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The Copenhagen Accord: abatement costs and carbon prices resulting from the submissions

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ABSTRACT

As part of the Copenhagen Accord, individual countries have submitted greenhouse gas reduction proposals for the year 2020. This paper analyses the implications for emission reductions, the carbon price, and abatement costs of these submissions. The submissions of the Annex I (industrialised) countries are estimated to lead to a total reduction target of 12–18% below 1990 levels. The submissions of the seven major emerging economies are estimated to lead to an 11–14% reduction below baseline emissions, depending on international (financial) support. Global abatement costs in 2020 are estimated at about USD 60–100 billion, assuming that at least two-thirds of Annex I emission reduction targets need to be achieved domestically. The largest share of these costs are incurred by Annex I countries, although the costs as share of GDP are similar for Annex I as a group and the seven emerging economies as a group, even when assuming substantial international transfers from Annex I countries to the emerging economies to finance their abatement costs. If the restriction of achieving two-thirds of the emission reduction target domestically is abandoned, it would more than double the international carbon price and at the same time reduce global abatement costs by almost 25%.

1. Introduction

The 2009 United Nations Climate Change Conference, commonly known as the Copenhagen Summit, marked the culmination of two years of negotiations in the context of the United Nations Framework Convention on Climate Change (UNFCCC) and the Bali Action Plan.[1] The negotiations aimed to create a comprehensive, legally binding international treaty to replace the Kyoto Protocol, which expires in 2012. Although the final Copenhagen Accord[2] was agreed upon by a large number of countries, the summit did not result in legally binding reduction targets for greenhouse gas emissions. Also several other important issues could not be settled, such as quantified goals for emission reduction from deforestation and forest degradation (REDD) and clear agreements on financial support for adaptation and mitigation measures in developing countries. For reducing emissions, a voluntary approach for setting targets

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[1] Adopted at the Conference of the Parties to the UNFCCC of December 2007 (http://unfccc.int/files/meetings/cop_13/application/pdf/cp_bali_action.pdf).

[2] More than 135 parties (including the EU and its Member States) have officially expressed their support for the Copenhagen Accord (www.unfcc.int). The countries that support the accord represent more than 85% of global GHG emissions.

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has been agreed. Annex I Parties[3] were invited to commit to emission reduction targets – pledges – for 2020 and Non-Annex I Parties (developing countries) to commit to mitigation actions. Parties were requested to submit these targets and actions to the UNFCCC Secretariat by 31 January 2010.

At this moment of time, many Annex I and Non-Annex I Parties have submitted reduction pledges and action plans for 2020. However, it is not easy to determine the effect of these pledges and actions on total emission reductions. Annex I countries have defined reduction targets relative to different base years and differ with regard to the use of offsets. Non-Annex I countries often use different formulations of action plans.

In this context, this paper assesses the contribution to climate change mitigation of the pledges submitted by all Annex I Parties and the mitigation action plans of the seven major emerging economies (China, India, Brazil, Indonesia, Mexico, South Africa and South Korea). Our analysis focuses on the following policy questions:

- What are the reduction contributions of the submissions to the Copenhagen Accord of Annex I countries and of seven major emerging economies? (Section 2)
- What are the abatement costs for Annex I and Non-Annex I countries? Who are the buyers and sellers of carbon credits and what is the price of these credits[4]? (Section 3)
- How sensitive are the above results to different developments in emissions trading and land use and forestry rules? (Section 4)

The calculations in this paper are mostly based on the FAIR model (den Elzen et al., 2008, 2010a), which was used in conjunction with the IMAGE land use model (Bouwman et al., 2006) and TIMER energy model (van Vuuren et al., 2007). The IMAGE and TIMER model provided the emissions baselines for calculating the reductions from the action plans of the major Non-Annex I countries as well information on the costs of emission reduction (see supporting information (SI) text).

2. Reduction implications of the Copenhagen Accord submissions

2.1. *Submissions of Annex I countries*

Most Annex I countries have formally submitted their emission reduction targets for 2020 to the Copenhagen Accord.[5] These submissions largely reflect national positions set out in the last year. Some countries have submitted both a high pledge that is conditional on a high level of ambition from other countries or domestic legislation (see the UNFCCC website for details on the conditions), and a low pledge that is unconditional. Therefore, we include both a low pledge scenario (all countries implement their low pledge) and a high pledge scenario (all countries implement their high pledge) in our analysis. For countries that have made a conditional pledge only, such as Canada, Japan and the USA, we have assumed that this pledge is valid for both the low and high pledge situation. The emission reduction targets against 1990 emission levels and baseline for the main Annex I regions are presented in Table 1.

The aggregated reduction target for 2020 of all Annex I pledges is 12% for the low pledge scenario and 18% for the high pledge scenario, relative to the 1990 level, for all greenhouse gas emissions excluding land use CO_2 (whereas according to the IPCC 25–40% below 1990 levels is needed for meeting the long-term 2 °C climate target specified in the Copenhagen Accord). Table 1 also presents the reduction target below the baseline used in this study, as this is a better indication of the required reduction effort. The reduction targets in Table 1 are very similar to those of other studies (European Climate Foundation, 2010; Climate Action Tracker: www.climateactiontracker.org; Stern and Taylor, 2010).

There are several major uncertainties that can strongly influence the emission reductions resulting from the Annex I pledges. These relate to the contingency of the pledges, the land use, land-use change and forestry (LULUCF) rules, the use of surplus assigned amount units (AAUs) and the potential double-counting of offsets. The SI elaborates further on these uncertainties. Here we briefly discuss the uncertainties about LULUCF rules and use of surplus AAUs, as analysed in the sensitivity analysis in Section 4.

