CLIMATE CHANGE

Scientific Assessment and Policy Analysis

WAB 500102 031

Balancing the carbon market

Analysing the international carbon market and abatement costs in 2020 for low-concentration targets: policy choices and uncertainties

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Report
500102 031

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Wetenschappelijke Assessment en Beleidsanalyse (WAB) Klimaatverandering

Het programma Wetenschappelijke Assessment en Beleidsanalyse Klimaatverandering in opdracht van het ministerie van VROM heeft tot doel:

- Het bijeenbrengen en evalueren van relevante wetenschappelijke informatie ten behoeve van beleidsontwikkeling en besluitvorming op het terrein van klimaatverandering;
- Het analyseren van voornemens en besluiten in het kader van de internationale klimaatonderhandelingen op hun consequenties.

De analyses en assessments beogen een gebalanceerde beoordeling te geven van de stand van de kennis ten behoeve van de onderbouwing van beleidsmatige keuzes. De activiteiten hebben een looptijd van enkele maanden tot maximaal ca. een jaar, afhankelijk van de complexiteit en de urgentie van de beleidsvraag. Per onderwerp wordt een assessment team samengesteld bestaande uit de beste Nederlandse en zonodig buitenlandse experts. Het gaat om incidenteel en additioneel gefinancierde werkzaamheden, te onderscheiden van de reguliere, structureel gefinancierde activiteiten van de deelnemers van het consortium op het gebied van klimaatonderzoek. Er dient steeds te worden uitgegaan van de actuele stand der wetenschap. Doelgroepen zijn de NMP-departementen, met VROM in een coördinerende rol, maar tevens maatschappelijke groeperingen die een belangrijke rol spelen bij de besluitvorming over en uitvoering van het klimaatbeleid. De verantwoordelijkheid voor de uitvoering berust bij een consortium bestaande uit PBL, KNMI, CCB Wageningen-UR, ECN, Vrije Universiteit/CCVUA, UM/ICIS en UU/Copernicus Instituut. Het PBL is hoofdaannemer en fungeert als voorzitter van de Stuurgroep.

Scientific Assessment and Policy Analysis (WAB) Climate Change

The Netherlands Programme on Scientific Assessment and Policy Analysis Climate Change (WAB) has the following objectives:

- Collection and evaluation of relevant scientific information for policy development and decision–making in the field of climate change;
- Analysis of resolutions and decisions in the framework of international climate negotiations and their implications.

WAB conducts analyses and assessments intended for a balanced evaluation of the state-of-the-art for underpinning policy choices. These analyses and assessment activities are carried out in periods of several months to a maximum of one year, depending on the complexity and the urgency of the policy issue. Assessment teams organised to handle the various topics consist of the best Dutch experts in their fields. Teams work on incidental and additionally financed activities, as opposed to the regular, structurally financed activities of the climate research consortium. The work should reflect the current state of science on the relevant topic.

The main commissioning bodies are the National Environmental Policy Plan departments, with the Ministry of Housing, Spatial Planning and the Environment assuming a coordinating role. Work is also commissioned by organisations in society playing an important role in the decision-making process concerned with and the implementation of the climate policy. A consortium consisting of the Netherlands Environmental Assessment Agency (PBL), the Royal Dutch Meteorological Institute, the Climate Change and Biosphere Research Centre (CCB) of Wageningen University and Research Centre (WUR), the Energy research Centre of the Netherlands (ECN), the Netherlands Research Programme on Climate Change Centre at the VU University of Amsterdam (CCVUA), the International Centre for Integrative Studies of the University of Maastricht (UM/ICIS) and the Copernicus Institute at Utrecht University (UU) is responsible for the implementation. The Netherlands Environmental Assessment Agency (PBL), as the main contracting body, is chairing the Steering Committee.

