

The EU 40 % greenhouse gas emission reduction target by 2030 in perspective

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Abstract We assess the fairness and ambition level of the EU's Intended Nationally Determined Contribution (INDC) of reducing domestic greenhouse gas emissions by at least 40 % relative to 1990. For this, we calculate which reduction targets for other major emitting economies are comparable to the EU target, given widely diverging effort-sharing approaches. We introduce a novel approach in which the EU target is taken as starting point for allocating emission reductions to other regions. Under this approach, the global emission level is an outcome of the analysis, contrary to standard effort-sharing approaches in which the global climate goal is specified. We find that the INDC of the EU, if other regions take on comparable targets based on a differentiated convergence per-capita approach, could be sufficient for a global 2 °C pathway. However, if emissions are allocated according to a historical responsibility approach, the global emission level in 2030 is much higher than the level of 2 °C pathways. Furthermore, we conclude that India, Mexico, and Brazil have more ambitious INDCs than the EU according to both a differentiated convergence per-capita approach and a historical responsibility approach.

Keywords Climate change · INDCs · Burden sharing · Effort sharing · Mitigation

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1 Introduction

Many countries have put forward greenhouse gas (GHG) emission reduction pledges for 2020 in the Cancún Agreements under the United Nations Framework Convention on Climate Change (UNFCCC 2010, 2012). Several studies have analyzed the effect of these pledges on global emissions and the chance of achieving the international agreed goal of keeping global temperature increase well below 2 °C by the end of the century (Rogelj et al. 2010; van Vliet et al. 2012; den Elzen et al. 2013a; Hof et al. 2013; UNEP 2014) and on abatement costs (den Elzen et al. 2011; Wada et al. 2012; Dellink et al. 2011; Peterson et al. 2011). However, emission reductions beyond 2020 are more important for achieving the international agreed climate goal of 2 °C (Tavoni et al. 2015; Riahi et al. 2015). According to the latest UNEP emission gap report (UNEP 2015) the median emission level needed for a likely (more than 66 %) chance of keeping temperature increase to below 2 °C is 42 GtCO₂eq by 2030, with a range of 31–44 GtCO₂eq. At the same time, business-as-usual emissions are projected to increase during this period.

In 2011, at the UN climate summit in Durban, countries agreed to negotiate a new international climate agreement by 2015, applicable to all countries and to be implemented from 2020. One of the key elements in the new agreement is the long-term reduction targets beyond 2020, as part of the so-called Intended Nationally Determined Contributions (INDCs). At the UN climate summit in Lima in 2014, it was agreed that countries should submit INDCs well before the Paris climate summit in December 2015. By October 29, 2015, 129 INDCs had been submitted to the UNFCCC secretariat, covering 156 countries (as the EU28 submitted one INDC).¹ Many of these INDCs include some text about the fairness and ambition level, which shows that questions related to fairness and ambition are high on the political agenda. Furthermore, in the Paris Agreement (UNFCCC 2015), adopted in December 2015, countries agreed to submit new or updated national climate plans by 2020 (known as nationally determined contributions). Every five years after that, countries agreed to submit new contributions, which have to go beyond previous efforts depending on the collective progress toward achieving the global long-term temperature goal.

In this context, it is important to assess the fairness and ambition level of emission reduction targets of different countries. This can be done according to different effort-sharing approaches. Such effort-sharing approaches are guided by certain equity principles, and based on the UNFCCC principle of common but differentiated responsibilities and respective capabilities (CBDR-RC, United Nations 1992). As the EU claims to be at the forefront of international efforts (European Commission 2014), the main aim of this paper is to assess the fairness and ambition level of the EU's INDC. In order to assess this, we address the following research questions:

1. Which targets for other countries or regions are comparable to the EU target of a 40 % reduction in domestic GHG emissions by 2030 relative to 1990, given different effort-sharing approaches?
2. Is the global emission level resulting from implementation of the INDC of the EU and comparable reductions from other countries consistent with 2 °C GHG emission pathways?

¹ The current status of the submitted INDCs can be found under <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

3. How do reduction efforts of other countries that are comparable to the reduction effort of the EU 40 % target relate to their announced INDCs?

In order to assess the above questions, several effort-sharing approaches are applied to allocate emission reduction commitments among regions. There is a vast literature on effort-sharing approaches (for an overview, see Höhne et al. 2014; Clarke et al. 2014; Gupta et al. 2007), in which many different approaches are proposed according to many different equity principles. However, to our knowledge and based on the overview literature, all the existing effort-sharing approaches have the same global starting point, which can be an emission target, a target for long-term GHG concentrations, or a maximal temperature increase such as 2 °C. Based on this global target the relevant parameters (like per-capita convergence level) of the approach are determined, and finally the allocation of the emission allowances (or emission reductions) across countries is calculated.

We adopt a new method of effort sharing by taking the EU target, instead of a global target, as starting point to determine the relevant parameters. In our approach, global emissions are the outcome of the effort-sharing approach (Fig. 1). We argue that this approach is better suited to assess which targets of other countries are comparable to a proposed reduction target of a specific country, and in how far a proposed reduction target is consistent with the 2 °C climate goal. This approach can be applied to the INDCs of all countries, but in this paper we focus specifically on the INDC of the EU as example of how this approach can be applied. Our approach is complementary to the standard effort-sharing approach of starting with a global target. For assessing how much individual regions should contribute to emission reductions to achieve a global target, the standard effort-sharing approach is better suited, but we argue that our approach is better suited for analyzing the fairness and ambition levels of INDCs relative to each other.

