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Analysis of the Copenhagen Accord pledges and its global climatic impacts—a snapshot of dissonant ambitions

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Abstract
This analysis of the Copenhagen Accord evaluates emission reduction pledges by individual countries against the Accord's climate-related objectives. Probabilistic estimates of the climatic consequences for a set of resulting multi-gas scenarios over the 21st century are calculated with a reduced complexity climate model, yielding global temperature increase and atmospheric CO_2 and CO_2-equivalent concentrations. Provisions for banked surplus emission allowances and credits from land use, land-use change and forestry are assessed and are shown to have the potential to lead to significant deterioration of the ambition levels implied by the pledges in 2020. This analysis demonstrates that the Copenhagen Accord and the pledges made under it represent a set of dissonant ambitions. The ambition level of the current pledges for 2020 and the lack of commonly agreed goals for 2050 place in peril the Accord's own ambition: to limit global warming to below 2 °C, and even more so for 1.5 °C, which is referenced in the Accord in association with potentially strengthening the long-term temperature goal in 2015. Due to the limited level of ambition by 2020, the ability to limit emissions afterwards to pathways consistent with either the 2 or 1.5 °C goal is likely to become less feasible.

Keywords: climate change, greenhouse gas emissions, global warming, climate negotiations, Copenhagen Accord

S Online supplementary data available from stacks.iop.org/ERL/5/034013/mmedia

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1. Introduction

In Copenhagen, December 2009, representatives of 193 governments gathered at the 15th session of the Conference of the Parties (COP15) of the United Nations Framework Convention on Climate Change (UNFCCC, henceforth also called 'the Convention') and the 5th session of the Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol (CMP5); about 120 of them were represented by Heads of State. Work initiated in Bali in 2007, with the aim to urgently enhance the implementation of the Convention in order to prevent dangerous anthropogenic interference with the climate system (UNFCCC 2007), was to be completed at COP15. In the end, the conference resulted in the 'Copenhagen Accord' (henceforth called 'the Accord') (UNFCCC 2009d), which was negotiated as part of a closed negotiating segment by 26 nations. Not reflecting the ambitions of, or involving, many of the Parties, it was only 'taken note of' by the Conference of the Parties. The total number of Parties that have expressed their intention to be associated with the Accord is 138 (information as of 19 August 2010). Additionally, decisions were made to continue negotiations under both the Convention (UNFCCC 2009c) and the Kyoto Protocol (KP, henceforth also called 'the Protocol') (UNFCCC 2009b) tracks until the end of 2010. The UNFCCC Secretariat clarified that the provisions of the Accord do not have any legal standing within the UNFCCC process (UNFCCC 2010f). Although its significance as a political agreement is disputed among Parties, it cannot be neglected as it is framing the ongoing negotiations towards a global agreement.

In the Accord, Parties '[· · ·] agree that deep cuts in global emissions are required according to science, [· · ·] with a view to reduce global emissions so as to hold the increase in global temperature below 2 °C' and hereby preventing 'dangerous anthropogenic interference with the climate system'. 1.5 °C is referenced in the Accord in association with potentially strengthening the long-term temperature goal based on 'various matters presented by the science' in 2015. Tables for individual country mitigation pledges were left empty in the Accord. By the end of August 2010, 85 countries from both developed and developing countries had submitted pledges. The final version of the Accord does not include long-term reduction goals, such as a global reduction target for 2050. Global targets of −50% from 1990 levels by 2050 and an aggregate developed country target of at least −80% by 2050 were present in informal drafts that circulated until a few hours before the conclusion of the negotiations, and are also part of current negotiation texts in preparation for COP16 (as of August 2010) (UNFCCC 2010b).

Here, we analyse the Accord with the pledges as they were communicated to the UNFCCC by mid-April 2010 (UNFCCC 2010d, 2010e). The focus of our analysis is the extent to which these pledges bridge the gap from current policy to what is needed to achieve the Accord's climate-related objectives. Many groups have already carried out analyses to assess the emission levels resulting from the Accord (Climate Analytics and Ecofys 2010, Climate Interactive 2010, den Elzen *et al* 2010a, European Commission 2010, Levin and Bradley 2010, Macintosh 2010, Stern 2009, UNEP 2010), but the analysis presented here is one of the few—besides the analysis of Climate Analytics and Ecofys (2010) and den Elzen *et al* (2010a)—that considers specific provisions, such as the banking of surplus emission allowances, and debits and credits resulting from land use, land-use change and forestry (LULUCF) accounting, that can deteriorate the level of ambition for emission reductions in 2020. Additionally, we perform individual probabilistic multi-gas climate runs for each emission pathway, not present in other analyses in the literature. This analysis builds on and provides an extension of our earlier work (Rogelj *et al* 2010).