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Preface

This report was commissioned by the Netherlands Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB). The steering committee of this project consisted of Gerie Jonk (Ministry of Environment), Marcel Berk (Ministry of Environment), Joelle Rekers (Ministry of Economic affairs), Maurits Blanson Henkemans (Ministry of Economic Affairs), Bas Clabbers (Ministry of Agriculture) and Remco vd Molen (Ministry of Finance).

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Executive Summary

This report describes our analysis of the impact of various policy choices and scientific uncertainties on the price of tradable emission units on the global carbon market in 2020 and the associated abatement costs. Our analysis was done under the assumption that the overall goal is to stabilise long-term greenhouse gas concentrations at 450 ppm CO_2-eq. To meet these stabilisation targets on the long-term, Annex I countries as a group need to reduce by 25-40% below 1990 levels by 2020, and non-Annex I countries as a group need to keep emissions substantially below baseline (about 15 to 30%). The integrated modelling framework FAIR 2.2 is used for our analysis. The main findings of this study are: the degree of ambition for reductions of Annex I and non-Annex I countries is the most important policy choice influencing the price and abatement costs. Other less important policy choices include the ambition of US climate policy and the participation of the developing countries in the global carbon market. By allowing the use of forest-based options – including avoiding deforestation – for compliance in a well-designed carbon trading system, the global abatement costs could be reduced by between 25% and 65%. This would also make ambitious mitigation targets more feasible. In addition to the policy choices, important scientific uncertainties, in particular the baseline emissions (i.e. emissions in the absence of climate policy) and the assumed marginal abatement costs, strongly influence the carbon market.

Main findings of this study (in more detail):

– *The level of ambition for reductions by the Annex I and non-Annex I countries, in a future international agreement on climate change, is one of the most important policy choices influencing the carbon price on the carbon market and abatement costs in 2020*. For the default case, assuming a 30% emission reduction below 1990 levels for Annex I in 2020 and a 15% reduction below baseline emissions for non-Annex I, compatible with stabilising GHG concentration at 450 ppm CO_2-eq, the global abatement costs are about 0.4% of GDP, and the permit price is about 75US\$/tCO_2-eq (Figure ES.1: vertical line). A higher Annex I and non-Annex I reduction of 40% and 30% increases the global costs by about half (see Figure ES.1). Reducing the Annex I and non-Annex I reduction lowers the global abatement costs by 20-30%, but leads to global emissions in 2020 at the upper limit of emission corridors that can still attain the 450 ppm CO_2-eq target in the long term.

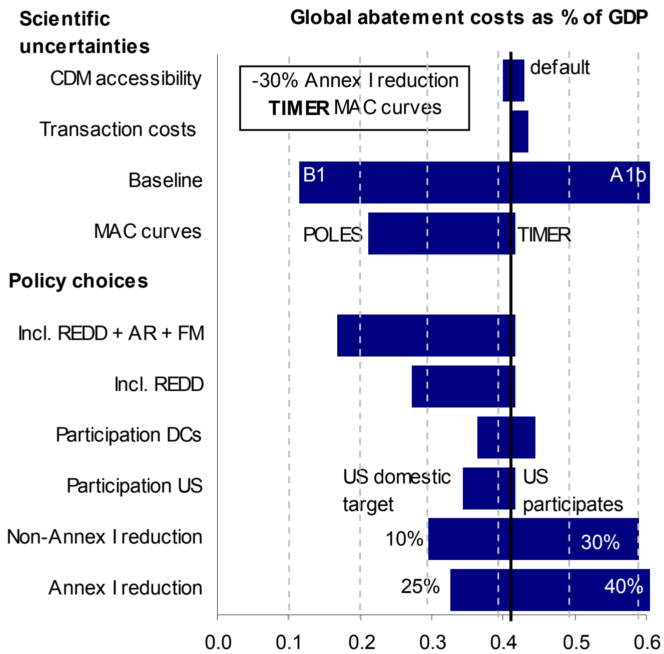


Figure ES.1. The impact of the key factors on the global abatement costs in 2020. The impact on the carbon price is about the same.

