount under the assumption of a equal price on all kind of GHG emissions, which we call the shadow carbon price here. We use MACCs that have been produced by the global POLES model[8]. POLES is a world energy-economy partial equilibrium simulation model of the energy sector until 2050. The model covers all energy & process-related

8 For a detailed documentation of the POLES model, see https://ec.europa.eu/jrc/en/publication/poles-jrc-model-documentation.

GHG emissions. MACCs are provided for 50 countries (including all countries assessed in this report) and 20 regions. Data is provided up to a maximum shadow carbon price of 1.200 EUR/t. The MACCs are based on the data from the EnerBlue scenario and describe mitigation potentials additional to the EnerBlue scenario. The EnerBlue scenario assumes the continuation of current policies in a way that the 2030 targets defined as part of the COP21 NDCs are successfully achieved.

Using the POLES MACCs we calculated the emissions reduction potentials at different shadow carbon prices. We use the 1.5°C and 2°C budgets pathways described in Section 2.2 as a basis for carbon price levels in certain years to determine at which shadow carbon price the global reduction pathway would be met according to the POLES data. An important modification is the following: As the global pathways discussed in Section 2 contain emissions reductions between 2010 and 2015, the emissions for the 2°C pathway amount to 33.5 $GtCO_2$ and 31.2 $GtCO_2$ for the 1.5°C pathway, while the POLES data start with 40.3 $GtCO_2$ in 2015. This would lead to higher cumulated emissions until 2030. Hence, we choose a shadow carbon price for 2030 that makes sure that we meet the global emissions budget for 2015-2050. In particular, the emissions reduction in 2030 is higher than in the global pathways (see Figure 5). It is important to note that for the 1.5 °C pathway, the emissions reduction also has to be faster than linear between 2030 and 2050. The resulting shadow carbon prices for 2030 and 2050 are then applied to each of the selected countries in order to calculate the individual reduction potentials, which correspond to the global cost-effective pathway.

Figure 5: The global 2 °C pathway with emissions reductions starting in 2015 in comparison to the Climate Action Tracker's 2 °C pathway




The 2 °C pathway (red line) is consistent with the Climate Action Tracker's 2 °C pathway (blue line), as the cumulative emissions agree for 2015-2050 and pathways agree after 2050.

Another issue we encounter is that the POLES mitigation potentials are insufficient to reach the climate target for the 2°C-consistent pathway (11.5 Gt$CO_2$e) and even more for the 1.5°C-consistent pathway (3.5 Gt$CO_2$e) in 2050 determined in Section 2.2. One constraint is the maximum carbon price of 1.200 EUR/t provided by POLES, which corresponds to 16.5 Gt$CO_2$e in 2030 and 14.5 Gt $CO_2$e in 2050. Even if the highest price is assumed for 2030, it is not sufficient to reach the target for the same price in 2050. This means that in our particular model configuration, further emissions reductions will have to be achieved through negative emissions. In this respect, we assume that for higher carbon prices, there is a generic carbon dioxide removal technology that enables carbon dioxide removal up to the required amount. Examples for such technologies are bio-energy-with carbon capture and sequestration (BECCS) and direct air capture (DAC) of $CO_2$. Moreover, we assume it to be independent of the individual country and we distribute the additional emissions reductions proportionally to the countries' remaining emissions. For reasons of transparency, we also provide the maximal reductions according to POLES for each country. Finally, we note that some recent studies suggest that more radical interventions on the demand side allows avoiding the use of carbon dioxide removal technologies other than land use management (cf. IPCC 2018).

## 5.2 Results from the cost-effectiveness approach

The results of distribution of emissions for the seven selected countries, the EU and the world based on the POLES data are shown in Table 9 and Table 10. The emissions levels of the pathways for the 1.5°C and 2°C budget for year 2030 (Table 9) and year 2050 (Table 10) are compared against the historical values from the year 2005 and the year 2015. The tables show the absolute emissions values as well as the relative reduction in percent for energy- and industry-related GHG emissions.

Table 9: Comparison of absolute and relative energy- and industry-related GHG emissions in 2030 among different pathways for selected countries, EU28 and world

| Energy- and process-related emissions | Cost-effective emissions level to remain compatible with the respective temperature limit [$GtCO_2e$] | | Cost-effective emissions reduction in 2030 vs. 2015 | | Cost-effective emissions reduction in 2030 vs. 2005 | |
|---|---|---|---|---|---|---|
| **Country** | **2°C-consistent** | **1.5°C-consistent** | **2°C-consistent** | **1.5°C-consistent** | **2°C-consistent** | **1.5°C-consistent** |
| Brazil | 0.47 | 0.39 | -30% | -42% | -1% | -18% |
| Canada | 0.31 | 0.23 | -53% | -66% | -55% | -67% |
| China | 6.59 | 4.61 | -46% | -62% | -11% | -38% |
| Japan | 0.61 | 0.44 | -51% | -64% | -53% | -66% |
| India | 1.87 | 1.25 | -28% | -52% | 29% | -14% |
| Germany | 0.44 | 0.33 | -46% | -59% | -51% | -63% |
| United States | 2.87 | 2.12 | -52% | -65% | -57% | -68% |
| EU28 | 2.03 | 1.54 | -46% | -59% | -56% | -67% |
| World | 22.91 | 16.48 | -43% | -59% | -31% | -51% |