2. Methods

The global climatic consequences of the Accord are assessed against a set of scenarios. Two options for 2020 (case 1 and case 2) are constructed based on the range of pledges and actions submitted to the Accord. To calculate emission levels in 2020, a bottom-up approach is applied with the emission module of the Potsdam Integrated Model for Probabilistic Assessment of Emission Paths (PRIMAP) (Nabel *et al* 2010b). Emissions are reduced (see tables S1 and S3 in the supplementary data available at stacks.iop.org/ERL/5/034013/mmedia for an overview of the considered mitigation actions) from a composite reference pathway which incorporates policy in place[9] before COP15/CMP5. When no targets or actions are available for a country, the pre-defined reference pathway is assumed. Emissions are extended beyond 2020 assuming either further growth or a 2050 global reduction target. For calculations of the climatic consequences, a probabilistic approach with the reduced complexity climate model MAGICC (Meinshausen *et al* 2008) is used, with model parameters closely representing estimates of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2007b).

2.1. Reference pathway

A reference pathway which accurately represents past emission levels as reported by Parties is paramount to calculate target levels that are defined as a percentage below a particular base year level. Analogously, target levels which are defined as a deviation from a certain baseline require country projections. Therefore, a comprehensive composite reference scenario (further referred to as the PRIMAP4 scenario) was constructed for all parties. Targets are often defined on the so-called Kyoto greenhouse gas (GHG) basket and not on single GHGs. The Kyoto-GHG basket includes carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). To construct the CO_2-equivalent (CO_2eq) Kyoto-GHG basket, the global warming potentials (GWP) that are used under the Protocol for reporting purposes (UNFCCC 1997b) as well as under the Convention (UNFCCC 2002) are used. These GWPs

[9] In accordance with the assumptions made in the International Energy Agency's (IEA) World Energy Outlook (IEA 2009). For example the 20% pledge of the European Union (EU) was already in place before COP15/CMP5 as part of the European Climate and Energy Package and is therefore included in the reference pathway.

are those specified in the Second Assessment Report of the IPCC (IPCC 1996).

This PRIMAP4 reference scenario with annual country resolution is constructed as a composite pathway. A detailed description of the methodology can be found in Nabel *et al* (2010b). The PRIMAP4 scenario is based on the following emission data sources in descending order of prioritization: (1) National Inventory Submissions to the UNFCCC (UNFCCC 2009a) as submitted by Parties. Only Annex I countries[10] have the obligation to provide these annual submissions. For Non-Annex I countries, data from (2) National Communications to the UNFCCC (UNFCCC 2009e) are considered. These two reported historical data sources are complemented with (3) historical data from the Carbon Dioxide Information Analysis Centre (CDIAC) for CO_2 from fossil fuel and cement (Boden *et al* 2009) and (4) historical data from the Emission Database for Global Atmospheric Research (EDGAR) for CH_4 and N_2O (JRC and PBL 2009). For future projections, emissions from (5) the International Energy Agency's (IEA) World Energy Outlook (IEA 2009), (6) the Prospective Outlook on Long-term Energy Systems (POLES) model (ENERDATA 2009) and (7) the downscaled composite scenario based on the SRESA1B pathway developed in the framework of the ad hoc group for the Modelling and Assessment of Contributions of Climate Change (MATCH) are used (Höhne *et al* 2010). To complement the MATCH pathways for fluorinated gases (HFCs, PFCs and SF_6), (8) the downscaled SRESA1B pathway of the Netherlands Environmental Assessment Agency was used (van Vuuren *et al* 2006).

For international shipping, historical data provided by the International Maritime Organization (IMO) (Buhaug *et al* 2009) is combined with IMO's best estimate of the SRESA1B scenario. For international aviation, historical emission and projection data (Owen *et al* 2010) is completed with future trend data from the OMEGA project (Meinshausen and Raper 2009).

The data underlying the calculations on LULUCF accounting are based on the KP LULUCF activities calculated by using proxies developed from the LULUCF sectoral data reported in national inventories to the UNFCCC. A detailed description of the LULUCF activity reference data is provided online (Nabel *et al* 2010a).

2.2. Emissions assessment

The PRIMAP4 scenario described above is the starting point for a bottom-up assessment of the emission implications of the Accord. Many Parties provided a range of emission targets with the more ambitious end being conditional, for example, upon a global comprehensive agreement or access to financing. The two ends of the ambition range lead to our cases for 2020: 'case 1' applies the low ambition and 'case 2' the high ambition options. Our assessment is based on the international pledges of Parties in the framework of the Accord only, although in some cases (e.g. China) some interpretations of national climate plans could be more ambitious than the international pledge of a Party.