Apart from the different approach, this paper presents an update of earlier work by focusing on post-2020 INDCs. To our knowledge, the only studies focusing on INDC assessments using effort-sharing approaches are Meinshausen et al. (2015) and the online assessment by Climate Action Tracker (<http://climateactiontracker.org/>). The Climate Action Tracker takes as starting point a 2 °C global emission pathway, and our approach can be regarded as complementary to this study. The approach of Meinshausen et al. has some similarities with ours, it involves a major economy country taking the lead, and in a

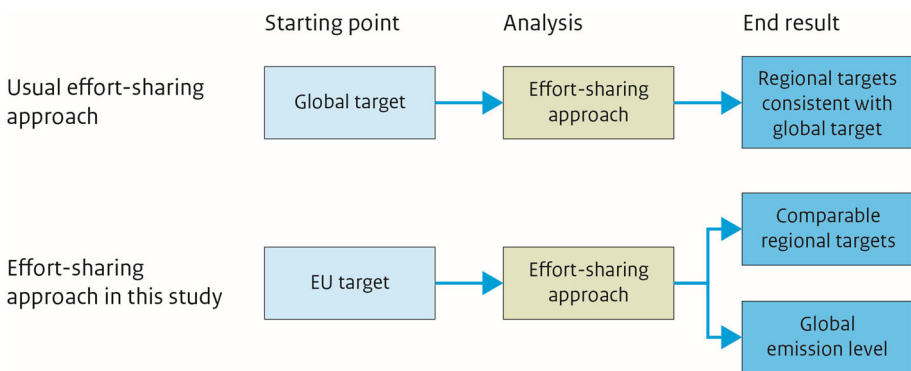


Fig. 1 Effort-sharing approach used in this study

bottom-up manner, other countries then determine what they consider a fair comparable target, based on a “per-capita convergence” or “equal cumulative per-capita” approach.

This paper is organized as follows. Section 2 introduces the effort-sharing approaches applied in this study and describes the main assumptions and the methodology of calculating the emission reduction targets and abatement costs. Section 3 provides the results, and Sect. 4 provides a discussion and concludes.

2 Methods

2.1 Effort-sharing approaches

A vast number of effort-sharing approaches have been proposed in literature (see, for instance, den Elzen et al. 2007; Chakravarty et al. 2009; Baer et al. 2009; Pan et al. 2014c; Gupta and Bhandari 1999; Höhne et al. 2006; Ringius et al. 1998; Bode 2004; Russ and Criqui 2007; Meyer 2000; BASIC Experts 2011). Each of these proposed effort-sharing approaches is guided by some sort of equity principle according to Article 3.1 of the UNFCCC and has applied in some form the principle of CBDR-RC. There have also been several attempts in organizing effort-sharing approaches according to their equity principle and in analyzing the outcomes of approaches (Rose et al. 1998; Höhne et al. 2014; Clarke et al. 2014; Pan et al. 2014a, b; den Elzen and Lucas 2005; van Ruijven et al. 2012a, b; Ringius et al. 1998, 2002; Meinshausen et al. 2015; Raupach et al. 2014; Hof and den Elzen 2010).

This paper does not aim to contribute to this discussion, but rather at covering the range of proposals that are being discussed by Parties under the convention. As argued by Meinshausen et al. (2015), this range can be reasonable well covered by two effort-sharing approaches: common but differentiated convergence (CDC, Höhne et al. 2006) which is a modified per-capita convergence approach, and an approach based on historical responsibility.

Under the CDC approach, per-capita emission allowances of countries converge from current levels to an equal level for all countries, but differentiated over time. Like Höhne et al. (2006), we assumed a convergence time of 40 years. Regions start their convergence if their per-capita GHG emission level reaches a certain threshold level, which for this paper is set at the global average per-capita emission level. If per-capita emissions are below the global average, regions can follow their baseline emissions until their per-capita emissions reach the global average level. As 2030 is exactly midway in the convergence period, this implies that for regions above this threshold value in 2010, the difference in per-capita emission levels of non-EU regions with the level of the EU has halved between 2010 and 2030. Under our population projections, the 40 % EU target leads to a per-capita emission level of 6.5 tCO₂eq by 2030, compared to 9.5 tCO₂eq in 2010. The per-capita emission level of, for instance, the USA was 21.3 tCO₂eq in 2010 or 11.8 tCO₂eq above the level of the EU. This implies that the per-capita emission target level of the USA under our CDC approach is 6.5 tCO₂eq plus half of 11.8 tCO₂eq, which equals 12.4 tCO₂eq by 2030.