The LULUCF rules for the current Kyoto commitment period state that individual countries should account the greenhouse gas fluxes from afforestation/reforestation and deforestation (ARD), and can choose to include also forest management (FM) (with a cap on accruing emissions allowances), cropland management, grazing-land management and re-vegetation. The rules for the post-2012 commitment period, however, are still under negotiation. Some countries have indicated whether their targets include or exclude debits and credits accounting for land use and forestry, but others are vague on this point. Table 1 in the SI gives the estimated credits for all Annex I Parties during the 2nd commitment period arising from ARD and from four accounting options of FM currently under negotiations, according to the work of the Joint Research Centre.[6] Depending on the accounting options, credits resulting from LULUCF would result in additional emission

[3] Annex I Parties of the Kyoto Protocol consist of the 1997 list of the industrialised countries and the emerging market economies of Central and Eastern Europe.

[4] In this paper we consider (i) an international carbon price, i.e. the price of Certified Emission Reductions (CER) traded under the Clean Development Mechanism (CDM) and Joint Implementation (JI) and the price of assigned amount units (AAUs); (ii) a domestic carbon price, i.e. the CER price on the emissions trading system (ETS) of a region, like the EU ETS, which corresponds in our model with the maximum marginal costs of abating the last ton of CO_2 emissions.

[5] See http://unfccc.int/home/items/5264.php.

[6] Cropland management, grazing-land management and re-vegetation are not included in this analysis, due to lack of data. However, it is likely that their contribution will be significantly smaller than that of ARD and FM.

Table 1 – Emission reduction targets for main Annex I regions resulting from submissions to the Copenhagen Accord.

2020	Greenhouse gas emissions (excluding land use CO_2), in $GtCO_2eq$		Low pledge		High pledge	
Country/ region	1990	Baseline 2020	Reduction target below 1990	Reduction target below baseline	Reduction target below 1990	Reduction target below baseline
Canada	0.6	0.8	−3%	19%	−3%	19%
USA	6.1	7.6	3%	23%	3%	23%
EU27+[a]	5.6	5.1	20%	13%	30%	24%
Japan	1.3	1.3	25%	31%	25%	31%
Russia	3.3	2.2	15%	−35%	25%	−19%
Ukraine[b]	1.1	0.5	18%	−73%	19%	−73%
Oceania[c]	0.5	0.8	−10%	23%	12%	40%
Total Annex I	18.5	18.3	12%	11%	18%	17%

Based on submissions to the Copenhagen Accord (http://unfccc.int/home/items/5264.php) as reported by June 2010, using emissions reported for 1990 or any other reference year specified by the Parties based on UNFCCC greenhouse gas inventory and baseline emissions for 2020 based on model calculations. Reduction targets as presented here may differ from the original pledges because of different reference years (Australia, Canada, USA) and because some pledges include land use CO_2 (Australia), whereas the table shows reduction targets excluding land use CO_2. For example, for Australia, including deforestation emissions would increase the reduction target for the high pledge from 12% to 23% below 1990 levels.

[a] EU27+ includes EU-27, plus Croatia, Iceland, Norway and Switzerland.
[b] Ukraine region includes Ukraine and Belarus.
[c] Oceania includes Australia and New Zealand.

allowances ranging from 1.8% to 4.1% of 1990 Annex I emissions.[7,8] For the cost calculations in Section 3, we assumed additional emission allowances of 2.8% of 1990 Annex I emissions.

A major uncertainty concerns the use of surplus AAUs, notably from Russia and Ukraine. This first of all relates to the surplus AAUs during the Kyoto period that may or may not be used. But secondly, as the reduction pledges for 2020 of Russia and Ukraine are above their baseline emission projection, these will generate new surplus AAUs. Section 4 shows the effect on emission reductions, the carbon price and abatement costs if these surplus AAUs are not used or are sold completely.

2.2. *Submissions of Non-Annex I countries*

Many Non-Annex I Parties have submitted their national mitigation action plans to the UNFCCC secretariat.[9] This paper focuses on the submissions of the seven largest-emitting Non-Annex I countries, which represent more than two-thirds of total Non-Annex I emissions (including land use CO_2) in the baseline in 2020. The submissions of these countries consist of detailed domestic actions, overall intensity targets, some combined with additional measures, and often include additional clauses, such as dependence on international finance, technology, and capacity-building support by developed countries. More specifically, the submissions of the major Non-Annex I countries are as follows:

- China pledges (i) to reduce CO_2 emissions per unit of GDP by 40–45% relative to 2005; (ii) to increase non-fossil fuels in primary energy consumption to around 15%; and (iii) to increase forest coverage by 40 million ha and forest stock volume by 1.3 billion m^3 relative to 2005 levels.
- India pledges to reduce emissions per unit of economic output by 20–25% relative to 2005 levels.
- Brazil pledges to reduce emissions by 36–39% relative to baseline. Measures to achieve this include increasing energy efficiency, improving agriculture techniques, increasing hydropower capacity, increasing use of biofuels and renewable energy, and finally reducing of deforestation emissions measures. The last measure contributes about 75% (670 $MtCO_2$) to the total reduction.
- South Africa commits to reduce emissions by 34% relative to baseline. In addition to this 2020 target, the country pledges a 42% reduction target by 2025. These reductions are compared to a national reference scenario with ''unconstrained growth''. The reductions presented in this study are lower, because our baseline assumptions are lower due to the inclusion of autonomous efficiency improvements. South Africa's submission is conditional on financial resources, transfer of technology and capacity building support by developed countries.
- Mexico pledges unconditional a reduction of 51 $MtCO_2eq$ by 2012 relative to baseline as part of the Special Climate Change Program 2009. Mexico aims to reduce greenhouse

[7] Emissions from LULUCF are highly uncertain. Uncertainty on future accounting rules further increase this uncertainty. The inclusion of LULUCF credits through different rules could have a significant impact on the range of reduction pledges in this study, particularly for those countries with large forest areas, such as Russia, the United States, Canada, Australia and New Zealand.