2.2.1. Developed countries. The emission levels in 2020 for developed countries are calculated by applying the emission reduction percentages of their pledges to their respective base year emissions. On top of these reduction pledges, various provisions from the Protocol are considered. Developed countries, for which land-use change and forestry was a net source in 1990, fall under the provisions of article 3.7 of the Protocol (UNFCCC 1997a). This paragraph states that countries shall add their emissions from land-use change to their base year emissions from which the allowed emissions in the respective commitment period are calculated. Specifically, this provision is assumed for the 2000 reference year for Australia's 2020 pledge under the Accord. Once emission levels based on the pledges are calculated, credits from LULUCF accounting and surplus allowances are added.

LULUCF accounting in developed countries can generate emission credits or debits which influence the final allowances of countries for their industrial, fossil and agricultural emissions. The Accord did not address this issue. The rules for the first KP commitment period (CP1) are described in the Protocol and the Marrakesh Accords (UNFCCC 2001). Under article 3.3 of the Protocol, individual countries must account for GHG fluxes from afforestation, reforestation, and deforestation, and under article 3.4 they can choose additional activities to account for. Those additional activities are forest management, cropland management, grazing-land management and revegetation. Debits or credits from forest management activities are subject to a country-specific cap, listed in the appendix to the Annex of Decision 16/CMP.1 (UNFCCC 2005). Setting the size of the cap for each country was informed by 3% of the base year emissions and 15% of the forest management sector. Continuation of the same rules but with forest management accounting made mandatory would likely result in net credits of 0.3 gigatonnes CO_2eq ($GtCO_2$eq) per year from 2013 to 2020. For illustration, we assume that the cap on forest management is increased to 4% of 1990 emissions as a proxy for the lower ambition options currently discussed, for example introducing exception clauses for not having to account for so-called natural disturbances (UNFCCC 2010a). Our LULUCF accounting assumption leads to yearly allowances of 0.5 $GtCO_2$eq for the group of developed countries which specified to use LULUCF accounting to achieve their target in communications prior to the Accord (UNFCCC 2010a). As no post-2012 LULUCF accounting rules have been agreed, there is clearly some uncertainty in regard to the final net effect. These LULUCF allowances are included in case 1, while in case 2 we assume LULUCF accounting to result in a net zero effect. For case 1, target emissions of a country pledge 'including LULUCF' will be increased by credits from LULUCF accounting and vice versa for debits.

Furthermore, if a developed country reaches emission levels which are below its initially attributed assigned amount units (AAUs) in CP1, the difference between the real emission

[10] So-called Annex I countries are listed in Annex I of the UNFCCC (UNFCCC 1992), see the supplementary data (available at stacks.iop.org/ERL/5/034013/mmedia).

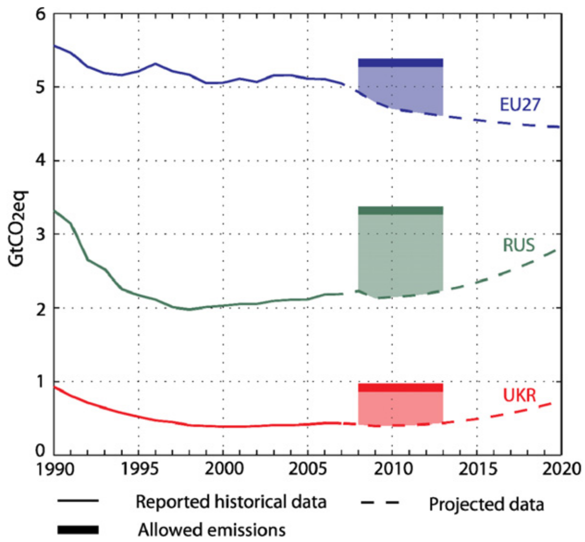

Figure 1. Illustration of estimation of surplus assigned amount units (AAUs) for Ukraine (UKR), the Russian Federation (RUS) and the European Union (EU27). Reported data to the UNFCCC is plotted as thin solid lines up to 2007. The dashed line shows the projections of the PRIMAP4 reference scenario and case 1 targets without provisions for 2020. The thick solid line segments between 2008 and 2012 show the emission allowances under the Kyoto Protocol for each respective country. The coloured area under the thick line segments hence represents the estimated surplus emissions allowances for the first commitment period of the Kyoto Protocol for each country.