Historical responsibility is seen as a key criterion by the BASIC countries (BASIC Experts 2011). The idea to set differentiated emission reduction targets according to the impact of historic emissions on temperature rise was argued for by Brazil, together with a simple methodology for illustrative purposes (UNFCCC 1997). However, there have been many different proposals to implement an effort-sharing approach based on historical

responsibility since then (Rive et al. 2006; BASIC Experts 2011; den Elzen et al. 2005). Moreover, it matters strongly whether historical responsibility is interpreted as “proportional” or “conceptual.” Quoting Friman and Strandberg (2014): “The conceptual view treats historical responsibility in a manner that avoids direct linkage between past emissions and present responsibilities. It typically looks at the present unequal distribution of capacity to act, and argues that the history of the creation of this distribution must be evaluated in moral terms. (...) The proportional view, on the other hand, defines responsibility in proportion to historical contribution.” Many developed countries have started to interpret historical responsibility in conceptual terms, while most developing countries interpret the concept in proportional terms. Although both interpretations are legitimate under the UNFCCC, we choose the proportional interpretation, as this leads to an outcome which better captures the range of effort-sharing approaches we aim to explore in this study. Given this interpretation, one of the most important choices is the time period that is considered for cumulative emissions.² Again, as we are interested in capturing the range of effort-sharing approaches and earlier start years generally lead to higher reduction requirements for high-income countries, we use an early start year of 1850 for determining cumulative GHG emissions. The historical emissions (including all GHGs) were based on the EDGAR dataset (JRC/PBL 2012) for the period 1970–2010 and on the MATCH dataset (Höhne et al. 2011) for the period 1850–1970, as described in den Elzen et al. (2013b). These data are publicly available.³ We follow Rive et al. (2006) with regard to the allocation methodology, which implies that a countries’ required deviation from the baseline (see Sect. 3.2) is given by the countries’ cumulative emissions between 1850 and 2010 relative to those of the EU, times the deviation of the baseline for the EU for achieving its 40 % reduction target (see Eqs. 1 and 2 and Supplementary Information for calculations). This implies that the global emission reduction is a direct function of the deviation from baseline of the EU and the cumulative share of global emissions of the EU.

$$E_r = \sum_{t=1850}^{2010} e_{rt} \quad (1)$$

where E_r are total cumulative emissions in MtCO₂eq in region r and e_{rt} are annual emissions in region r at year t

$$RR_{rt} = \frac{E_r}{E_{EU}} RR_{EU,t} \quad (2)$$

where RR_{rt} is the deviation of the baseline in region r at year t and $RR_{EU,t}$ is the deviation of the baseline in the EU at year t (both in MtCO₂eq).

We compare the CDC and historical responsibility approach with two allocations based on mitigation costs. The first is our main reference case, in which marginal abatement costs are equalized in all regions. This reference case is included in this study for comparison, as it results in the most efficient way to reduce emissions, without being based on a specific equity principle. As the burden of a carbon tax tends to fall on those regions with high emission intensities or with a large potential to reduce emissions (Hof et al. 2009), this approach leads to relatively high reduction targets for developing countries. Under the second approach, emission allowances are distributed in such a way that *equal relative*

² For simplification, we use cumulative greenhouse gas emissions as proxy for contribution to climate change (den Elzen et al. 2013b).

³ <http://www.pbl.nl/en/publications/countries-contributions-to-climate-change>.

costs as share of GDP are the same across regions. The common cost level was again determined using the expected direct cost of achieving the EU 40 % domestic GHG emission reduction target (Sect. 3). We have applied this approach using the same method as was used in the model intercomparison project LIMITS (Kriegler et al. 2013; see Supplementary Information for details). Although the equal relative costs method has been proposed as operational rule of the ability to pay criterion by Rose et al. (1998), it does not lead to equal welfare impacts as the same fraction of GDP is valued differently in countries with different income levels. We therefore mainly included the results of such an allocation to provide insight into regional cost differences assumed by our marginal abatement cost (MAC) curves (see Sect. 2.2).

In the calculations, it is assumed that all regions should reach the 2030 emission reduction targets resulting from the effort-sharing approaches through domestic emission reduction (no purchasing of emission credits was allowed). This is also the reason why we have excluded approaches which lead to emission allocations which are higher than projected baselines. Many resource-sharing approaches (i.e., approaches that allocate allowances instead of reduction requirements) are of this nature, such as the equal cumulative emission per-capita principle (Pan et al. 2014c; Pan 2005). Since we are interested in comparing domestic emission targets, we do not allow for emission trading. Therefore, we do not take into account resource-sharing approaches that lead to emission allocations higher than baseline levels in our analysis.

2.2 Model framework for determining emission targets and abatement costs

The integrated modeling framework FAIR (den Elzen et al. 2014) was used for calculating emission targets and abatement costs. This model uses information on marginal abatement costs (MAC) of reducing (1) energy- and industry-related CO₂ emissions from the energy model TIMER (Chapter 4.1 of Stehfest et al. 2014), (2) CO₂ emissions from forestry from the G4M model (Kindermann et al. 2008), and (3) non-CO₂ GHG emissions from a variety of sources, including EPA (2013), Lucas et al. (2007), and Graus et al. (2004) for methane and nitrous oxide, and Schwarz et al. (2011) for the fluorinated GHGs (HFCs, PFCs and SF₆), see Supplementary Information for more detail. The non-CO₂ MAC curves have been made consistent with the baseline used in this study (Sect. 3.2). In addition, the MAC curves have been made time dependent to account for technology change and the removal of implementation barriers, based on the method of Lucas et al. (2007). To analyze the uncertainty in results, we included an analysis of energy- and industry-related CO₂ MAC curves from Enerdata's POLES energy model⁴ (Enerdata 2010).