For 2030, the cost-effective pathway based on the 1.5°C-consistent budget assumes emissions levels that, depending on the country, are between 42 and 66%

lower than in 2015. For the 2°C pathway, the emissions reduction ranges from 30 to 53%. The highest emissions reduction need to take place in Canada, followed by the United States. For Germany and the EU28, the reduction rates are both about 46%. For all countries, the relative emissions reduction of the 1.5°C pathway compared to 2015 are between 12 and 24%-points higher than the reductions for the 2°C pathway in 2030.

The emissions levels for both pathways are also compared to the historical values in the year 2005. The differences for the two ambitious pathways vary considerably among the countries. For Brazil, China and India, the reductions are significantly less ambitious with regard to 2005. This reflects the increase in emissions between 2005 and 2015 in these countries. This is particularly the case for India, where to remain compatible with the 2°C pathway emissions in 2030 could still be higher than in 2005, but will have to decrease in both, 1.5°C and 2°C scenarios. For Canada, Japan, the United States and the EU28, the reductions are somewhat more ambitious with regard to 2005, which results from emissions decreasing between 2005-2015.

For 2050, the emissions reductions in the 1.5°C- and 2°C-consistent pathways in comparison to 2015 are enormous for all selected countries. For the 1.5°C pathway, they range between 86% and 94%. For the 1.5°C pathway as well as for 2°C pathway, the highest emissions reduction have to take place in Germany and Canada. Overall, the relative emissions reduction of the 1.5°C pathway are between 10 and 28%-points higher than the reductions for the 2°C-consistent pathway in 2050 compared to year 2015. The difference is the highest for India and the lowest for Canada.

Table 10: Comparison of absolute and relative energy- and industry-related GHG emissions in 2050 among different pathways for selected countries, EU28 and world

| **Energy- and process-related emissions** | **Cost-effective emissions level to remain compatible with the respective temperature limit [$GtCO_2e$]** | | **Cost-effective emissions reduction in 2050 vs. 2015** | | **Cost-effective emissions reduction in 2050 vs. 2005** | |
|---|---|---|---|---|---|---|
| **Country** | **2°C-consistent** | **1.5°C-consistent** | **2°C-consistent** | **1.5°C-consistent** | **2°C-consistent** | **1.5°C-consistent** |
| Brazil | 0.17 | 0.06 | -74% | -91% | -64% | -88% |
| Canada | 0.11 | 0.04 | -84% | -94% | -84% | -95% |
| China | 3.26 | 1.10 | -73% | -91% | -56% | -85% |
| Japan | 0.28 | 0.09 | -77% | -92% | -79% | -93% |

| **Energy- and process-related emissions** | **Cost-effective emissions level to remain compatible with the respective temperature limit [$GtCO_2e$]** | | **Cost-effective emissions reduction in 2050 vs. 2015** | | **Cost-effective emissions reduction in 2050 vs. 2005** | |
|---|---|---|---|---|---|---|
| **Country** | **2°C-consistent** | **1.5°C-consistent** | **2°C-consistent** | **1.5°C-consistent** | **2°C-consistent** | **1.5°C-consistent** |
| India | 1.08 | 0.36 | -58% | -86% | -26% | -75% |
| Germany | 0.14 | 0.05 | -82% | -94% | -84% | -95% |
| United States | 1.21 | 0.41 | -80% | -93% | -82% | -94% |
| EU28 | 0.80 | 0.27 | -79% | -93% | -83% | -94% |
| World | 12.19 | 4.10 | -70% | -90% | -63% | -88% |

Contrary to the emissions reduction in 2030, where emissions could stay above the 2005 level for China, in this case all countries have emissions levels in 2050 far below the level in 2005. The emissions reduction for the 1.5°C pathway for the seven countries and the EU28 range between 75% and 95%. The lowest reduction occurs for India, while Canada, Germany, the United States and the EU 28 all show reductions between 94 and 95%. For the 2°C pathway, the reduction in comparison to 2005 varies from 28% to 85%. For all countries except India, the relative emissions reduction for the 1.5°C pathway compared to 2005 are 11 to 49%-points higher than the reductions for the 2°C pathway in 2050.