and their allowances can be banked as surplus AAUs to be used in subsequent commitment periods under the provisions specified in article 3.13 of the Protocol. Because of weak CP1 targets and due to the economic slowdown after the collapse of the Soviet Union, the emissions of some countries with economies in transition are well below their AAUs. This is particularly the case for Russia (5.6 $GtCO_2eq$), Ukraine (2.5 $GtCO_2eq$) and other countries in Eastern Europe which are now part of the European Union (2.8 $GtCO_2eq$) (see figure 1). The Accord does not address these estimated 11 $GtCO_2eq$ of surplus AAUs. Credits from LULUCF accounting (RMUs) cannot be banked (UNFCCC 2001). RMUs, however, can be used domestically or traded in CP1 by countries already having surplus AAUs and therefore still result in 1.0 $GtCO_2eq$ of additional surplus allowances. This yields a total of 12 $GtCO_2eq$ surplus AAUs banked from CP1 to subsequent commitment periods. Depending on the quantitative emission reduction or limitation commitments (UNFCCC 2010c) Parties negotiate for after 2012, additional surplus AAUs are estimated in the range of 2–12 $GtCO_2eq$. In our case 1, the banked AAUs from CP1 are added on top of the pledged pathways as a linearly increasing wedge, shown in figure 2(a), while surplus generated after 2012 is used after 2020. Case 2 assumes that Parties agree to not purchase banked AAUs from CP1 but at the same time allows for the generation and use of about 2 $GtCO_2eq$ of new surplus AAUs after 2012.

2.2.2. Developing countries. In contrast to the relatively precise pledges of developed countries, developing countries specify their mitigation actions, labelled as Nationally Appropriate Mitigation Actions (NAMAs), in a plethora of ways. A common method to specify developing countries' actions is in terms of reductions from an implied, but often unspecified, future 'business-as-usual' scenario. Also, some proposed actions are framed in terms of emission intensity improvements, i.e. a decrease of emissions per gross domestic product (GDP). For example, China proposed a decrease of 40–45% in their CO_2 emission intensity from 2005 to 2020. This could amount to slightly higher or lower intensity improvements than projected in the reference scenario, e.g. 40% is projected as emission intensity improvement in the reference case by IEA based on World Bank GDP-Purchasing Power Parity projections (IEA 2009). For China, we quantified the most encompassing of the stated pledges, i.e. the CO_2 intensity improvement target, but not the partially overlapping renewable energy and reforestation pledges. Only countries with quantitative descriptions in their NAMAs are included in this analysis. Emission reductions occurring in the land-use sector are treated separately (cf below).

2.2.3. International shipping and aviation. Besides national emissions, the emission contribution from international bunkers is also calculated to obtain the global total. Emissions from international shipping and aviation are not addressed by the Accord. Therefore we apply the announcements by the respective industry association (ICS 2009) and the specialized agency of the United Nations (ICAO 2009), recognizing that at this stage there is no clear indication of if or how these are to be achieved in practice.

2.2.4. Global land-use emissions. Because of the large uncertainties in the data for land use and land-use change emissions provided in the National Communications of developing countries, global pathways of deforestation are based on those developed in the framework of the representative concentration pathways (RCP) for the IPCC Fifth Assessment Report process. As reference pathway, we assume the global harmonized RCP8.5 pathway (Riahi *et al* 2007). From this global pathway the announced deforestation reduction ranges from Brazil, Indonesia and other countries are subtracted such that case 1 and case 2 global deforestation pathways are created.

2.2.5. Emission extensions beyond 2020. The Accord only specifies pledges for 2020. As the global climatic assessment strongly depends on what happens after 2020, two different extensions of the emission pathway beyond 2020 were developed. The 'reference growth' case allows emissions to grow further according to the growth rates found in the PRIMAP4 scenario if no 2050 targets from before the Accord were available. The 'global 2050 target' variants halve the global Kyoto-GHG basket of emissions by 2050 from 1990 levels, and emissions continue to decrease after 2050 with an exponential decrease at a rate equal to the average reduction rate in the last decade before 2050. The pathways resulting from these two variants are depicted in figure 2(a).