The energy- and industry-related CO₂ MAC curves were determined by imposing a carbon tax in the TIMER model and recording the induced reduction in CO₂ emissions. The model's behavior is mainly determined by the substitution processes of various technologies based on long-term prices and fuel preferences. These two factors drive multinomial logit models that describe investments in new energy production and consumption capacity. The demand for new capacity is limited by the assumption that capital goods are only replaced at the end of their technical lifetime. The long-term prices that drive the model are determined by resource depletion and technology development. Resource depletion is important for both fossil fuels and renewables (for which depletion and costs depend on annual production rates). Technology development is determined

⁴ See <http://www.enerdata.net/enerdatauk/knowledge/subscriptions/forecast/marginal-abatement-cost-curves-MACCs.php>.

using learning curves or through exogenous assumptions. Emissions from the energy system are calculated by multiplying energy consumption and production flows by emission factors. A carbon tax can be used to induce a dynamic response, such as the increased use of low- or zero-carbon technologies, energy efficiency improvements, and end-of-pipe emission reduction technologies.

The MAC curves from forestry activities (deforestation, afforestation, and reforestation) were derived by introducing a carbon price in the IIASA's G4M and GLOBIOM forestry model (Böttcher et al. 2011; Kindermann et al. 2008), which means that (1) forest owners are paid for any carbon that is stored in forest living biomass above baseline level, and (2) they have to pay a tax if the amount of carbon in forest living biomass is below the baseline level. G4M is a geographically explicit agent-based model to assess afforestation, deforestation, and forest management decisions at 30 arcminutes level (equal to 1.86 km at the equator). The model uses recent baseline projections based on results of the POLES energy model for future bioenergy demand and related assumptions on population growth, economic development (GDP) (Böttcher et al. 2011). The most important parameters of G4M are mean annual increment, maximum share of saw logs in the mean annual increment, and harvesting cost. Mitigation measures considered in the G4M model include reducing deforestation, increasing afforestation, changes in rotation lengths of existing managed forests, changes in the ratio between thinning and final fellings, and changes in harvest intensity.

For cost calculations for 2030, we see that the potential for reducing CO₂ emissions from forestry activities will be fully used for both developed and developing regions (Angelsen et al. 2014). As the mitigation costs of these activities are often lower than reducing emissions in other sectors, CO₂ emissions from land use are reduced more than the average reductions in all sectors, especially for Brazil, Indonesia, Australia and New Zealand, and Russia.

To explore the consequences of the uncertainty in cost estimates, we also used energy- and industry-related CO₂ MAC curves information from the POLES energy model (Russ and Criqui 2007; Russ and van Ierland 2009). The POLES version of Enerdata (2010) is used. The POLES CO₂ MAC curves were selected for the uncertainty analysis since: (1) both TIMER and POLES have information at the level of multiple sectors and world regions (both Annex I and non-Annex I), so can be incorporated in our integrated model; (2) both models show a wide range of outcomes across various models for Annex I as a group (Fig. 3.1 in Amann et al. 2009). The dynamics of the POLES model are based on a recursive simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through the international energy price. The model is developed in the framework of a hierarchical structure of interconnected modules at the international, regional, and national levels. It contains technologically detailed modules for energy-intensive sectors, including power generation, iron and steel, the chemical sector, aluminum production, cement making, non-ferrous minerals, and modal transport sectors. All energy prices are determined endogenously. Long-term oil prices depend primarily on the relative scarcity of oil reserves.

FAIR distinguishes 26 world regions, including the individual countries the USA, Canada, Russia, Japan, India, Brazil, and Mexico. The region Indonesia includes East Timor and Papua New Guinea, the region China includes Mongolia, Taiwan, Hong Kong, and Macau, and the region Oceania includes Australia and New Zealand. Europe is modeled as two separate regions: Western and Central Europe. Together, they represent the EU28 and Norway, Switzerland, Iceland, Albania, and the former Yugoslavian states. This implies that FAIR has a somewhat broader than formal definition of the EU. However, in

terms of total GHG emissions the EU28 and the FAIR region Western and Central Europe are very close, the difference being about 0.25 GtCO₂e (about 5 %) in 2010,⁵ and as such this small difference in regional breakdown does not have a large effect on the results.

2.3 Baseline

The IMAGE model framework was used to create a middle-of-the-road baseline scenario. The baseline is based on the SSP2 storyline (O'Neill et al. 2014) and includes all Kyoto GHG emissions. For the energy- and industry-related CO₂ MAC curves from POLES, we use the POLES baseline emissions from this sector as these are calibrated to this specific baseline. The POLES baseline is broadly similar to the reference scenario of the IEA World Energy Outlook (IEA 2009) and has been corrected for the economic crisis. In both the IMAGE and POLES baselines, the largest absolute increase in GHG emissions occurs in China and India, whereas emissions in most developed countries more or less stabilize at 2010 levels by 2030. The projected global GHG emission level, including emissions from international shipping but excluding emissions from international aviation, is about 61 GtCO₂eq in 2030 in the IMAGE baseline and 62 GtCO₂eq in the POLES baseline, compared with about 48 GtCO₂eq in 2010. The Supplementary Information shows more background information about the assumed baseline emissions for the regions included in our study.