[8] Land use and forestry measures tend to remove CO_2 and thus decrease the atmospheric CO_2 built up. However, it cannot be guaranteed that the accounted land use and forestry adjustments reflect real, additional and permanent changes – there is no way to ensure that carbon stored in a planted forest or in agricultural soils will not be subsequently released.

[9] See http://unfccc.int/home/items/5265.php.

Table 2 – Outcome of the Copenhagen Accord mitigation action plans of the seven largest emitting emerging economies (for details, see SI text).

2020	Baseline emissions	Pledged target			
Country	$GtCO_2eq$	Low pledge		High pledge	
		$GtCO_2eq$	Reduction target below baseline	$GtCO_2eq$	Reduction target below baseline
China	13.8	13.0	6%	13.0	6%
India	3.4	3.4	−1%	3.3	3%
Brazil (including land use CO_2)	2.4	1.6	37%	1.5	38%
Mexico (including land use CO_2)	0.9	0.8	6%	0.6	30%
South Africa	0.6	0.5	12%	0.5	12%
South Korea	0.9	0.7	30%	0.7	30%
Indonesia (including land use CO_2)	2.5	1.8	26%	1.5	41%
Total emerging economies	24.5	21.8	11%	21.0	14%
Other Non-Annex I countries	9.8	9.8	0%	9.8	0%
Land use CO_2 emissions outside Brazil, Indonesia and Mexico	1.7	1.7	0%	1.7	0%
Total Non-Annex I	36.0	33.3	7%	32.6	10%

gas emissions up to 30% below baseline, but conditional on adequate international financial and technological support.

- South Korea (30%) and Indonesia (26–41%) have submitted reductions pledges relative to their baseline emissions. The submission of Indonesia is conditional on financial international support.

The effect of the mitigation action plans of the seven major emerging economies on emission reduction targets is presented in Table 2. The SI describes the methodology how these reduction targets are calculated in this study.

The difference between the high and low pledges is due to the reduction pledges of Brazil, Indonesia, Mexico and South Africa being partly conditional on financial international support. The high pledges result in an emission target of about 14% and the low pledges an emission target of 11% below baseline for the seven emerging economies combined. This means that the target for all Non-Annex I countries combined, assuming that all other Non-Annex I countries do not reduce emissions, is 10 to 7% below baseline levels. The emission target level of Non-Annex I as a whole would be 32.6–33.3 $GtCO_2eq$, which is within the range from other studies (European Climate Foundation, 2010; Climate Action Tracker: www.climateactiontracker.org; Stern and Taylor, 2010).

Without financial international support, the total pledge of the emerging economies could be close to the low-end range, and with support close to the high-end range. With regard to the reduction level of individual countries, Brazil, Mexico and South Africa have provided quite ambitious climate plans and reduction pledges. The emission reductions of the pledges of China and India are relatively small, 3 and 6%, respectively. Note, however, that both China and India have domestic policies in national plans that are expected to lead to further emission reduction – around 1.4 $GtCO_2eq$ for full implementation (den Elzen et al., 2010a) – but have not submitted these actions to the Accord. Therefore, these domestic climate plans have not been accounted for here.

A major uncertainty in estimating emission reduction targets of Non-Annex I countries is that baseline emissions against which the proposals are defined are not mentioned or specified in the submissions to the Copenhagen Accord. There might be a tendency to report high baseline emissions so that the targets can be more easily achieved. den Elzen et al. (2010a) estimated that this could lead to a 1–1.5 $GtCO_2eq$ higher emission level in 2020.

3. Abatement costs implications of the Copenhagen Accord submissions

3.1. *Important modelling assumptions*

We have used the FAIR 2.3 model to calculate the abatement costs resulting from the submissions to the Copenhagen Accord. Total abatement costs consist of domestic abatement costs, cost or revenues due to emissions trading, Joint Implementation (JI) or the Clean Development Mechanism (CDM), and financial transfers earmarked for financing abatement costs in Non-Annex I countries. The permit demand and supply curves for carbon credits are calculated using marginal abatement cost (MAC) curves to determine the equilibrium permit price ('carbon price') on the international trading market, its buyers and sellers, and the resulting domestic and external reductions and abatement costs for each region.

The MAC curves used in the calculations have been derived from the IMAGE model, including the world energy model TIMER (Bouwman et al., 2006). The MAC curves for CO_2 emissions from energy and industry were derived from the energy model by measuring the abatement in response to increasing carbon tax levels. In order to capture the impact of inertia and technology development, these MAC curves have been recorded as a function of time and for different tax profiles (representing early action and delayed response situations) (see van Vuuren et al., 2004). The MAC curves are scaled on the basis of actual carbon price trajectory in the FAIR calculations. In the energy model, technologies are assumed to be globally transferable and costs differences therefore result from current and future differences in efficiency levels and energy supply mix in the baseline and availability of regional resources. In the baseline, it is assumed that some of these factors converge over time. For non-CO_2, the long-term abatement curves have been used derived from the EMF21 study (Weyant et al., 2006), but subject to some corrections as described by Lucas et al. (2007) (see also SI).