## 5.3 Limitations of the marginal abatement cost curves used and the cost-effectiveness approach in general

As the MACCs based on POLES are able to meet the reduction requirements only in 2030 but not 2050, we provide here the maximal emissions reductions available in POLES for 2050. One difference between the results from POLES and the global models, which the emissions pathways are based on, is that POLES makes very limited use of BECCS (in 2050 reduction from BECCS < 1 $GtCO_2e$). The global models, on the other hand, make substantial use of this option (for 1.5 °C pathway BECCS usually exceed 5 $GtCO_2e$ in 2050). This difference does not close the gap fully, but significantly reduces it.

We have assumed that the gap between the maximal reduction in POLES and the required reduction is split among countries proportionally to the lowest level of emissions in POLES. This would reflect a distribution of carbon-dioxide removal according to the remaining share of emissions. For reasons of transparency, Table 11 shows how this translates to changes with regard to the years 2005 and 2015. For the 1.5 °C pathway, the changes with regard to 2015 vary between 13% (Canada) and 34% (India) in 2050. The changes with regard to 2005 vary between 13% (Canada, Germany) and 64 % (India).The latter again reflects the low level of emissions in India in 2005.

Table 11: Maximum emissions reduction potential in 2050 according to the POLES model and relative deviations from the required reductions with regard to 2015 and 2005

| | **Minimum 2050 level in POLES [GtCO2e]** | **Gap between target and minimum level in POLES in 2050 vs. 2015 [ - ]** | | **Gap between target and minimum level in POLES in 2050 vs. 2005 [ - ]** | |
|---|---|---|---|---|---|
| **Country** | | **2°C-consistent** | **1.5°C-consistent** | **2°C-consistent** | **1.5°C-consistent** |
| Brazil | 0.20 | -4% | -21% | -6% | -30% |
| Canada | 0.13 | -3% | -13% | -3% | -13% |
| China | 3.78 | -4% | -22% | -7% | -36% |
| Japan | 0.32 | -4% | -19% | -3% | -17% |
| India | 1.25 | -7% | -34% | -12% | -61% |
| Germany | 0.16 | -3% | -14% | -3% | -13% |
| United States | 1.41 | -3% | -17% | -3% | -15% |
| EU28 | 0.92 | -3% | -17% | -3% | -14% |
| World | 14.12 | -5% | -25% | -6% | -30% |

Furthermore, the results are associated with some uncertainty due to the large uncertainties about long-term development of technology costs and fuel prices. The EnerBlue scenario assumes a continuous moderate increase of fossil fuel prices. The realisation of an ambitious mitigation pathway is likely to result in lower fossil fuel prices. A sensitivity analysis for approximately constant fuel prices shows little dependence of the effort-sharing distribution on it, as the differences in fuel prices are dominated by the high shadow carbon price.

Mitigation costs vary widely across different energy-economic models. Our results are based on the results of the POLES model alone. Considering different cost estimates from other models would highly increase the range of mitigation costs. However, in particular in the very high price regime of the 1.5°C-consistent pathway, the distribution of efforts itself can be expected to be not too sensitive to the cost assumptions, as mainly all technically feasible mitigation potentials have to be exploited.

## 5.4 Expansion of the cost-effectiveness approach to agriculture and waste emissions

The MACCs applied in the global cost-effectiveness approach to the distribution of emissions reductions to the (group of) countries under study here do not cover GHG emissions from the agriculture and the waste sector, which are included in the fairness-based approaches in Section 3. To enable a comparison of the results from both approaches in Section 5, we hence expand the cost-effective distribution to those sectors in this subsection. The main aim of this is to have a common set of historical GHG emissions levels for both approaches and to take into account the different shares of the sectors in the various countries. This is particularly relevant for Brazil, which has a very high share of emissions from agriculture, but also for China because of the absolute size of its agriculture sector. Furthermore, there are also moderate deviations between the historical energy- and process-related emissions included in the different approaches due to data updates and the use of different Global Warming Potentials (GWPs).[9] We also remove these differences here.

Due to the lack of MACCs for these two sectors, we cannot distribute the emissions from agriculture and waste based on cost-effectiveness. Instead, we use country-specific data on the current emissions of the sectors and the sectoral emissions trends as well as the globally necessary emissions reductions in the sectors. For the latter, we assume that the relative reduction with regard to the emissions trend is the same across countries and – in order to ensure consistency – apply the same global data we used to derive the energy- and process-related emissions from the global CAT pathways. For the current emissions and the emissions trends, we use the official data reported under the UNFCCC protocol for all countries under study, except for China and India, where we had to collect additional data from Ding et al. (2017) and Dhingra & Mehta (2017). We assume that current emissions trends flatten until 2030 in order not to overrate the current trends.