The more recently developed IMAGE baseline is better calibrated with recent emission trends and renewable installed capacities than the POLES baseline. A consequence is that under the IMAGE baseline, less mitigation effort for the EU is required to achieve the 40 % EU target compared to the POLES baseline. More specifically, in the IMAGE baseline EU emissions by 2030 equal 24 % below 1990 levels, while in the POLES baseline it equals only 8 % below 1990 levels.

For this study, baseline data—except data from POLES and land-use CO₂ emissions—were harmonized to match historical emission levels for the 1990–2010 period. The historical dataset includes the Kyoto GHGs CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆. The data for the Annex I countries are based on the 2012 national emission inventories submissions to the UNFCCC. For all non-Annex I countries, energy-related CO₂ emissions from IEA (2012) and non-energy-related emissions from EDGAR 4.2 (JRC/PBL 2012) were used. Harmonization was carried out by applying regional harmonization ratios in 2010 to match the total GHG emission level of the baseline to that of the historical dataset. Harmonization ratios converge from 2010 levels to unity in 2100. Our historical emissions slightly differ to those of the UNFCCC submissions, because (1) we used global warming potentials (GWPs) from the IPCC AR4 report (Forster et al. 2007) to aggregate emissions of different GHGs to CO₂ equivalents, whereas the UNFCCC used GWPs from the IPCC SAR report (UNFCCC 1995), and (2) we base CO₂ emissions from land use on the forestry model G4M, whereas the UNFCCC used national submissions for these CO₂ emissions. The POLES baseline has not been harmonized to historical datasets, as the MAC curves from POLES are calibrated to the unharmonized baseline.

3 Results

The results are presented according to our three research questions. First, the comparable targets for other major economies to the INDC of the EU will be presented, followed by an assessment of the resulting global emission level with the emission level consistent with a

⁵ According to the EDGAR database: <http://edgar.jrc.ec.europa.eu/>, accessed 11 November 2015.

2 °C pathway. Finally, the results from the effort-sharing approaches are compared to the INDCs of the major economies.

3.1 Comparable regional emission targets

Table 1 shows which targets for other major economies are comparable to the domestic EU 40 % target according to the two effort-sharing approaches and the two allocations based on costs. The results are given both relative to 2010 levels and 2030 baseline levels (both IMAGE and POLES baselines). Although the target of the EU was set to 40 % below 1990 level for both the POLES and IMAGE baselines, keep in mind that the reductions compared to the model baseline differ quite substantially, as the EU baseline reaches 24 % below 1990 levels in the IMAGE baseline and only 8 % under 1990 levels in the POLES baseline.

As the per-capita baseline emission levels of India, Indonesia, and Mexico are still below the global average by 2030, these countries do not have to reduce their emissions according to the CDC approach. In our baselines, all countries shown in Table 1 except for the three just mentioned have per-capita emissions which are higher than those of the EU by 2030. Therefore, the reductions compared to baseline are also higher. In short, as per-capita emissions of the EU are relatively low given its income level, for other industrialized regions and China the CDC approach leads to more ambitious reduction targets by 2030 than the EU compared to baseline.

The approach based on historical responsibility shows a completely different picture. Under this approach, the reduction targets depend on the region's cumulative emissions in the period 1850–2010 relative to those of the EU (see Sect. 2). The EU was responsible for about 18 % of global cumulative emissions in this period. The USA was responsible for a similar share and therefore receives similar reduction requirements in absolute terms. As current and future projected emissions are higher for the USA than for the EU, the reductions relative to 2010 and baseline levels are lower than the EU. A similar reasoning holds for the other regions, and therefore, the historical responsibility approach leads to reduction targets for other regions which are in general less stringent compared to baseline than the INDC of the EU. An exception is Indonesia, which is due to its relatively high historical CO₂ emissions as a consequence of deforestation.

Both the CDC and historical responsibility approach lead to lower reduction targets for the least developed countries India, Indonesia, and Mexico compared to a cost-optimal allocation of the emission reductions (*equal carbon tax*). For all other regions, an optimal allocation leads to allowances somewhere in between the CDC and historical responsibility approach with the exception of Brazil, which has a large relatively cheap potential to mitigate CO₂ emissions by reducing deforestation. The equal cost approach leads to lower reduction targets (compared to baseline) than the EU for those countries with a higher potential than the EU to reduce emissions at the given carbon price. A good example is India, which for a given carbon price has relatively high mitigation costs as its potential to reduce emissions is high. The area under the MAC curve is therefore larger than for the EU at a given carbon price. In order to arrive at the same relative costs as the EU, the emission reduction target has to be set much lower than under the optimal allocation.