The MAC curves capture the direct costs of emission reduction but not the macroeconomic implications of these costs. Macroeconomic costs (income or consumption losses) are more comprehensive, as they also capture indirect effects in the economy. However, they are more uncertain because they also depend on distribution effects, revenue recycling and the impacts on other investments. There are several reasons why macroeconomic costs can differ from abatement costs. Mitigation policies could, for instance, induce a reduced demand for fossil fuels, which could lead to additional income losses via fuel trade for fossil fuel exporters (OPEC countries, but also Russia and Canada). Another example is that international trade in emission permits will affect terms of trade (by changes in exchange rates). This will hurt permit sellers (again, Russia is among them).[10]

We assume that all individual Annex I countries must achieve at least two-thirds[11] of their target, after using credits for land use and forestry, through domestic emission reductions. The remainder of their target could be achieved by either the purchase of surplus AAUs from Russia and Ukraine, using JI in these countries or implementing CDM projects in Non-Annex I countries (‘offsetting’). In the FAIR model, only one equilibrium international carbon price for CDM, JI and emission trading is assumed (see SI). Non-Annex I countries only participate in CDM. Only a limited amount of the abatement potential is assumed to be operationally available on the market (see SI). This is because of the project basis of the CDM and implementation barriers, such as properly functioning institutions and project size (Michaelowa and Jotzo, 2005). It is assumed that the cheapest actions are financed domestically and the more expensive ones via CDM. To avoid double-counting of emission reductions, both the reductions from CDM projects and the costs are initially fully attributed to the donor country. As the mitigation actions submitted by Brazil, Indonesia, Mexico, South Africa and South Korea relate to domestic emission reductions only, their targets are assumed to be achieved completely domestically (i.e., no possibility of buying carbon credits), although part of the reductions are assumed to be financed internationally.

The carbon market includes emissions from all sources in the model, except from deforestation. The transaction costs associated with the use of the Kyoto mechanisms are assumed to consist of a constant USD[12] 0.55 per tCO_2eq emissions plus 2% of the total costs (Michaelowa and Jotzo, 2005). Apart from financial flows due to emissions trading, there are financial flows due to international financing support of Non-Annex I countries. For the high pledge scenario, it is assumed that Annex I countries finance 50% of total abatement costs of Brazil, Mexico and South Africa through a simple financial transfer.[13] For Indonesia, the costs associated from increasing the reduction target from 26 to 41% is assumed to be financed internationally. For the low pledge scenario, the same 50% financing of total abatement costs of Brazil and South Africa from Annex I countries is applied. For India, China and South Korea, no international financing was assumed. The costs of these financial transfers are allocated to Annex I countries in proportion to their GDP.

REDD measures in Non-Annex I countries are assumed to be financed 50% domestically and 50% by Annex I countries. The Non-Annex I country is assumed to receive the credits completely. Based on the Copenhagen Accord mitigation actions of some emerging economies (Brazil, Mexico and Indonesia), we derived the emission reductions below baseline excluding the REDD measures, and used this as basis for the cost calculations. The costs for REDD measures are calculated separately, and do not affect the international carbon price and financial flows of the carbon market. Costs calculations of REDD are based on MAC curves from the Global Forestry Model from IIASA (Kindermann et al., 2008). The MAC curves were corrected to match our baseline.

Section 2 showed that Russia and Ukraine submitted a pledge above their baseline emission projection, generating surplus AAUs. For the cost calculations, we assume that Russia and Ukraine maximise their profits from selling surplus AAUs by using an ‘optimal banking strategy’ consisting of limiting the supply of surplus AAUs on the market, thus raising the international carbon price and optimising their financial revenues (also see den Elzen et al., 2010b). More specifically, optimal banking is achieved by limiting the supply of new surplus AAUs to 25% of the total, while surplus AAUs from the first commitment period are not used at all.[14]

With regard to 2010 emissions of Annex I countries, we assume that the Kyoto targets for all Annex I countries (excluding the USA) are met. For regions that have emissions well below their Kyoto target, such as Russia and Ukraine, baseline emissions were chosen for the 2010 emission level.

Finally, we assume that credits from land use and forestry rules can be used by Annex I countries to reach the target. For the cost calculations, we assumed that a reference level for forest management is established against which future net emissions and removals will be compared to. For the majority of countries, the reference level reflects projected baseline

[10] van Vuuren et al. (2009) found that for regimes that assume participation of developed and developing countries long-term direct abatement costs correlate strongly with macroeconomic costs for most regions. This was also shown for oil-exporting regions as in general these regions have highly carbon intensive economies leading also to high abatement costs.

[11] Based on (1) the domestic target of the European emissions trading system, (2) the announcement of the Japanese government that Japan does at least 60% domestically, and (3) the likelihood that any US cap and trade regime would limit offsets from CDM and focus more on domestic abatement.

[12] We use constant 2005 USD throughout.

[13] This is based on the conditional pledge of Indonesia, which assumes that one-third of the most expensive abatement measures is financed. The associated costs of the most expensive one-third of total emission reduction (before entering into selling offsets via CDM or trading) equals about 50% of total abatement costs.

[14] Part of the remaining surplus AAUs (new and Kyoto) could be transferred to the commitment period beyond 2020.

emissions and removals. For others, the reference level is based on historic data. We also assumed that credits from forest management are capped at 3% of 1990 emissions. Based on the work of the Joint Research Centre, the above assumptions produce credits of about 530 $MtCO_2eq$ to 2.8% of 1990 Annex I emissions (Russia and Ukraine's credits are not used for trading due to their assumed 'optimal banking strategy'). This value is similar to the estimate of Rogelj et al. (2010), which is based on the assumptions that the land use and forestry rules remain the same as under the Kyoto Protocol, but with mandatory forest-management accounting and generated allowances capped at 4% of 1990 emissions.

3.2. *Abatement costs of Annex I countries and regions*

For the low pledge scenario, average Annex I costs (excluding Russia and Ukraine) are assessed to be about USD 50 billion (0.12% of GDP) in 2020, as shown in Table 3. Annex I costs are almost twice as much in the high pledge scenario. These costs include financial transfers from Annex I to Non-Annex I countries (equal to USD 18 billion for the high pledge scenario). Russia and Ukraine would profit from selling surplus AAUs, especially in the high pledge scenario. The low international carbon price in both the low and high pledge scenario (about 13 and 16 USD/tCO_2) can be explained by the low demand and high supply for carbon credits. This is largely caused by two main factors. These are the restriction of achieving two-thirds of total emission reductions domestically and the surplus AAUs of Russia and Ukraine (although restricted to only 25% of the surplus AAUs by 2020 due to the optimal banking strategy). Even though the international carbon price is low, many individual countries have to invest in more expensive abatement measures to achieve the two-thirds domestic reduction requirement.