Then the resulting pathways for the agricultural and waste emissions are added to the results for the energy- and process-related emissions, in total leading to

9 The global pathways and the fairness-based effort sharing calculations are based on the GWPs from the Second Assessment Report of the IPCC. The POLES model uses GWPs from AR4. This mainly concerns the GWP of methane. Since the major part of methane emissions comes from the agricultural sector not covered by POLES, the difference is of minor importance for the resulting effort-sharing distributions.

the figures given in Table 12 and Table 13. For all countries, the relative emissions reductions with regard to 2005 and 2015 are lower after including agricultural and waste emissions because the mitigation potential is substantially lower in these sectors. This effect is increased for those countries with a rising emissions trend in these sectors (Brazil, China and India). The change in relative emissions reductions is particularly large for Brazil because more than one third of its emissions in 2015 are from these sectors. For all other countries under study here, the change is smaller than in the global average, as is the share of agriculture and waste emissions in the total GHG emissions.

Table 12: Total GHG emissions reductions in 2030 when GHG emissions from agriculture and waste are added to cost-effective pathways for energy-and process-related emissions

| | **GHG emissions in 2005 [GtCO2]** | **GHG emissions in 2015 [GtCO2]** | **Minimum emissions reduction in 2030 vs. 2015** | | **Minimum emissions reduction in 2030 vs. 2005 [ - ]** | |
|---|---|---|---|---|---|---|
| **Country** | | | **2°C-consistent** | **1.5°C-consistent** | **2°C-consistent** | **1.5°C-consistent** |
| Brazil | 0.83 | 1.04 | -7% | -18% | +16% | +2% |
| Canada | 0.72 | 0.71 | -49% | -60% | -50% | -61% |
| China | 7.42 | 11.54 | -38% | -55% | -3% | -29% |
| Japan | 1.38 | 1.29 | -48% | -61% | -52% | -64% |
| India | 1.83 | 2.63 | -21% | -42% | +14% | -17% |
| Germany | 0.99 | 0.91 | -42% | -55% | -47% | -59% |
| United States | 7.20 | 6.46 | -46% | -58% | -51% | -62% |
| EU28 | 5.13 | 4.24 | -41% | -54% | -52% | -62% |
| World | 43.32 | 48.78 | -23% | -37% | -13% | -29% |

Table 13: Total GHG emissions reductions in 2050 when GHG emissions from agriculture and waste are added to cost-effective pathways for energy-and process-related emissions

| | **GHG emissi-ons in 2005 [GtCO2]** | **GHG emissi-ons in 2015 [GtCO2]** | **Cost-effective effort-sharing in 2030 vs. 2015 [ - ]** | | **Cost-effective effort-sharing in 2030 vs. 2005 [ - ]** | |
|---|---|---|---|---|---|---|
| **Country** | | | **2°C-consis-tent** | **1.5°C-consis-tent** | **2°C-consis-tent** | **1.5°C-consis-tent** |
| Brazil | 0.83 | 1.04 | -48% | -54% | -35% | -43% |
| Canada | 0.72 | 0.71 | -78% | -88% | -79% | -88% |
| China | 7.42 | 11.54 | -67% | -85% | -49% | -76% |
| Japan | 1.38 | 1.29 | -75% | -90% | -77% | -90% |
| India | 1.83 | 2.63 | -52% | -74% | -31% | -63% |
| Germany | 0.99 | 0.91 | -78% | -89% | -80% | -90% |
| United States | 7.20 | 6.46 | -74% | -86% | -77% | -87% |
| EU28 | 5.13 | 4.24 | -73% | -85% | -78% | -88% |
| World | 43.32 | 48.78 | -53% | -72% | -47% | -69% |

# 6 Comparison of the fairness-based effort sharing and the cost-effectiveness approach with regard to 1.5°C and 2°C compatibility

The two kinds of approaches used here, the cost-effectiveness approach and the fairness-based approaches, yield complementary insights into how to distribute the mitigation burden associated with the PA long-term temperature goal. The former provides knowledge about pathways to be taken by each country domestically. The latter provides knowledge about the range of a fair and equitable distribution of global mitigation efforts based on the criteria brought forward in the climate negotiations and the literature. The gaps between the different approaches for the countries under study provide an indication of the different roles of the countries in international cooperation on climate mitigation including climate finance and emissions trading. Therefore, detailed knowledge of the gaps for the individual countries is an important prerequisite for international climate negotiations and policy-making. In the following subsection, we thus analyse the gap between the approaches and draw conclusions on options to close it. Afterwards, we look at the gap between the cost-effectiveness approach and a current policies scenario for the energy- and process-related emissions. This enables us to derive, in which countries the potential for increasing ambition for a fixed specific marginal abatement cost is particularly high. For both gap considerations, we put special emphasis on the differences between 1.5°C-consistent and 2°C-consistent effort-sharing distributions. Finally, we draw conclusions on the needs for international cooperation in GHG mitigation with a focus on possible changes subsequently to the adoption of the PA.