3.2 Projected global emissions compared to 2 °C

In the baseline, global emissions are projected to be 61–62 GtCO₂eq by 2030. According to UNEP (2014), the global emission level by 2030 consistent with least-cost emission

Table 1 Emission reduction targets (including land-use CO₂ emissions) by 2030 for major emitting regions resulting from a cost-effective allocation (equal carbon tax) and three effort-sharing approaches

	Equal carbon tax		Equal relative costs		CDC ^b		Historical responsibility		INDC level ^c
	IMAGE	POLES	IMAGE	POLES	IMAGE	POLES	IMAGE	POLES	
% Change relative to 2010									
EU ^a									
USA	-24	-40	-23	-35	-33		-22	-20	-29
Canada	-33	-49	-20	-38	-31		-14	-12	-30 to -32 ^d
Australia and New Zealand	-14	-31	-9	-26	-28		1	-6	-20 to -22 ^e
Japan	-17	-38	-18	-31	-35		-14	-23	-17
Russia	-17	-29	-10	-3	-37		-16	-7	+6 to +14
China	29	-6	37	25	-25		50	56	+38
India	54	12	69	88	88		80	101	+75 to +99 ^f
Indonesia	29	-39	43	-15	57		33	-33	-1 to -17
Mexico	-7	-30	-6	-26	13		3	-15	+1 to -17
Brazil	-46	-58	-12	-55	-27		-12	-25	-29
World	2	-25	9	-5	-11		14	9	
% Change relative to 2030 baseline									
EU ^a									
USA	-21	-35	-21	-35	-21		-21	-35	-35
Canada	-18	-44	-16	-39	-27		-16	-25	-25
Australia and New Zealand	-33	-54	-19	-45	-30		-13	-21	-21
Japan	-23	-39	-18	-35	-36		-9	-17	-17
Russia	-16	-37	-17	-30	-34		-12	-21	-21
China	-18	-44	-10	-23	-38		-16	-27	-27
India	-17	-43	-12	-25	-52		-4	-7	-7
Indonesia	-18	-48	-10	-13	0		-4	-7	-7
	-18	-46	-8	-25	0		-15	-41	-41

Table 1 continued

Baseline and CO ₂ MAC curves	Equal carbon tax		Equal relative costs		CDC ^b		Historical responsibility		INDC level ^c
	IMAGE	POLES	IMAGE	POLES	IMAGE	POLES	IMAGE	POLES	
Mexico	-18	-32	-16	-28	0	0	-9	-17	
Brazil	-44	-54	-9	-52	-25	-28	-9	-18	
World	-19	-42	-12	-27	-29	-35	-9	-16	

Starting point of all calculations is a domestic 40 % GHG emission reduction target below 1990 levels for the EU. The calculations are based on using as input the baselines and energy- and industry-related CO₂ MAC curves from the IMAGE and POLES models

^a The IMAGE region EU includes Western and Eastern Europe (including Norway, Switzerland, Iceland, Albania, and the former Yugoslavian states), whereas for the POLES data the EU is restricted to the EU 28 countries

^b As the CDC approach does not depend on baseline assumptions, only the reductions relative to 2010 levels harmonized to historical data are shown. The reductions based on the POLES dataset differ slightly, but only as a consequence of different 2010 emission levels, as the POLES historical data have not been harmonized to historical datasets (see Sect. 2.3)

^c Taken from Admiraal et al. (2015), Table 3.1

^d The target of the USA (26–28 % reduction relative to 2005 levels, by 2025) has been extrapolated to a 36–38 % reduction by 2030, assuming a linear pathway toward the country's long-term goal of 83 % reduction by 2050 (Admiraal et al. 2015). Relative to 2010 levels, the reduction estimated for 2030 would be 30–32 %

^e Only Australia

^f The lower end of the range represents the conditional target of the INDC of India, and the high end represents the emission level resulting from current policies (Admiraal et al. 2015)

pathways to keeping global temperature increase below 2 °C with a likely (>66 %) probability is 30–44 GtCO₂eq, with a median estimate of 42 GtCO₂eq. These pathways assume immediate climate action in all countries and sectors from 2020 onward, starting from emission levels resulting from the countries' current pledges for 2020.

With a cost-optimal allocation based on an equal carbon tax, global emissions are estimated at 36.0 GtCO₂eq (POLES baseline and CO₂ MAC curves) to 49.4 GtCO₂eq (IMAGE baseline and TIMER MAC curves; Fig. 2). This large difference is the result of (1) higher EU baseline emissions according to POLES than IMAGE, resulting in a larger EU mitigation effort under the POLES baseline, and (2) POLES assuming more potential in developing regions and less in developed regions than TIMER, at a given carbon price. Both factors result in a much higher carbon price needed to achieve the EU 2030 target under the POLES baseline and CO₂ MAC curves than under the IMAGE baseline and TIMER CO₂ MAC curves. As for all other regions the same carbon tax as the EU is applied, this results in a much lower global emission level under the POLES baseline and CO₂ MAC curves.

Under the CDC approach, projected 2030 global emission levels are within the range for a likely chance of achieving 2 °C. As this method does not depend on baseline emissions or mitigation costs, the difference between the POLES (40.0 GtCO₂eq) and IMAGE (43.2 GtCO₂eq) baseline is relatively low. CDC leads to relatively high reductions compared to the equal relative costs method because per-capita emissions of the EU are low compared with countries such as the USA, Canada, Russia, and Australia and New Zealand. As every country converges to the same per-capita emissions level, countries with high per-capita emissions need to reduce more to achieve their target, leading to a higher global reduction.