Table 3 also shows the total abatement costs and domestic carbon price per Annex I country by source.[15] The abatement costs as share of GDP between Annex I countries and regions differ considerably, for both the high and low pledge scenarios. These differences can be explained by differences in reduction targets, in reduction potentials and in GDP levels. The domestic carbon price of each country is a good indicator of the first two of these components. It gives an idea of the maximum costs of the abatement measures that have to be implemented to reach the domestic target.

In the low pledge scenario, abatement costs are relatively high for Oceania, and to a lesser extent for Japan and the USA. These are also the countries with the highest pledged reductions relative to baseline (see Table 1). The domestic carbon prices are also the highest for these countries, ranging from 41 USD per tCO_2 (USA) to 79 USD per tCO_2 (Japan). The domestic carbon prices for these regions are therefore much higher than the international carbon price of 13 USD per tCO_2, which implies that the restriction of reaching two-thirds of the emission reduction target domestically substantially increase total abatement costs (see also Section 4).

In the high pledge scenario, where in particular Europe and Oceania have more ambitious pledges, costs as share of GDP are higher for all countries considered, except for Russia and Ukraine. These last two countries would benefit from selling carbon credits from surplus AAUs and JI projects at a higher international carbon price. In contrast Dellink et al. (2010) calculated the macroeconomic impacts of the Copenhagen Accord pledges, and found that the GDP impacts of the fossil fuel exporters, like Russia and Ukraine, are high. Also regions with the same emission reduction target in the high pledge scenario as in the low pledge scenario will face higher total costs. This is caused by the higher financial transfers to the major Non-Annex I countries, in particular to Mexico, Brazil and Indonesia, whos high conditional pledges depend on international support. In the low pledge scenario, total financial transfers amount to less than USD 4 billion, which is much less than the USD 18 billion necessary for the high pledge scenario. The relative cost differences between the high and low pledge scenario are the highest for Europe and Oceania, which was to be expected since these are the countries with the largest differences between the low and high pledge. In fact, according to our model calculations it is technically not possible for Oceania to reduce two-thirds of their high pledge target domestically, which explains their relatively high expenditures on buying carbon credits. It should be noted that the cost estimates of Oceania do depend heavily on additional emission allowances resulting from the assumed land use and forestry rules and could be much lower with different rules.

Our projected costs for Europe – close to USD 11 billion in 2020 for the low pledge and about USD 29 billion for the high pledge – are much lower than the 48–81 billion Euros projected by the European Commission (2010). The difference can largely be explained by the fact that our analysis is on the 20 and 30% emission reduction target only, whereas the analysis of the European Commission includes the whole energy package (i.e., meeting also the more expensive targets for renewable energy and energy savings).

3.3. *Abatement costs of Non-Annex I countries*

For the seven major Non-Annex I countries as a group, the total abatement costs are about USD 18 billion in 2020 for the low pledge scenario and 27 USD billion for the high pledge scenario, as shown in Table 4.[16] In terms of relative costs to GDP, the costs are similar for the seven major Non-Annex I countries and Annex I as a group, even excluding Russia and Ukraine. This is an interesting result, since these calculations already assume substantial financial transfers from Annex I to Non-Annex I countries.

As can be expected from the wide range in reduction targets (see Table 2), there are large differences in costs between the countries. According the calculations made here, for the low pledge scenario, costs as proportion of GDP are highest in Korea (about 0.7% of GDP), which is also the country with the most ambitious target. Total costs for Brazil and Indonesia are higher than the average costs of Annex I

[15] The SI describes how the emission reduction targets for both the high and low pledge scenario are met by the individual Annex I countries and regions.

[16] The SI describes how the seven major emerging economies are expected to achieve their targets.

Table 3 – Total abatement costs in 2020 by source for Annex I regions (in USD million; rounded to the nearest USD 10 million (negative sign indicates benefits)) and domestic carbon prices (in USD/tCO_2). The international carbon price is 13 and 16 USD/tCO_2 for the low and high pledge scenario.

	Domestic abatement costs	Emission trading costs/revenues	Financial transfers for financing[a]	Total abatement costs	Total abatement costs as % of GDP	Domestic carbon price
Low pledge scenario						
Canada	1150	660	120	1940	0.13%	31
USA	15,860	6780	1410	24,050	0.14%	41
Europe[b]	7400	1690	1490	10,580	0.06%	35[b]
Japan	7590	1640	450	9680	0.18%	79
Russia	0	−2870	130	−2730	−0.18%	0
Ukraine	0	−880	20	−860	−0.35%	0
Oceania	2720	790	110	3620	0.27%	61
Annex I excl. Russia and Ukraine	34,720	11,550	3590	49,860	0.12%	
Annex I	34,720	7810	3740	46,270	0.11%	
High pledge scenario						
Canada	1170	780	610	2560	0.18%	32
USA	16,050	7960	6960	30,970	0.19%	42
Europe[b]	17,670	3580	7340	28,590	0.16%	58[b]
Japan	7650	1990	2220	11,860	0.22%	80
Russia	0	−5280	650	−4630	−0.30%	0
Ukraine	0	−2490	100	−2390	−0.98%	0
Oceania	3550	2950	550	7040	0.53%	74
Annex I excl. Russia and Ukraine	46,080	17,250	17,680	81,020	0.19%	
Annex I	46,080	9480	18,440	74,000	0.17%	

[a] For financing of abatement costs of the emerging economies (Brazil, Indonesia, South Africa and Mexico).
[b] In the model, Western Europe and Central Europe are two separate regions. Combined, they represent Europe. The domestic carbon price is given for Western Europe; for Central Europe, the carbon price is much lower.

Table 4 – Total abatement costs in 2020 by source for Non-Annex I regions (million USD, rounded to the nearest 10 million USD (negative sign indicates benefits)) and domestic carbon prices (in USD/tCO_2). The international carbon price is 13 and 16 USD/tCO_2 for the low and high pledge scenario.