## 6.1 Comparison of the fairness-based effort-sharing distributions with cost-effectiveness-based distributions

For the majority of countries under study, the cost-effectiveness-based reduction of emissions is less stringent than it would have to be according to the fairness-based distribution in 2030 and 2050 both for a 2°C-consistent (Cancun compatible) and a 1.5°C-consistent (PA compatible) pathways (see Table 14). The main exceptions here are China and India, for which the fairness-based ranges of GHG emissions are substantially higher than the emissions based on a cost-effectiveness approach both in 2030 and 2050. For the United States and Brazil, this is also the case either in 2030 or in 2050, but only with regard to compatibility with the pre-Paris 2°C temperature goal.

By looking at the sum of the differences, we find that the cost-effectiveness-based emissions reduction potential within the countries under study is sufficient to achieve 2°C-consistency both in 2030 and 2050, provided that countries not assessed in this report reduce emissions to – on average – similar degree. This means that a fair effort sharing distribution can be achieved, when there is enough cooperation between China and India and the remaining countries under study. With regard to 1.5°C consistency, the potential is sufficient in 2030, though with much less leeway, and is far from being sufficient in 2050. This does not mean that the global reduction potential is insufficient, but only that from a fairness perspective, the countries under study would be required to support the rest of the world in exploiting emissions reduction potentials in a way to be determined.

For the EU, the increase of the gap between its fair share and the cost-effective share in global GHG emissions reduction is particularly high in 2030, where it is three times as high for compatibility with the 1.5°C temperature goal as for compatibility with the pre-Paris 2°C temperature goal. For Germany, the increase of the gap is lower with a central reason being its large share in the EU’s gap in 2030.

Table 14: The gap between fairness-based and cost-effectiveness-based effort-sharing distribution by country in absolute terms

| | **Gap between upper fair share range and cost-effective share in 2030 [GtCO2e]** | | **Gap between upper fair share range and cost-effective share in 2050 [GtCO2e]** | |
|---|---|---|---|---|
| **Country** | **2°C-consistent** | **1.5°C-consistent** | **2°C-consistent** | **1.5°C-consistent** |
| Brazil | -0.22 | -0.47 | 0.03 | -0.41 |
| Canada | 0.10 | 0.04 | -0.07 | -0.26 |
| China | 2.78 | 2.33 | 4.05 | 2.99 |
| Japan | -0.28 | -0.69 | -1.02 | -1.84 |
| India | 4.25 | 2.71 | 4.01 | 2.60 |
| United States | 0.23 | -1.04 | -1.48 | -3.33 |
| EU28 | -0.43 | -1.27 | -2.48 | -4.73 |
| - thereof Germany | -0.27 | -0.44 | -0.61 | -1.13 |
| TOTAL | 6.42 | 1.61 | 3.05 | -4.98 |

Values are positive for countries, where the cost-effectiveness-based reduction requirement is higher than its fair share reduction requirement.

## 6.2 Comparison of the cost-effectiveness-based distributions with NDCs

While the analysis of current and planned policies is often inhomogeneous between countries, the cost-effectiveness approach applied in Section 4 was based on the marginal abatements costs with regard to one single scenario coming from the POLES model. This scenario assumes the continuation of current policies in a way that the 2030 targets defined as part of the COP21 NDCs are successfully achieved. In this subsection, we therefore compare the distribution of emissions reductions based on the cost-effectiveness approach to the development of emissions in this scenario (“NDC scenario”). Still, the impact of current and planned policies by 2050 becomes highly uncertain in the long term. Hence, we focus here on 2030 and do not cover 2050. In Table 15, we provide the mitigation gaps in absolute terms and relative to the NDC scenario for 2030, as there is no common reference year for all the countries under study.

For 2030, the cost-effectiveness pathway based on the 1.5°C-consistent budget assumes emissions levels that are 42 to 72% lower than in the NDC scenario, depending on the country. For the 2°C-consistent pathway, the deviation ranges from 24 to 58%. The deviation for India is the highest, followed by China. For Germany, the reduction rates are 3-4%-points lower than for the EU28. For all countries, the relative emissions reduction of the 1.5°C-consistent pathway compared to the NDC scenario are 12-18%-points higher than the reductions for the 2°C pathway in 2030. For the EU (Germany), the gap between the NDC scenario and the cost-effectiveness-based pathway is lower than the global average, but increases slightly above average by 17%-points (18%-points) when moving from pre-Paris 2°C consistent pathways to PA-consistent pathways. It amounts to about 1.27 Gt $CO_2$e (0.24 Gt $CO_2$e) for 1.5°C-consistency, which correspond to an additional reduction by 22%-points (14%-points) compared to 1990.

The sum of gaps of the NDC scenario in the countries under study in 2030 amounts to 13.1 Gt$CO_2$e with regard to 2°C consistency and to 17.5 Gt$CO_2$e with regard to 1.5°C consistency. This corresponds to 47% and 62% of the energy- and process-related emissions in the current policies scenario in 2030 respectively. This shows that there is an enormous need to increase the ambition of their policies with regard to 2030.