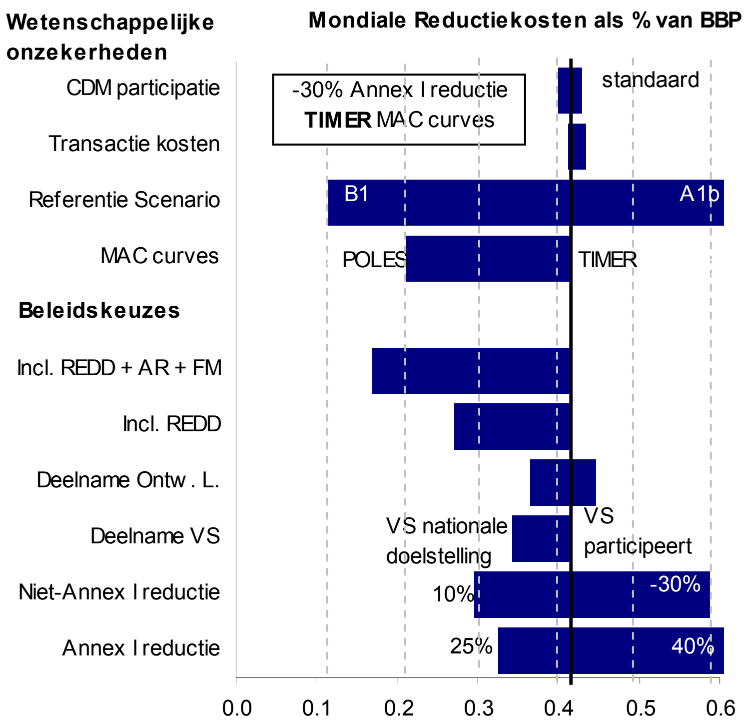
- *Including REDD (*reducing emissions from deforestation and forest degradation) *in the carbon market could decrease the global abatement costs significantly (by 25 to 40%). This could lead to low costs or even net gains for the non-Annex I countries. With the addition of AR (afforestation and reforestation), the global abatement costs could even be reduced by 40-65% in 2020.* The inclusion of the forest sector in the global carbon market could lower the abatement costs of meeting stringent reduction targets. Emission credits from REDD can offset part of the Annex I reduction, and increase the financial flows from Annex I to non-Annex I countries. ADCs, like Brazil, would also use REDD to meet their own reduction targets. The final abatement costs for non-Annex I decline, and may even turn into gains. It also has the benefit of reducing deforestation by 30-70% in 2020. It should be noted, however, that it is uncertain to what extent REDD, AR and FM measures can actually be implemented.
- *The main policy choices determining the abatement costs are: 1. Annex I and non-Annex I reduction targets; 2. including the forestry sector in the carbon market; 3. the participation of developing countries or the USA in the carbon market. This finding is robust for other MAC curves. The most important scientific uncertainty by far concerns the baseline emissions, followed by the MAC curves.* Important scientific uncertainties are the baseline emissions and the MAC assumptions. The baseline emissions have a high impact on the carbon price and abatement costs; a high baseline doubles the price and costs. The MAC assumption can also double the costs, i.e. the TIMER MAC curves lead in 2020 to abatement costs that are twice as high as the POLES MAC curves. Another aspect is that the TIMER curves are more similar across regions, so they lead to a lower incentive for emission trading. The Annex I costs are mainly influenced by the baseline and Annex I reduction target. The non-Annex I costs are also mainly influenced by the non-Annex I reduction target, the MAC curves and including REDD in the global market. More optimistic assumptions concerning these factors can convert the costs of non-Annex I countries into gains.
- *A gradual participation of non-Annex I or developing countries in the carbon market can lead to benefits for both Annex I and non-Annex I.* Emission trading and CDM can decrease the costs of meeting the reduction targets considerably. The global benefits can be on the order of 100-150 billion US$ by 2020. IET and CDM also lower the actual reduction targets of Annex I to about 20-25% below 1990 levels (from the Annex I reduction ambition of 30%). The remaining 5-10% is achieved through offsetting mechanisms that generate credits for reductions in Annex I countries. Non-Annex I countries need to reduce their emissions compared to baseline by around 15-20%, of which 5% can be sold through the carbon market via CDM and IET. This would take place under gradual participation of the developing countries in the global market, i.e. ADCs (advanced developing countries) would participate via IET and the other developing countries via CDM. With full participation of the developing countries via IET, the benefits would be even higher.