	Domestic abatement costs	Costs of REDD abatement	Emission trading costs/revenues	Financial transfers for financing	Total abatement costs	Total abatement costs as % of GDP	Domestic carbon price
Low pledge scenario							
Mexico	60	10	−110	0	−40	0.00%	4
Brazil	5080	1580	0	−3330	3330	0.27%	72
China	4040	0	−2980	0	1060	0.01%	4
India	20	0	−790	0	−760	−0.04%	0
Indonesia	1220	570	0	0	1800	0.28%	35
Korea[a]	12,120	0	0	0	12,120	0.73%	128
South Africa	810	0	0	−410	410	0.12%	42
Seven major emerging economies	23,370	2170	−3880	−3740	17,920	0.11%	
Rest of Non-Annex I	320	0	−3520	0	−3200	−0.05%	
High pledge scenario							
Mexico	16,190	20	0	−8110	8110	0.69%	273
Brazil	8140	1580	0	−4860	4860	0.39%	108
China	4900	0	−4050	0	850	0.01%	4
India	40	0	−850	0	−810	−0.04%	1
Indonesia	5540	1320	0	−5060	1800	0.28%	89
Korea[a]	12,120	0	0	0	12,120	0.73%	128
South Africa	810	0	0	−410	410	0.12%	42
Seven major emerging economies	47,750	2930	−4900	−18,440	27,340	0.17%	
Rest of Non-Annex I	380	0	−4540	0	−4160	−0.06%	

[a] In the FAIR model, Korea is one region, include both South and North Korea so that the reduction target of Korea is lower than the 30% pledged by South Korea.

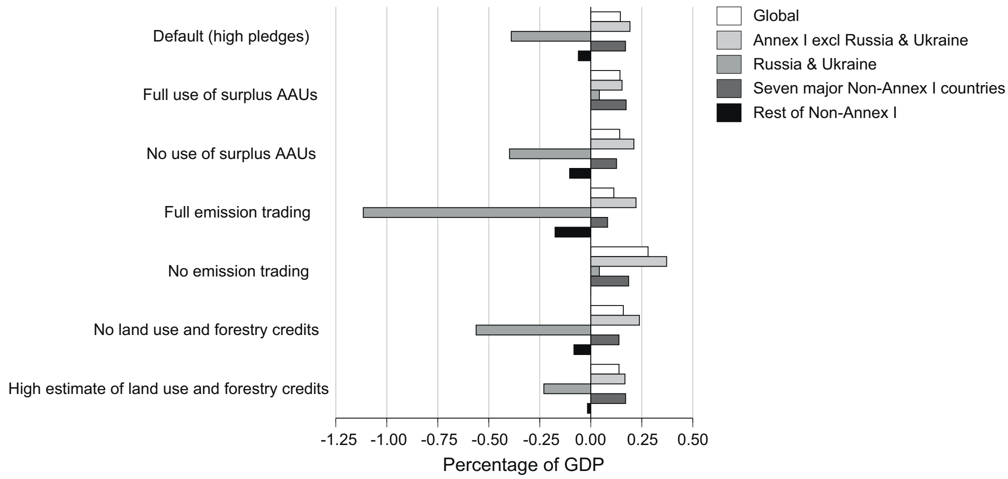

Fig. 1 – Total abatement costs as share of GDP in 2020 for large world regions according to different assumptions.

countries for the low pledge scenario, 0.27 and 0.28% of GDP, respectively. For Brazil, this is remarkable since these numbers already assume that half of their total costs are financed internationally by Annex I countries. Domestic carbon prices are correspondingly high for these countries (from USD 35 per tCO_2 for Indonesia to USD 128 per tCO_2 for Korea).

The high pledge scenario only leads to higher costs for Mexico and Brazil. Indonesia does have a higher target in the high pledge scenario, but the extra costs associated with this target are assumed to be financed externally. Especially Mexico is projected to incur high costs in the high pledge scenario; about 0.7% of GDP with a correspondingly very high domestic carbon price of USD 273 per tCO_2.

An interesting conclusion from Table 4 is that in the low pledge scenario, only the domestic carbon prices of Mexico, China and India are lower than the international carbon price USD 13 of per tCO_2. In the high pledge scenario, this is the case for China and India only. Since CDM projects are only profitable in countries where the domestic carbon price is below the international carbon price, of the seven major Non-Annex I countries only China and India would serve as host countries for CDM projects. This results in India having a net profit from the Copenhagen submissions (a result of their own close to zero reduction pledge), while China can largely compensate their domestic abatement costs to fulfil the Copenhagen submissions by the gains from CDM projects.

4. Sensitivity of results

Different interpretations of the submissions to the Copenhagen report are possible. Three of the most important aspects influencing the final emission reductions and costs resulting from the pledges are how surplus AAUs are dealt with, how much of the reductions is done domestically, and land use and forestry rules. Obviously, the costs also depend on the MAC curves that have been used. The TIMER energy model used to derive the costs curves for the energy- and industry related emissions for this study has, compared some other models, somewhat higher costs than average in the short-term, and a relatively high degree of converge of costs between regions (van Vuuren et al., 2009). This implies that using other costs curves may result is somewhat lower costs for the Non-Annex I countries. However, as regional costs are also strongly determined by the relative reduction target we do not feel that this would qualitatively change our conclusions. As we have discussed the impact of using different MACs elsewhere (den Elzen et al., 2009) – here we focus on the other three issues.