Table 15: The gap between an NDC scenario and cost-effectiveness-based effort-sharing distribution by country in absolute and relative terms

| | **NDC scenario 2030** | **Gap with regard to 2°C consistency** | | **Gap with regard to 1.5°C consistency** | |
|---|---|---|---|---|---|
| **Country** | **[GtCO2e]** | **[GtCO2e]** | **[-]** | **[GtCO2e]** | **[-]** |
| **Brazil** | **0.68** | 0.21 | -31% | 0.29 | -43% |
| **Canada** | **0.46** | 0.16 | -34% | 0.24 | -51% |
| **China** | **13.63** | 7.04 | -52% | 9.02 | -66% |
| **Japan** | **1.01** | 0.41 | -40% | 0.57 | -56% |
| **India** | **4.44** | 2.57 | -58% | 3.19 | -72% |
| **United States** | **4.80** | 1.93 | -40% | 2.68 | -56% |
| **EU28** | **2.81** | 0.79 | -28% | 1.27 | -45% |
| - thereof Germany | 0.57 | 0.14 | -24% | 0.24 | -42% |
| **TOTAL** | **27.84** | **13.10** | **-47%** | **17.26** | **-62%** |

Absolute values are positive for countries, where the cost-effectiveness-based reduction requirement is higher than the reduction based on current NDCs. Vice versa for relative values.

## 6.3 Conclusions

In this study, we have looked at the implications of the PA's long-term temperature goal on the distribution of efforts using fairness-based and cost-effectiveness-based approaches in comparison to the less ambitious long-term temperature goal of the Cancun Agreements. We emphasize one more time that these two kinds of approaches to effort-sharing concern different types of efforts: the cost-effectiveness-based approach focuses on the question, how to distribute the implementation of the necessary reduction of physical GHG emissions in a cost-effective way. This has no direct implication on the responsibility for mitigating the emissions. On the contrary, the fairness-based approaches focus on the question what the share of each country in global emissions reduction is based on ethical considerations without implying that sufficient domestic mitigation potentials exist.

For both kinds of approaches, the more ambitious long-term temperature goal of the PA compared to the former Cancun target results in substantially higher reduction requirements for all countries. Given that there has been a gap between NDCs and the Cancun target of holding global warming below 2°C, the Paris temperature limit calls even more for a rise of an ambition of the NDCs. For the effort- and process-related GHG emissions, in particular, the gaps with regard to a cost-effective pathways have increased by 32% on average. For the EU, the increase of the gap with 61% is particularly large. This shows the clear need to reconsider the EU’s long-term targets in light of the PA. By comparing the gap between the two kinds of approaches, we have seen that there is substantial cost-effective emissions reduction potential in China and India that may not be tapped, when efforts are distributed based on fairness-based approaches. When we look at consistency with a 1.5°C-compatible emissions pathways in the longer term up to 2050, however, the fairness-based emissions allowances in the major emitting countries considered cannot be met by redistributing the reductions of a cost-effective pathway among each other. This suggests that for compatibility with the more ambitious temperature goal of the PA, it will become even more important to have a truly global international cooperation on climate change mitigation.

There are several mechanisms for international cooperation between countries. First, there is the option of trading emissions allowances via emissions trading systems, as they already exist within the EU, in Japan, in China and in some parts of the United States. Here, it is important to install trading systems in further countries and link the various schemes in a way that makes sure that also domestic mitigation targets are met as well. Second, there is the option of joint mitigation measures, e.g. via transfer of mitigation technologies. In this regard, the PA’s Article 6 prescribes the role of such cooperative approaches to serve only for a total rise of ambition globally. Third, there is the option of direct financial transfers between countries with limited emissions allowances and limited mitigation potentials to the remaining ones. This predominantly applies to development aid, which currently is covered mainly by the Green Climate Fund.

In spite of the need for international cooperation, it remains to be revoked that the GHG emissions reductions attributed to the domestic targets in the current NDCs for all countries under study here do not meet the level of emissions reductions required for a global cost-effective pathway, even with regard to compatibility with the “old” Cancun 2 °C goal. Therefore, a substantial increase of ambition in all of the countries is possible without deviating from a global cost-effective pathway. Even if we take into account that there is high uncertainty about the development of mitigation costs, the order of the existing gap justifies no hesitation about moving beyond the ambition of the current NDCs.