The *historical responsibility* approach leads to global emission levels above those which are consistent with 2 °C pathways. There are two major reasons for this. First of all, the EU has a relatively large share in global cumulative emissions between 1850 and 2010 and therefore this approach leads to relatively stringent targets for the EU compared to other

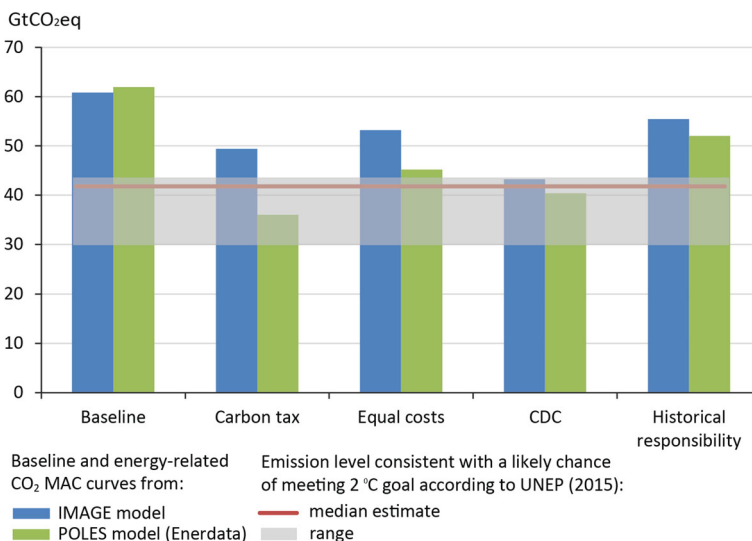


Fig. 2 Global GHG emissions by 2030 resulting from the effort-sharing approaches compared to the likely range consistent with least-cost emission pathways with a likely chance of meeting 2 °C (the latter of which based on UNEP (2015)) for the IMAGE and POLES baselines and MAC curves

approaches such as CDC (see Sect. 3.1; Table 1). Secondly, especially for the IMAGE baseline an additional explanation is that the baseline emissions of the EU are already substantially below 1990 levels by 2030, so that the deviation from baseline is relatively small. As the required reductions for the other regions not only depend on their cumulative emissions between 1850 and 2010, but also on the reduction of the EU (see Eqs. 1 and 2), all other regions also face relatively low reduction requirements.

The projected reductions under the *equal relative costs* approach strongly depend on baseline assumptions and MAC curves, for the same reasons as they did for the carbon tax. However, total reductions are less than under a carbon tax, so that under both baselines and MAC assumptions the reductions are not sufficient for achieving the reductions that are required for a 2 °C pathway, with projected global emission levels of about 45 and 53 GtCO₂eq. The reason that equal relative costs lead to higher global emission levels than a carbon tax is that the impact on mitigation costs of a given carbon tax is lower in developed countries than in developing countries, due to the higher potential being available in the latter group (Hof et al. 2009). Therefore, if in all countries the same carbon tax as the EU is applied, mitigation costs as share of GDP is (much) higher in developing countries. From this automatically follows that if all countries have the same mitigation costs as share of GDP, total emission reductions are lower.

3.3 Comparison of INDCs

Our third research question is how the “comparable” reduction targets given in Table 1 compare to the countries’ submitted INDCs. The reductions of the INDCs were based on Admiraal et al. (2015; Table 3.1). For those countries that have not specified a reduction target for 2030, such as the USA, the reduction for 2030 was estimated by assuming that long-term targets for the year 2050 will be achieved by a linear reduction pathway from the emission level resulting from the INDC (in the case of the USA, 2025). Figure 3 compares

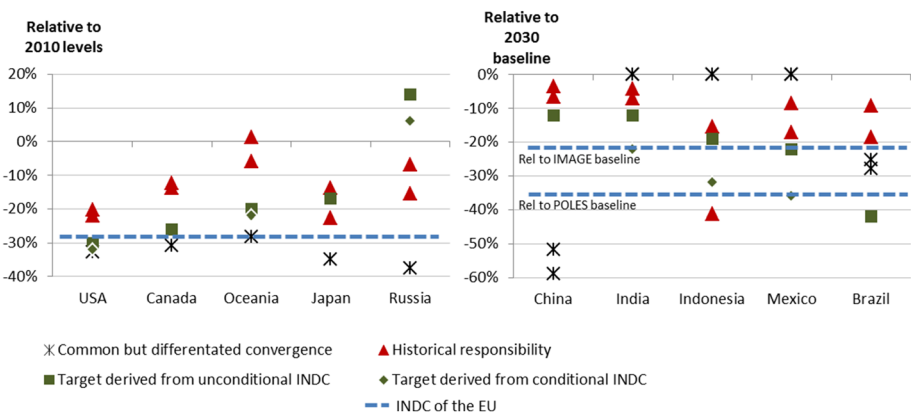


Fig. 3 Range in 2030 GHG emission reduction targets resulting from the effort-sharing approaches (Table 1) compared to derived targets for 2030 based on submitted INDCs (based on Table 3.1 of Admiraal et al. 2015), presented relative to 2010 levels for the high-income countries, and relative to IMAGE or POLES baseline for the low-income countries and emerging economies. Both the conditional and unconditional INDCs are shown for those countries that submitted both. For the effort-sharing targets, the results of the IMAGE and POLES baselines and CO₂ MAC curves are shown. The dotted blue line shows the 40 % EU target for comparison (as the IMAGE and POLES differ with respect to the EU baseline, both the reductions relative to the IMAGE and POLES baselines are shown)

the INDC targets for 2030 with the range resulting from the effort-sharing approaches CDC and historical responsibility. For the high-income countries, reductions are presented relative to 2010 emission levels, whereas for low-income countries and emerging economies, reductions are relative to 2030 baseline levels. Indonesia and Mexico submitted an unconditional and a more ambitious conditional INDC, both of which are shown in the figure. For India, we have assumed, as in Admiraal et al. (2015), that the conditional INDC includes the effects of India's greenhouse gas intensity target, non-fossil electricity target, as well as the carbon sink target. The unconditional INDC only includes the effect of the greenhouse gas intensity target, but as the latter is not limiting, the emission level resulting from current policies is shown here.