Samenvatting

Dit rapport beschrijft een modelanalyse van de impact van de verschillende beleidskeuzes en wetenschappelijke onzekerheden op de koolstofprijs van verhandelbare emissie-eenheden op de mondiale koolstofmarkt in 2020 en de bijbehorende reductiekosten. De analyse veronderstelt op de lange termijn stabilisatie van de concentraties van broeikasgassen op 450 ppm CO_2-eq. Om wereldwijde broeikasgasemissies op een dergelijk laag stabilisatieniveau te brengen, wat de kansen vergroot om de gemiddelde temperatuurtoename wereldwijd te beperken tot 2ºC, zouden Annex I of geïndustrialiseerde landen hun emissies moeten reduceren met 25-40% ten opzichte van hun 1990 emissieniveaus rond het jaar 2020, terwijl niet-Annex I of ontwikkelingslanden 15-30% moeten afwijken van hun referentie-emissies. Voor de analyse gebruiken we het geïntegreerde model FAIR 2.2. De analyse toont aan dat de reductie-doelstelling van broeikasgas emissies van de Annex I en niet-Annex I landen in 2020 de meest belangrijkste beleidskeuze is, welke in belangrijke mate de toekomstige koolstofprijs en reductiekosten beïnvloedt. Andere minder belangrijke beleidskeuzes zijn de reductiedoelstelling van de Verenigde Staten en de deelname van de ontwikkelingslanden in de mondiale koolstofmarkt. Door het toestaan van het gebruik van de mitigatie opties voor land-gebruikemissies – met inbegrip van het vermijden van ontbossing – in een goed ontworpen systeem van verhandelbare emissie-eenheden, kunnen de mondiale reductiekosten worden verminderd met 25% en 65%. Hierdoor worden ook meer ambitieuze reductiedoelstellingen haalbaar. In aanvulling op de beleidskeuzes, zijn er ook belangrijke wetenschappelijke onzekerheden, in het bijzonder de referentie-emissies (d.w.z. emissies in de afwezigheid van klimaatbeleid) en de veronderstelde marginale reductiekosten, die een sterke invloed hebben op de koolstofprijs op de koolstofmarkt en de reductiekosten.

De belangrijkste conclusies (in meer detail):

- *Het ambitieniveau van de broeikasgas reductiedoelstellingen van de Annex I en niet-Annex I landen in 2020 in een toekomstige internationale klimaatovereenkomst is een van de meest belangrijke beleidskeuzes, welke in belangrijke mate de koolstofprijs en reductiekosten in 2020 beïnvloedt*. De standaardberekeningen veronderstellen voor de Annex I landen als groep een emissiereductie van 30% onder 1990-waarden voor 2020. Voor de niet-Annex I landen als groep nemen we emissiereducties aan van rond de 15% onder de referentie-emissies binnen dezelfde tijdspanne. Deze reducties in 2020 zijn in overeenstemming met het stabiliseren van de broeikasgas concentraties op 450 ppm CO_2-eq op de lange termijn. De resulterende mondiale reductiekosten kosten zijn ongeveer 0,4% van het BBP, en bedraagt de koolstofprijs ongeveer 75US$/tCO2-eq (Figuur ES.1: verticale lijn). Een hogere Annex I en niet-Annex I reductiedoelstelling van 40% (t.o.v. 1990 emissies) en 30% (t.o.v. referentie-emissies), resp. leiden tot een stijging van de totale kosten met ongeveer de helft (Figuur ES.1). Vermindering van de Annex I en niet-Annex I reductiedoelstelling verlaagt de wereldwijde reductiekosten met 20-30%, maar leidt tot een stijging van mondiale broeikasgas emissies in 2020 tot aan de bovengrens van het emissiebereik, die nog in overeenstemming is met lange termijn stabilisatie op 450 ppm CO_2-eq.