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# A.1 Annex 1: Studies included in the analysis of the Climate Action Tracker

| Study name | Included in harmonsiation |
|---|---|
| 001 (den Elzen, Beltran, Hof, van Ruijven, & van Vliet, 2013) | yes |
| 002 (Van Vuuren, Isaac, Den Elzen, Stehfest, & Van Vliet, 2010) | yes |
| 003 (Hof & Den Elzen, 2010) | yes |
| 004 (Knopf et al., 2009) | yes |
| 005 (den Elzen, Höhne, & Moltmann, 2008) | yes |
| 007 (Hof & Den Elzen, 2010) | yes |
| 008 (den Elzen, Lucas, & van Vuuren, 2008) | yes |
| 009 (van Vuuren et al., 2009) | yes |
| 010 (den Elzen, Höhne, Brouns, Winkler, & Ott, 2007) | yes |
| 011 (den Elzen & Meinshausen, 2006) | yes |
| 012 (den Elzen, Lucas, et al., 2005) | yes |
| 013 (Den Elzen & Lucas, 2005) | yes |
| 014 (Criqui et al., 2003) | yes |
| 015 (Berk & den Elzen, 2001) | no, outdated |
| 016 (Kuntsi-Reunanen & Luukkanen, 2006) | no, different stabilisation level |
| 017 (Winkler, Letete, & Marquard, 2011) | yes |
| 018 (Chakravarty et al., 2009) | yes |
| 019 (Bows & Anderson, 2008) | yes |
| 021 (Vaillancourt & Waaub, 2004) | no, different stabilisation level |
| 022 (Miketa & Schrattenholzer, 2006) | no, different stabilisation level |
| 023 (Bode, 2004) | no, different stabilisation level |
| 025 (Böhringer & Welsch, 2006) | yes |
| 026 (Groenenberg, Blok, & van der Sluijs, 2004) | no, different stabilisation level |
| 027 (WBGU, 2009) | yes |
| 028 (Knopf et al., 2012) | no, data inconsistencies |
| 031 (Nabel et al., 2011) | yes |
| 032 (Peterson & Klepper, 2007) | yes |
| 034 (Onigkeit, Anger, & Brouns, 2009) | yes |
| 035 (Jacoby, Babiker, Paltsev, & Reilly, 2008) | yes |
| 036 (Edenhofer et al., 2010) | yes |

| Study name | Included in harmonsia-tion |
|---|---|
| 037 (Höhne & Moltmann, 2009) | yes |
| 038 (Kriegler et al., 2014a) | yes |
| 042 (Jayaraman, Kanitkar, & Dsouza, 2011) | yes |
| 043 NIES (Kriegler et al., 2014b) | yes |
| 044 PNNL (Kriegel et al., 2014) | yes |
| 045 PBL (Kriegel et al., 2014) | yes |
| 046 IIASA (Kriegel et al., 2014) | yes |
| 047 PIK (Kriegel et al., 2014) | yes |
| 048 FEEM (Kriegel et al., 2014) | yes |
| 049 (Kober, Zwaan, & Rösler, 2012) | no, data inconsistencies |
| 050 (Baer et al., 2008) | yes |
| 051 (Pan, Teng, Ha, & Wang, 2014) | yes |
| 052 (Pan, Teng, & Wang, 2014b)10 | yes |
| 057 (Robiou du Pont et al., 2016) | yes |

## A.2 Annex 2: Number of observations for each equity category and country

The following tables summarise the number of observations included for each equity category and each country in 2030 and 2050:

Table 16: Number of observations for each equity category and country

| **2030 (1.5°C)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **Capa-bility** | **Eq. Cumulative per capita emissions** | **Equa-lity** | **Capab-ility/ costs** | **Respon-sibility/ capabi-lity/ need** | **Respon-sibility** | **Staged** | **To-tal** |
| Brazil | 8 | 2 | 11 | 0 | 17 | 8 | 20 | 66 |
| Canada | 8 | 1 | 12 | 0 | 17 | 8 | 20 | 66 |
| China | 8 | 2 | 15 | 0 | 17 | 8 | 20 | 70 |
| EU28 | 6 | 2 | 9 | 0 | 11 | 6 | 11 | 45 |
| India | 8 | 2 | 15 | 0 | 17 | 8 | 20 | 70 |
| Japan | 8 | 2 | 16 | 0 | 17 | 8 | 21 | 72 |
| USA | 8 | 2 | 16 | 0 | 17 | 8 | 21 | 72 |
| TOTAL | 54 | 13 | 94 | 0 | 113 | 54 | 133 | 461 |

10 Approaches for equal cumulative emissions per capita from this study were excluded from out equity ranges due to data inconsistencies.