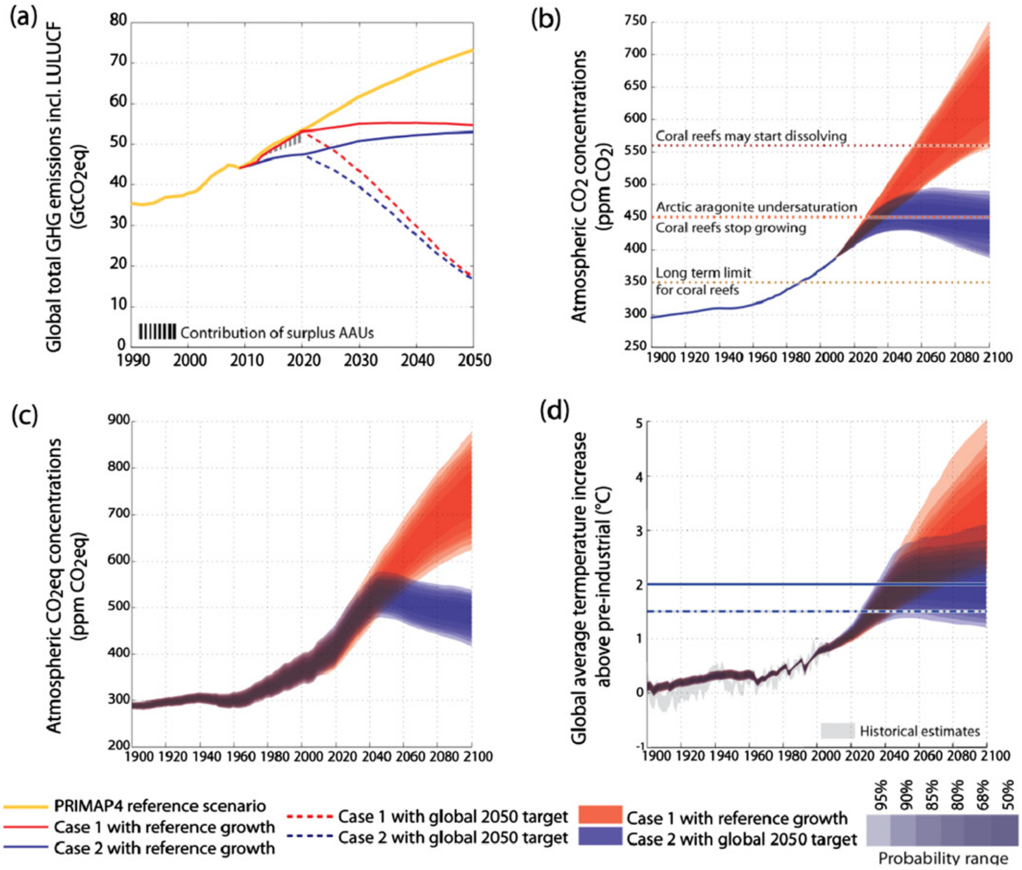

Figure 2. Overview of emission pathways and their climatic consequences. (a) Global emission pathways of the PRIMAP4 reference scenario (yellow line), the case 1 (blue line) and case 2 (red line) interpretation of Copenhagen Accord pledges for 2020. The shaded area shows the contribution of banked surplus emission allowances. The dashed lines show the emission pathways with a global 2050 target being halving global emissions by 2050 from 1990 levels. Climatic consequences are shown for case 1 with reference growth (solid red line) and case 2 with a long-term target (dashed blue line). (b) Probability ranges for atmospheric CO_2 concentrations with thresholds due to ocean acidification (McNeil and Matear 2008, Silverman *et al* 2009, Steinacher *et al* 2009, Veron *et al* 2009). (c) Atmospheric CO_2eq concentrations. (d) Probability ranges for global temperature increase above pre-industrial with 1.5 and 2 °C thresholds. Historical temperature data estimates from Brohan *et al* (2006).

2.3. Climatic assessment

Global climatic consequences (temperature, CO_2 and CO_2eq concentrations) are calculated with the PRIMAP climate module. To calculate the climatic consequences of each global scenario, emissions of GHGs, tropospheric ozone precursors and aerosols are generated by building on the multi-gas characteristics within a large set of IPCC scenarios (Nakicenovic and Swart 2000), using the Equal Quantile Walk method (Meinshausen *et al* 2006). Subsequently, these emissions are run through the reduced complexity coupled carbon cycle climate model MAGICC6.3 (Meinshausen *et al* 2008) to obtain future concentrations and temperature probability distributions. Each resulting emission pathway is run with 600 different sets of climate model parameters as in the 'illustrative default' case in (Meinshausen *et al* 2009) and with a distribution of the climate sensitivity closely representing IPCC AR4 estimates (IPCC 2007b). Before being used as input to the climate model, the global bottom-up pathway is harmonized to historical emission levels in 2000 in accordance with the IPCC scenarios of the Special Report on Emission Scenarios (SRES) (Nakicenovic and Swart 2000).