Figuur ES.1. De impact van de belangrijkste factoren voor de mondiale reductiekosten in 2020. De impact op de koolstofprijs is ongeveer gelijk.

- *Het opnemen van het vermijden van ontbossing, i.e. REDD in de koolstofmarkt kan leiden tot een aanzienlijke daling van de mondiale reductiekosten (met 25 tot 40%). Dit kan leiden tot lage kosten of zelfs nettowinsten voor de minst ontwikkelde niet Annex I landen. Met de toevoeging van herbebossing, kunnen de mondiale reductiekosten zelfs worden verlaagd met 40-65% in 2020*. De opname van REDD in de wereldwijde koolstofmarkt kan de reductiekosten voor het halen van ambitieuzere reductiedoelstellingen verminderen. Emissiekredieten uit het vermijden van ontbossing kunnen een deel van de Annex I reducties compenseren en leiden tot verhoging van de financiële stromen van Annex I naar niet in Annex I. De zogenoemde 'opkomende economieën', zoals Brazilië, zouden ook het vermijden van ontbossing kunnen gebruiken om aan hun eigen reductiedoelstelling te voldoen. De uiteindelijke reductiekosten voor de niet-Annex I landen als groep kunnen hierdoor aanzienlijk worden verminderd, en zelfs omslaan in winst. Daarnaast leidt het opnemen van REDD tot een 30-70% reductie van het huidige ontbossingtempo in 2020. Hierbij moet worden opgemerkt dat het onzeker is in hoeverre REDD, herbebossing en bosmanagement maatregelen ook daadwerkelijk kunnen worden uitgevoerd.
- *De belangrijkste beleidskeuzes, die de toekomstige koolstofprijs en reductiekosten bepalen, zijn: 1. Annex I en niet-Annex I reductiedoelstellingen, 2. opnemen van het vermijden van ontbossing, i.e. REDD in de koolstofmarkt; 3. de deelname van ontwikkelingslanden in de koolstofmarkt of de VS reductie-inspanning. Deze bevindingen zijn robuust voor andere aannames voor de marginale broeikasgasreductie-kostencurves (MACs)*. De belangrijkste wetenschappelijke onzekerheid betreft veruit de referentie-emissies, gevolgd door aannames voor de MACs. De baseline-emissies hebben een grote impact op de koolstofprijs en kosten, en hoge referentie-emissies kunnen zelfs leiden tot een verdubbeling van de prijs en kosten. Andere MAC aannames bv. die van het POLES energie model in plaats van het TIMER energiemodel leiden tot 50% lagere reductiekosten. Daarnaast leiden de POLES MACs tot meer handel in emissierechten. De Annex I kosten worden vooral beïnvloedt door de referentie emissies en Annex I reductiedoelstelling. De niet Annex I kosten worden ook hoofdzakelijk beïnvloedt door de niet Annex I reductiedoelstelling, de MACs en het opnemen van REDD in de koolstofmarkt. Meer optimistische aannames met betrekking tot deze factoren kunnen leiden tot winsten i.p.v. kosten voor de niet-Annex I landen.