4.1. *Impact of the use of surplus AAUs*

With regard to surplus AAUs, there are two main uncertainties (den Elzen et al., 2010b). The first uncertainty is how surplus AAUs from the first commitment period (2008–2012) are dealt with. In the default calculations, we assumed that these Kyoto surplus AAUs cannot be banked or sold. According to our calculations, the Kyoto surplus AAUs from Russia, Ukraine and Eastern Europe amount to around 13 $GtCO_2eq$, leading to a decrease in ambition level of 1.3 $GtCO_2eq$ (about 6.5% of 1990 Annex I emissions)[17] in 2020 (a similar estimate has been made by the Point Carbon report (2009)). Estimates in the same order of magnitude have been given by Rogelj et al. (2010) of 2 $GtCO_2eq$ and Stern and Taylor (2010) of 1–2 $GtCO_2eq$. Secondly, the pledges for 2020 of Russia and Ukraine are above our baseline projection, meaning that new surplus AAUs are generated. If these surplus AAUs are banked and used, the emission reduction would decrease by 0.7 $GtCO_2eq$ for the high pledge scenario. The default calculations assume optimal banking of surplus AAUs by Russia and Ukraine. In practice, this means no use at all of Kyoto surplus AAUs and trade of about 0.2 $GtCO_2eq$ of new surplus credits.

To determine the possible impact of the above uncertainties, we analysed two extreme assumptions for using surplus AAUs: full use of both Kyoto and new surplus AAUs, and no use of surplus AAUs at all. The effects of these two extremes on total abatement costs for four aggregated world regions are

[17] If consumed for compliance purposes at a constant rate over the period 2013–2023.

shown in Fig. 1 with more information presented in Table 5. The full use scenario leads to lower costs for Annex I countries, excluding Russia and Ukraine, due to the high supply of surplus AAUs from Russia and Ukraine. In fact, this high supply causes the international carbon price to even fall to zero (given the assumption that two-thirds of the total reduction target of Annex I countries has to be achieved domestically). Another consequence of the full use of surplus AAUs scenario is that the negative costs of Russia and Ukraine change to positive costs (consisting of financial transfers to Non-Annex I countries). The remaining Non-Annex I countries do not gain from financial revenues from CDM anymore, due to a zero price for CERs (note that we assume one global carbon market – see SI). The effect of surplus AAUs not being used leads to only a minor change for Russia and Ukraine, since they still receive money for JI projects at a higher international carbon price. The higher carbon price also results in higher benefits for the rest of the Non-Annex I countries (and for China and India) and slightly higher costs for Annex I countries excluding Russia and Ukraine.

In terms of emission reductions, the full use of surplus AAUs case leads to a decrease in Annex I reductions from 18% to 9% below 1990 levels. The no use of surplus AAUs case slightly increases the reduction target to 19% below 1990 levels.

4.2. *Impact of emission trading*

In the default calculations, we assumed that two-thirds of Annex I emission reduction targets and all of Non-Annex I reduction targets need to be achieved domestically. The two extreme scenarios for emission trading are no emissions trading at all (which is the same as achieving all reduction targets domestically) and full emissions trading (no requirements on the share of emissions that need to be achieved domestically). As with the optimal banking case, we assume that 25% of new surplus AAUs from Russia and Ukraine can be sold, and no use of Kyoto surplus AAUs. Naturally, in the no emission trading scenario, also no surplus AAUs can be sold.

Full emissions trading lowers domestic emission reductions by Annex I countries, increases their demand for emissions trading and CDM, and thus doubles the international carbon price on the international market, while reducing the domestic carbon prices. As expected, this increase in flexibility decreases global abatement costs (by 25%, see Fig. 1 and Table 5). The revenues for Russia and Ukraine and those Non-Annex I countries that sell emission credits increase, because these regions sell more carbon permits at a higher price. While the costs for the seven major Non-Annex I countries as a group would decrease, in our calculations these countries together would buy carbon credits to achieve their targets (a result from the fact that the domestic carbon prices of most Non-Annex I countries are much higher than the international carbon price in the default scenario; see Table 4). Interestingly, releasing the "two-thirds domestic" requirement increases total abatement costs for Annex I (excluding Russia and Ukraine) as a whole. Even though their domestic abatement costs decrease, this is more than compensated by the increase in emission trading costs caused by the much higher international carbon price.

Table 5 – Robustness of results for the high pledge scenario.

2020	Emission reduction targets		Carbon price	Total abatement costs (including financial transfers for financing)				
Scenario	Annex I	Non-Annex I	International	Global	Annex I excl. Russia and Ukraine	Russia and Ukraine	Seven major emerging economies	Rest of Non-Annex I
	Relative to 1990 levels	Relative to baseline	USD/tCO_2	Billion USD				
Default (high pledge)	18	10	16	97	81	−7	27	−4
a. Full use/trading surplus AAUs	9	10	0	93	65	1	28	0.01
b. No use/trading surplus AAUs	19	10	25	95	89	−7	20	−7
a. Full emission trading	18	10	36	76	94	−20	13	−12
b. No emission trading	19	10	0	188	157	1	29	0
a. No land use credits	20	10	21	107	100	−10	22	−6
b. High estimate land use credits	16	10	6	92	70	−4	27	−1

Apparently, having an implicit demand restriction by assuming a "two-thirds domestic" requirement for all Annex I countries is beneficial for Annex I as a whole, because this keeps the international permit price low.

As expected, global costs increase substantially – from about USD 100 to 188 billion – if no emissions trading is allowed. The costs would increase for all four main world regions, but the major increase in costs takes place in Annex I countries.

4.3. *Impact of land use and forestry rules*

In the default calculations, we assume that credits from land use and forestry amount to 2.8% of 1990 Annex I emissions (see Section 2). According to our calculation, if no credits from land use and forestry may be used to reach the targets, the Annex I emission reduction target would increase from 18 to 20% below 1990 levels (Table 5). This would raise total abatement costs of the Annex I countries as a whole (excluding Russia and Ukraine) by USD 15 billion. The international carbon price would increase from USD 16 to USD 21 per tCO_2, leading to lower costs, or higher benefits, for the other three main world regions.