3. Results, discussion and conclusion

3.1. Resulting 2020 emission levels

Global aggregate emission levels for the case 1 and case 2 interpretation of the Accord are 53.2 and 47.4 $GtCO_2$eq in 2020, respectively, as summarized with other results in table 1. Furthermore, case 1 yields emissions in 2020 which are virtually equal to the emissions of the PRIMAP4 scenario. This illustrates that the net effect of current Accord pledges in case 1 would globally not stimulate any actions beyond those which were already in place before COP15/CMP5, if countries would pool or freely exchange their emission allowances. Figure 2(a) shows the calculated pathways.

Aggregate emission allowances of developed countries in 2020 are 19.9 and 15.7 $GtCO_2$eq, or 6.5% above and 15.7% below 1990 levels in case 1 and 2, respectively. Other analyses, for example by the European Commission (2010), yield deeper aggregate reduction percentages for developed countries in their most ambitious cases. The main reason for this is that—for comparison with IPCC ranges—we consider the developed

Table 1. Characteristics of four analysed pathways.

	Case 1 Post-2020 reference growth	Case 2 Post-2020 reference growth	Case 2 Global 2050 target	Illustrative '2 °C compliant'
2020 emissions ($GtCO_2eq$)				
Global	53.2	47.4	47.4	40.3
Annex I	19.9	15.7	15.7	13.1
Non-Annex I	29.0	28.2	28.2	24.4
Land-use CO_2	2.5	1.8	1.8	1.2
Int. transport	1.9	1.8	1.8	1.6
2050 emissions ($GtCO_2eq$)				
Global	54.7	53.1	17	17
Annex I	6.4[a]	6.4[a]	N/A[b]	N/A[b]
Non-Annex I	45.3	44.2	N/A[b]	N/A[b]
Land-use CO_2	1.6	1.1	1.1	0.9
Int. transport	1.4	1.4	0.6	0.6
2100 emissions ($GtCO_2eq$)				
Global	43	42	1	3
Cumulative emissions from 2000 to 2050 (total emissions) ($GtCO_2eq$)				
Global	2776	2638	2080	1792
Average 2020–2050 reduction rate (emissions excl. LULUCF)				
Global	No reduction	No reduction	3.0%	2.3%
2100 CO_2 concentrations (ppm CO_2)				
Median estimate	650	636	448	431
Likely (80%) range	568–714	558–697	408–475	395–456
2100 CO_2eq concentrations (ppm CO_2eq)				
Median estimate	748	730	484	465
Likely (80%) range	659–838	644–813	439–525	425–501
Maximal 21st century temperatures above pre-industrial				
Median estimate (°C)	3.3	3.2	2.0	1.8
Likely (80%) range (°C)	2.5–4.2	2.4–4.1	1.5–2.6	1.4–2.4
Probability > 1.5 °C	100%	100%	93%	84%
Probability > 2 °C	$>$99%	$>$99%	49%	37%
Probability > 3 °C	64%	60%	3%	2%

[a] 2050 targets by Annex I Parties communicated prior to the Copenhagen Accord are taken into account (see the supplementary data available at stacks.iop.org/ERL/5/034013/mmedia).

[b] Because for this pathway no assumptions are made about the share of emission reductions by either Annex I or Non-Annex I Parties in 2050, only the global value is relevant for this exercise.

countries' group to consist of all countries listed in Annex I of the UNFCCC (UNFCCC 1992), i.e. including Turkey[11].

Looking at the individual developed countries' results reveals weak ambition levels. The European Union's target is a reduction of 20 or 30% below 1990 levels. Smaller annual reductions from now to 2020 would be required to achieve the 20% target, than the average reductions from 1980 to 2010 (−0.51% and −0.65% p.a. relative to 2000 levels, respectively). The United States' target is 17% below 2005, equivalent to only 3% below 1990 levels. Canada aligned itself with the USA target which results in an effective target of 3% above 1990 levels. Canada's proposed 2020 emission allowances would be above its current KP target (6% below 1990 levels), making Canada the only country weakening its ambition level following the Accord. Targets for Russia, Ukraine and Belarus still imply emission levels above projected PRIMAP4 levels, generating additional so-called 'hot air'. Pledges of two developed countries have significantly higher ambitions: Japan and Norway with 25%, and 30%–40% below 1990, respectively. Ultimately, even the optimistic interpretation of the Accord's pledges results in effective reductions by 2020 far outside the 25–40% range of aggregated emission reductions for developed countries specified in Box 13.7 of IPCC AR4 (IPCC 2007a). That box provided data for the lowest category of analysed mitigation scenarios which stabilize atmospheric CO_2eq concentrations between 445 and 490 ppm CO_2eq and have a best estimate global temperature increase of 2.0–2.4 °C at equilibrium.