As we have deliberately chosen two effort-sharing approaches that cover the range of the political debate, the range in emission reduction targets resulting from the two effort-sharing approaches is very large for most countries. Therefore, most of the reduction efforts implied by the INDCs are within the range resulting from the effort-sharing approaches. Of the high-income countries, only Russia has submitted an INDC which is less stringent than the effort-sharing range based on the INDC of the EU. The INDCs of Canada and Oceania are relatively close to the high end of the effort-sharing range, while Japan is close to low end of the effort-sharing range.

Interestingly, of the major low-income and emerging economies included in this study, India, Mexico, and Brazil have more ambitious INDCs than what results from both effort-sharing approaches. As Mexico and India have baseline per-capita emissions which remain below the global average until 2030, the CDC approach does not imply reduction targets for these countries. Furthermore, their historical responsibility is relatively low so that both effort-sharing approaches lead to relatively low reduction targets. Moreover, the INDCs of Mexico and Brazil imply substantial reductions compared to baseline.

Comparing these results with the analysis by Climate Action Tracker (CAT, <http://climateactiontracker.org/>, as of November 19, 2015) shows some similarities, but also some differences. Most importantly, CAT calculates the reduction targets based on a wide range of effort-sharing approaches for meeting the 2 °C goal, whereas here the considered effort-sharing approaches do not necessarily meet this goal. CAT rates the INDC of the EU as “medium,” and Mexico, India, Brazil, and China receive the same rating. This is broadly in line with the results as shown by Fig. 3 and Table 1. CAT rates the INDC of Russia as inadequate, which is also in line with our results. The differences are for Japan, Australia, Canada, Indonesia, and Japan. CAT rates the INDCs of these countries as inadequate, a rating which does not immediately seems in line with our results, although a direct comparison is not possible as the CAT uses a different approach than ours. Even so, an important reason seems to be that the historical emissions of these countries in the period 1850–2010 are also relatively high, but similar to those of the EU, and therefore according to this approach the INDCs do not underperform in ambition level compared to the EU. If we would rate the INDC of the EU according to historical responsibility, we would also arrive at an inadequate rating for the EU, based on Fig. 2.

4 Discussion and conclusions

There is a large body of literature that applies effort-sharing approaches to provide insight into fair regional contributions to climate change mitigation, given a specified global climate goal. In this study, a novel approach is introduced that starts with a specified

regional target (in our case, the INDC of the EU) and applies effort-sharing to determine comparable targets for other regions. The global mitigation effort is an outcome, not a starting point, of our analysis. This approach is well suited to address the relative ambition level of INDCs. We have applied this approach to assess the fairness and ambition level of the EU's INDC, but it can also be applied to frame reduction targets of other regions. Moreover, other effort-sharing approaches could be included if countries wish to compare their INDC according to a specific effort-sharing approach.

One important caveat is that, although we have selected two effort-sharing approaches that cover the political range reasonably well (CDC and historical responsibility based on cumulative emissions between 1850 and 2010), there are other effort-sharing approaches that lead to results which are outside the range of the effort-sharing approaches which we have applied. Therefore, a broader selection of effort-sharing approaches may result in a wider range of regional targets and consequently of global emission levels resulting from these targets. This is especially the case for resource-sharing approaches that lead to surplus emission allowances or allowance levels that exceed baseline emission projections. We have, however, deliberately not taken such effort-sharing approaches into account as the aim is to assess the INDC of the EU, which only consist of a domestic emission reduction target. The possibility of emission trading is therefore excluded from the analysis.

Concluding, we have found that the INDCs of the USA, Canada, Australia, Japan, China, and Indonesia are largely comparable to the INDC of the EU, based on the range resulting from a CDC and a historical responsibility approach. The INDC of Russia seems less ambitious than the INDC of the EU. Interestingly, the INDCs of India, Mexico, and Brazil are more ambitious than the INDC of the EU, both according to a CDC and a historical responsibility effort-sharing approach. According to a CDC effort-sharing approach, the INDC of the EU could well be consistent with a 2 °C emission pathway. However, from a historical responsibility point of view, the INDC of the EU falls well short (about 10 GtCO₂ in 2030) of achieving a 2 °C emission pathway. This large difference is due to (1) relatively low and decreasing per-capita emissions of the EU, and (2) a relatively large contribution to global historical emissions. The first factor leads to relatively high reduction efforts for non-EU countries under a CDC approach, while the second factor leads to relatively low reduction efforts for non-EU countries under a historical responsibility approach.

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