The land use and forestry rules currently under negotiations could lower the reduction level of developed countries, for the energy/industry emissions, by up to about 4% of Annex I 1990 emissions (see Table 1 in SI, option C without caps). If this would happen, it would lower Annex I emission reductions from 18 to 16% below 1990 levels. As a result, this would lower the costs of Annex I as a region (excluding Russia and Ukraine) by about USD 10 billion. The benefits of the regions selling carbon permits (mainly Russia, Ukraine and the other Non-Annex I regions) would be reduced due to the lower international carbon price.

5. Summary and conclusions

This paper analysed the emission reductions and abatement costs resulting from the submissions to the Copenhagen Accord, with a special focus on the impact of three main uncertainties: surplus AAUs, emissions trading, and land use and forestry rules. As many countries submitted both an unconditional low pledge and a conditional high pledge, we have calculated results for a "low pledge scenario" (all countries are committed to their low pledges) and a "high pledge scenario" (all countries commit themselves to their high pledges).

The Copenhagen Accord pledges lead to a reduction of 12–18% below 1990 levels for Annex I countries and 11–14% below baseline for the seven major Non-Annex I countries, assuming optimal banking of surplus AAUs. Under our default assumptions – optimal banking of surplus AAUs by Russia and Ukraine, achieving two-thirds of emission reductions domestically, medium assumptions for land use and forestry rules – Annex I emissions would end up 12% (low pledge scenario) to 18% (high pledge scenario) below 1990 levels in 2020. The reductions of the seven major emitting Non-Annex I countries amount to 11–14% below their baseline emissions in 2020 (including REDD measures). If all other Non-Annex I countries do not reduce emissions, the Non-Annex I countries as a group would be about 7–10% below BAU.

The global abatement costs are projected to be around 60–100 billion (low versus high pledges). The costs relative to GDP seem to be similar in the Annex I countries and the main Non-Annex I countries. Total global abatement costs in 2020 are projected to be USD 60 billion for the low pledge scenario and USD 100 billion for the high pledge scenario. For the costs as share of GDP, this equals 0.09% and 0.15%, respectively. In terms of absolute numbers, the largest share of total abatement costs is carried by Annex I countries excluding Russia and Ukraine (USD 50 billion in the low pledge scenario and USD 81 billion in the high pledge scenario). These numbers include the costs of financial transfers to Non-Annex I countries to support abatement measures, which amount to USD 4 billion in the low pledge scenario and USD 18 billion in the high pledge scenario. In terms of costs as share of GDP, however, total abatement costs are of the same order of magnitude for Annex I countries and the seven major Non-Annex I countries – even when taking into account financial transfers.

According to our calculations, the countries with the lowest costs are Russia, Ukraine, India and China. Since the pledges of Russia and Ukraine are far above their projected baseline emissions in 2020, they would receive surplus AAUs and hence would profit from selling these. It should be noted that fuel trade losses have not been accounted for. The submission of India would probably lead to hardly any reduction in emissions, so that India would profit from CDM projects. China's submission leads to a reduction of emissions, but they can compensate most of their domestic abatement costs by revenues generated through CDM projects.

The numbers found are subject to considerable uncertainty. Three of the most important uncertainties include surplus AAUs of Russia and Ukraine, land use and forestry rules, and the domestic reduction requirement. If instead of optimal banking of surplus AAUs, all surplus AAUs of Russia and Ukraine (Kyoto and new surpluses, about 9% of 1990 Annex I emissions) would be traded, the carbon market would be flooded by surplus AAUs, causing the international carbon price to fall to zero. In the high pledge scenario, this would halve the emission reduction of Annex I countries and reduce Annex I abatement costs (excluding Russia and Ukraine) by more than 20%. Global abatement costs would only decrease by 4%, however, since the international carbon price of zero means that Russia, Ukraine and the rest of Non-Annex I countries lose their profits from selling carbon permits or CDM projects. Full use and trading of surplus AAUs therefore leads to (i) lower emission reductions by Annex I as a whole, and (ii) a shift in costs from Annex I countries (excluding Russia and Ukraine) to the rest of the world. No use of surplus AAUs at all would not substantially affect the results, since instead of selling surplus AAUs, Russia and Ukraine would implement cheap emission reduction measures, for which they receive carbon credits and can sell these on the carbon market.

According to our analysis, the effect of land use and forestry rules currently under negotiations on Annex I emission reductions may be between one third and half of the effect of full use of surplus AAUs. The cost implications differ, however, since contrary to full use of surplus AAUs, more lenient land use and forestry rules imply lower emission reduction targets for Annex I countries. The effect on Annex I abatement costs is therefore larger. The reduction in global abatement costs is slightly lower, due to the very low international carbon price (and thus lower profits for Russia, Ukraine and the rest of Non-Annex I countries). If credits for land use and forestry are not used at all to achieve the targets, total Annex I emission reduction increase from 18 to 20% below 1990 levels, the international carbon price increases from 16 to 21 USD per tCO_2 and the global abatement costs slightly.

An interesting result is the low international carbon price resulting from all submissions; even in the high pledge scenario, the carbon price is limited to USD 16 per tCO_2 in 2020. The sensitivity analysis on emissions trading shows that the most important reason for this low carbon price is the restriction to achieve a minimum share of the pledged reduction domestically. This share is two-thirds for Annex I countries and 100% for Non-Annex I countries (since they receive funding from Annex I countries to reduce their emissions). If this restriction is given up, the international carbon price more than doubles to USD 36 per tCO_2, while global abatement costs fall by almost 25%. It may seem counterintuitive that the international carbon price increases and at the same time global abatement costs decrease. However, the reason is simple: a minimum requirement for domestic emission reduction lowers the demand for carbon permits, but does not affect their supply. This decreases the international carbon price, but has an upward effect on the domestic carbon prices. Global abatement costs are higher, because emissions are not reduced wherever it is cheapest to do so.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.envsci.2010.10.010.

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