Our assessment of developing countries' actions in 2020 results in aggregate emissions of 29.0 and 28.2 $GtCO_2eq$, for case 1 and 2, respectively. These emission levels are excluding deforestation-related emissions, as they are treated separately (cf below). The quantified reductions reflect deviations below the PRIMAP4 reference scenario of 5 and 7% respectively.

[11] Turkey is listed in Annex I of the Convention, but did not take up commitments under the KP and thus is not listed in Annex B of the Protocol. Moreover, Turkey so far did not submit a pledge to the Copenhagen Accord and thus its reference path is used. We choose to include Turkey in the Annex I aggregate to assure consistency with IPCC ranges for Annex I.

These percentages are not directly comparable with the IPCC AR4, as only a 'substantial deviation' was specified in Box 13.7 of the AR4 (IPCC 2007a). A quantification of this 'substantial deviation from baseline' has been attempted by den Elzen and Höhne (2008, 2010) and resulted in a rough range of 15–30% deviation below 'the baseline' in 2020. A strict comparison with the latter range is not possible due to the lack of absolute emission levels to compare with. As the NAMAs analysed here represent about 68% of total projected developing country emissions in 2020, they appear to be a good proxy for estimating the overall aggregate level of ambition for developing countries. Whilst there are uncertainties in the projections of developing country emissions, by building on data which is officially reported by Parties, this analysis has tried to be closely aligned with actual Party intentions as expressed under the Accord.

The international transport sector's contribution to the global 2020 emission level is 1.9 GtCO_2eq in case 1, with 1.1 GtCO_2eq from international shipping and 0.7 GtCO_2eq from international aviation. In case 2, lower shipping emissions reduce the contribution of the international transport sector to 1.8 GtCO_2eq.

The influence of the Accord's pledges on land-use-related emissions in 2020 is assessed globally. Case 1 yields global land-use emissions of 2.5 GtCO_2eq. This results from our reference level emissions in 2020 of 3.3 GtCO_2eq lowered by the less ambitious end of the REDD-related (reducing emissions from deforestation and forest degradation) pledges. In case 2, net emissions are 1.8 GtCO_2eq. The latter level might actually be too optimistic, as discussed below.

If nations would agree to a 50% reduction by 2050 from 1990 levels, then global industrial emissions will need to decline on average 3.0–3.5% (compared to 2000 levels) in each year between 2020 and 2050 for case 1 and 2 respectively. Such reductions would require unprecedented political will to incentivize the necessary technological and economic innovation and can be regarded as extreme based on current scenario literature (den Elzen *et al* 2010b). It should also be pointed out, that a 50% reduction from 1990 levels by 2050 is considerably more ambitious than the same reduction relative to e.g. 2005 levels, as global emissions rose by 21% between 1990 and 2005.

Uncertainties are an inherent part of global emission assessments. For example, even inventories for historical emissions (Boden *et al* 2009, IEA 2009, IPCC 2007a, JRC and PBL 2009) have uncertainty ranges of ±10% for fossil and industrial CO_2 emissions and up to ±75% for CO_2 emissions from land-use. The latter uncertainty range is still without taking into account recent re-estimates for peat-fire (van der Werf *et al* 2010) and peat-degradation (Hooijer *et al* 2010) emissions. The uncertainty range for the results of this analysis is at least as large as the uncertainties in historical emissions, and is further increased by the uncertainties in the quantification of future action and compliance.

3.2. Climatic impacts

Case 1 with reference growth after 2020 results in a likely global temperature increase of 2.5–4.2 °C above pre-industrial in 2100 and is still increasing afterwards. For the 'likely' range we assume an 80% range around the median, corresponding to the IPCC's 'likely' definition of 66%–90% (IPCC 2005). Using the same IPCC uncertainty definitions, 2 °C is exceeded with virtual certainty (>99% chance) as illustrated in figure 2(d). Therefore this scenario is not in line with the Accord's aim to limit the global temperature increase to 2 °C. Case 2 with reference growth yields very similar results because of the high cumulative emissions between 2000 and 2050 implied by the emission trajectory (Meinshausen *et al* 2009). A scenario with case 2 emission levels in 2020 and a global 2050 target of 50% below 1990 levels results in a likely range of 1.5–2.6 °C of maximal 21st century global temperature increase and a 49% chance to stay below 2 °C. Probability plots of the climatic results for case 1 with reference growth and case 2 with a global 2050 target are shown in figures 2(b)–(d).