- *Een geleidelijke deelname van de niet-Annex I of ontwikkelingslanden in de koolstof-markt kan leiden tot voordelen voor zowel de Annex I als niet-Annex I landen*. Emissiehandel en CDM kunnen de kosten voor het halen van de reductiedoelstellingen aanzienlijk verminderen. Het voordeel kan zelfs 100 tot 150 miljard US$ in 2020 bedragen. Het kan ook de daadwerkelijke reductieniveaus van Annex I na handel en CDM verlagen tot ongeveer 20-25% onder 1990 niveaus (t.o.v. de Annex I reductiedoelstelling van 30%). De afname van 5-10% wordt bereikt door middel van koolstofkredieten vanuit de niet-Annex I landen. De niet-Annex I landen moeten hun emissies met ongeveer 15-20% reduceren ten opzichte van het referentiescenario, waarvan 5% kan worden verkocht via de koolstofmarkt via CDM en emissiehandel. Dit gebeurt onder een geleidelijke toename in de deelname van de ontwikkelingslanden in de mondiale koolstofmarkt, i.e. opkomende economieën doen mee via emissiehandel en de andere ontwikkelingslanden via CDM. Met een volledige participatie van de ontwikkelingslanden via emissiehandel zouden de voordelen nog hoger kunnen zijn.

List of acronyms

ADC	Advanced Developing Countries
AR	Afforestation and Reforestation
AWG-KP	Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
COP	Conference of the Parties
CER	Certified Emission Reduction
DC	Developing Countries
ERU	Emission Reduction Unit
FAIR	Framework to Assess International Regimes for the differentiation of commitments
FM	Forest Management
GCOMAP	Generalized Comprehensive Mitigation Assessment Process Model
GDP	Gross Domestic Product
GHG	Greenhouse gas
$GtCO_2$-eq	Giga tons of Carbon Dioxide Equivalent
GTM	Global Timber Model
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
JRC	Joint Research Centre of the European Commission
LDC	Least Developed Country
LULUCF	Land-Use, Land-Use Change and Forestry
NAI	Non-Annex I
MAC	Marginal Abatement Costs
$MtCO_2$-eq	Mega tons of Carbon Dioxide Equivalent
OECD	Organisation for Economic Cooperation and Development
POLES	Prospective Outlook on Long-term Energy Systems
REDD	Reducing Emissions from Deforestation and Degradation
TIMER	Targets Image Energy Regional model
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

The ultimate goal of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilise atmospheric concentrations of greenhouse gases (GHG) at a level that prevents dangerous human interference with the climate system (UNFCCC 1992). The European Union (EU) has interpreted this goal as a maximum temperature increase of 2°C compared to pre-industrial levels (European-Council 1996; 2005). Such a target requires stabilising greenhouse gas concentrations at low levels. The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) showed that scenarios that aim to stabilise atmospheric GHG concentrations at the lowest level assessed by the IPCC (around 450 ppm CO_2-eq), typically have a peak in global emissions before 2015 and a reduction of emissions to well below half of the 2000 level by the middle of the 21st century (IPCC 2007). In addition, the IPCC indicated that in order to achieve low stabilisation targets, Annex I or developed countries as a group need to reduce their emissions to within a range of 25% to 40% below 1990 levels by 2020 (Gupta et al. 2007), even if emissions in non-Annex I or developing countries deviate substantially from baseline – i.e. no climate policy (Box 13.7). In August 2007, the Parties to the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP) agreed that a reduction in GHG emissions by Annex I countries in a range from 25% to 40% below 1990 levels by 2020 would provide a practical basis for further consideration. Currently, however, this range has not been accepted by the UNFCCC as the guiding level for the determination of mid-term Annex I reduction targets.

The IPCC authors responsible for Box 13.7 elaborated further on the issue of substantial deviation from the baseline by analysing the underlying studies and the literature obtained after the completion of the IPCC report (den Elzen and Höhne 2008). They concluded that in addition to the Annex I emission reduction of 25-40%, a deviation from the baseline emission levels by the entire group of non-Annex I countries of 15-30% by 2020 would be needed to meet 450 ppm CO_2-equivalent. These non-Annex I reductions would have to be achieved domestically in their entirety and should be fully additional to the reductions achieved by Annex I countries. However, Annex I countries may support the non-Annex I countries in meeting their reductions through a mixture of financing, carbon trading or other mechanisms. The EU has accepted these findings as input for the climate negotiations at the Fourteenth Conference of the Parties (COP 14) in Poznan, Poland and the COP 15 in Copenhagen, Denmark (see EU Council conclusions (2008) and submissions to the AWG-KP on long-term cooperative action).