| **2030 (2.0°C)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **Capa-bility** | **Eq. Cu-mulative per cap-ita emis-sions** | **Equa-lity** | **Capa-bility/ costs** | **Respon-sibility/ capabi-lity/ need** | **Respon-sibility** | **Staged** | **To-tal** |
| Brazil | 6 | 1 | 2 | 12 | 15 | 6 | 23 | 65 |
| Canada | 6 | 4 | 3 | 15 | 15 | 6 | 24 | 73 |
| China | 6 | 9 | 3 | 17 | 15 | 6 | 19 | 75 |
| EU28 | 4 | 9 | 5 | 13 | 13 | 6 | 15 | 65 |
| India | 6 | 10 | 5 | 18 | 15 | 6 | 23 | 83 |
| Japan | 6 | 4 | 4 | 15 | 15 | 6 | 25 | 75 |
| USA | 6 | 4 | 5 | 16 | 15 | 6 | 25 | 77 |
| TOTAL | 40 | 41 | 27 | 106 | 103 | 42 | 154 | 513 |

| **2050 (1.5°C)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **Capab-ility** | **Eq. Cu-mulative per cap-ita emis-sions** | **Equa-lity** | **Capab-ility/ costs** | **Respon-sibility/ capabi-lity/ need** | **Respon-sibility** | **Staged** | **To tal** |
| Brazil | 6 | 2 | 11 | 0 | 13 | 13 | 20 | 65 |
| Canada | 6 | 1 | 12 | 0 | 13 | 8 | 20 | 60 |
| China | 6 | 2 | 15 | 0 | 13 | 8 | 20 | 64 |
| EU28 | 4 | 2 | 9 | 0 | 11 | 6 | 11 | 43 |
| India | 6 | 2 | 15 | 0 | 13 | 8 | 20 | 64 |
| Japan | 6 | 2 | 16 | 0 | 13 | 8 | 21 | 66 |
| USA | 6 | 2 | 16 | 0 | 13 | 8 | 21 | 66 |
| TOTAL | 40 | 13 | 94 | 0 | 89 | 59 | 133 | 428 |

| **2050 (2.0°C)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **Capa-bility** | **Eq. Cu-mulative per cap-ita emis-sions** | **Equa-lity** | **Capab-ility / costs** | **Respon-sibility/ capabi-lity/ need** | **Respon-sibility** | **Staged** | **To-tal** |
| Brazil | 4 | 2 | 12 | 1 | 14 | 6 | 26 | 65 |
| Canada | 4 | 3 | 15 | 4 | 14 | 6 | 27 | 73 |
| China | 4 | 3 | 17 | 9 | 14 | 6 | 22 | 75 |
| EU28 | 4 | 5 | 13 | 9 | 13 | 6 | 15 | 65 |
| India | 4 | 5 | 18 | 10 | 14 | 6 | 26 | 83 |

| 2050 (2.0°C) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Country** | **Capa-bility** | **Eq. Cu-mulative per cap-ita emis-sions** | **Equa-lity** | **Capab-ility / costs** | **Respon-sibility/ capabi-lity/ need** | **Respon-sibility** | **Staged** | **To-tal** |
| Japan | 4 | 4 | 15 | 4 | 14 | 6 | 22 | 69 |
| USA | 4 | 5 | 16 | 4 | 14 | 6 | 28 | 77 |
| TOTAL | 28 | 27 | 106 | 41 | 97 | 42 | 166 | 507 |

## A.3 Annex 3: Why the effort sharing ranges do not include LULUCF

The CAT methodology for assessing and rating (I)NDCs focuses on $CO_2$ and other GHG emissions from fossil fuel combustion, industry, agriculture and waste sources [1], which account for 93% of global GHG emissions in 2010. CO2 and other GHG emissions from land-use, land use change and forestry (LULUCF), which account for around 7% of global GHG emissions, are not included in the effort sharing ranking system. There are several inter-related factors that lead to the approach of excluding the LULUCF sector from the effort sharing ranges.

Firstly, results from the IPCC's most recent Fifth Assessment Report (AR5) show that long-term transformation of the global economy needed to achieve 1.5 or 2°C requires emissions cuts in the energy sector for 2025, or 2030, and these cannot be replaced by reductions in emissions from the land-use sector. Limiting warming below 2°C and 1.5°C requires deep and long-lasting changes in energy and industrial greenhouse gas emissions. While reducing deforestation is important, as is maintaining the sink or carbon storage capacity of forests, soils and other ecosystems, enhancing emissions reductions only from LULUCF will not replace the required reductions in emissions within energy and industry sectors, given the long legacy of committed emissions after installation of new high-emissions infrastructure. Emissions reductions of 2025 and 2030 benchmarks for 1.5°C pathways actually assume large reductions in emissions from *all* sectors including the LULUCF sector. Further enhancing these, as discussed above, will not replace the required reductions in emissions within energy and industry sectors. When assessing progress towards decarbonisation, the inclusion of LULUCF into a emissions reduction target has the potential to disguise increasing trends of energy and industrial emissions in the country concerned. Lastly, the CAT methodology for determining effort sharing ranges uses the scientific literature on the subject, which is predominantly based on GHG emissions not including LULUCF. The LULUCF sector has very different economics, drivers and longer-term dynamics than those that, by and large, govern the development of energy and industrial systems enjoining emissions from this sector.

For more information on LULUCF emissions please see the CAT website: https://climateactiontracker.org/methodology/indc-ratings-and-lulucf/.

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