Rising global average temperature levels are not the only possible 'dangerous anthropogenic interference with the climate system'. For example, increasing atmospheric CO_2 levels cause increasing ocean acidification and will adversely impact marine ecosystems (Doney *et al* 2009, Hoegh-Guldberg and Bruno 2010). A recent study (Veron *et al* 2009) defines an atmospheric CO_2 concentration of below 350 ppm CO_2 as a long-term safe limit needed for coral reefs, while a CO_2 concentration of 450 ppm CO_2 would cause reefs to be in rapid and terminal decline. Silverman *et al* (2009) indicate furthermore that coral reefs cease to grow and start dissolving at 560 ppm CO_2. Both in Arctic (Steinacher *et al* 2009) and Antarctic (McNeil and Matear 2008) oceans, aragonite undersaturation—causing calcium carbonate shells beginning to dissolve—is projected to occur at atmospheric concentration levels of 450 ppm CO_2. For case 1 and without a 2050 target, median estimates would exceed the 450 ppm CO_2 threshold in approximately 2030. The 560 ppm CO_2 threshold is very likely exceeded by the end of this century. Even for case 2 (with a global 2050 target and exponential decline afterwards), estimated likely CO_2 levels (408–475 ppm CO_2) would imply a rapid decline of coral reefs and arctic aragonite undersaturation during the 21st century. Continuous mitigation effort through the entire century and beyond will be necessary to return atmospheric CO_2 concentrations to a level considered safe for marine ecosystems.

When looking at the range of analyses of the Accord (cf above), estimated 2020 emission levels are in broad agreement. However, in some cases, emissions of 48 GtCO_2eq or higher in 2020 are interpreted as congruent with being '2 °C compliant' (Bowen and Ranger 2009, Stern 2009, UNEP 2010). Such pathways often rely on ambitious global emission reduction rates e.g. 5% yearly from 2021 to 2030. Although not impossible nor strictly infeasible, global annual reduction rates of 5% in the decade after 2020 would require far reaching policy interventions in the coming years to motivate key investments.

Thus, we investigate a fourth illustrative scenario (see table 1), which we label '2 °C compliant'. Following the assessment of Box 13.7 of the AR4 (IPCC 2007a), we apply an aggregate developed country reduction of 30% below 1990 levels and a 'substantial deviation from baseline' of 20% for developing countries to the PRIMAP4 scenario. Global land-use CO_2 emissions are taken from RCP4.5 (Clarke *et al* 2007, Smith and Wigley 2006, Wise *et al* 2009). This results in global emission levels of 40–44 $GtCO_2$eq in 2020, depending on the baseline (the global PRIMAP4 reference scenario is rather low). These 2020 emission levels would limit the decline of global industrial emissions on average to below 2.3% (compared to 2000 levels) in each year between 2020 and 2050—if keeping the goal of halving global emissions from 1990 to 2050. In order to reach this 2050 milestone, starting from 2020 emission levels of 44 $GtCO_2$eq or higher would imply reduction rates that are sometimes considered extreme based on the current scenario literature (den Elzen *et al* 2010b).

As the Accord has no legally binding character, parties can add, modify or withdraw their submitted pledges or actions without any restriction. Since mid-April—the moment the snapshot of mitigation actions for this study was taken—several parties have done so. As a positive example, additional actions were submitted by Papua New Guinea, Moldova, Mauritania and others. Most of these actions are unfortunately not quantifiable because of a lack of quantitative details in the submissions. A clear assessment with respect to the global PRIMAP4 pathway is therefore not possible. For Indonesia, an increased reduction in deforestation was assumed for case 2. As this reduction, which is conditional on international support, was not part of their submission, the current deforestation pathway might show an overly optimistic picture for the Accord's outcome. For our analysis, these changes in the pledges will slightly change the aggregate emission numbers, but not the key results of our analysis.

3.3. Conclusion

If the average national ambition level for 2020 is not substantially improved and loopholes closed in the continued negotiations, only low probability options remain for reaching the 2 °C (and possible 1.5 °C) ambition of the Accord. Most developed country submissions to the Accord indicate that only with a global and comprehensive agreement countries are inclined to commit to more, and likewise for developing countries the required level of support through financing, technology and capacity building is needed. With the negotiation mandates having been extended to the end of 2010, committing to higher ambitions and agreement by all Parties still remains possible. It is clear from this analysis that higher ambitions for 2020 are necessary to keep the options for 2 and 1.5 °C open without relying on potentially infeasible reduction rates after 2020. In addition, the absence of a mid-century emission goal—towards which Parties as a whole can work and which can serve as a yardstick of whether interim reductions by 2020 and 2030 are on the right track—is a critical deficit in the overall ambition level of the Copenhagen Accord.

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