Presently, the Clean Development Mechanism (CDM) is the only international climate policy instrument that leads to measured, verified and quantified emission reductions in non-Annex I countries. However, since Certified Emission Reductions (CERs) from CDM projects are used for Annex I country compliance, they cannot be counted towards the reductions in non-Annex I countries noted above. According to the Bali Action Plan (UNFCCC, COP 13), developed countries should support developing countries in achieving their reduction actions through additional technology, financing and capacity building. Emission trading schemes (between countries with binding emission targets) are thought to be important instruments for implementing the emission reduction targets. This is expected to create a large international carbon market. However, it is unclear how reductions by non-Annex I countries will affect the carbon market. The question is, to what extent would participation in the carbon market of non-Annex I countries affect Annex I mitigation costs?

In the context of the ambitious Annex I and non-Annex I reductions required under a 2°C target, our report evaluates the price of tradable emissions units on the international carbon market (hereafter known as carbon price) and abatement costs in 2020. It focuses on a default scenario, assuming a 30% reduction target below 1990 levels for Annex I and a 15% reduction target below baseline for non-Annex I. More specifically, our report addresses the following central questions: what is the impact of the scientific uncertainty and a range of policy-related choices[1] (see Table 1 for an overview) that are part of the negotiation process on the supply and demand side of the carbon market? Does this also involve the resulting carbon price and the total abatement costs?

Table 1. Default assumptions for the policy and scientific choices as explored in this report for the default scenario by 2020 and levels of variation used for the uncertainty analysis of Section 6, leading to higher and lower costs compared to the costs for the default case.

Policy choice	Higher costs case	Default scenario	Lower costs case
Ambition for emission reductions in various parts of the world			
Reduction of Annex I countries as a group	40% below 1990 level	30% below 1990 level	25% below 1990 level
Participation of USA	Same as default	USA participates (same reduction below baseline as Annex I)	USA domestic target (return to 1990 levels)
Reduction of non-Annex I countries as a group	20% below baseline	15% below baseline	10% below baseline
Participation of developing countries (DCs)	Only participation in CDM*	Advanced developing countries (ADCs) participate in international emissions trading IET[v] and other DCs in CDM	Full participation of DCs in IET
The impact of forestry-related measures			
Including reducing emissions from deforestation and degradation (REDD)	Same as default	No REDD	Selecting the MAC that results in the lowest costs
Afforestation and reforestation (AR)	No afforestation	No afforestation	Selecting the MAC that results in the lowest costs
Forest management (FM)	No forest management	Conservative estimate	Selecting the MAC that results in the lowest costs
Scientific choice	Higher costs case	Default case	Lower costs case
MAC curves	Same as default	TIMER MAC curves	POLES MAC curves (see section 5)
Baseline	IMAGE IPCC SRES A1b	Baseline similar to WETO 2006	IMAGE IPCC SRES B1
Transaction costs	US$3 per ton CO_2-eq emissions plus 10% of the total costs	US$0.55 per ton CO_2-eq emissions plus 2% of the total costs	No transaction costs
CDM accessibility factor*	10%	20%	30%

* See Section 2. [v] For the countries that participate in IET, full abatement potential is available for the market. MAC: Marginal abatement curve. For forestry-related measures, several MACs are available (see Section 4).

The policy-related choices analysed here are the following:
- the level of ambition in terms of emission reductions by Annex I and non-Annex I countries,
- the emission reduction target of the USA,
- the participation of developing countries in the carbon market, and
- the inclusion of the forest sector into the future carbon market, in particular including reducing emissions from deforestation and degradation (REDD), afforestation and reforestation (AR) and forest management (FM).

The scientific uncertainties include:
- the assumed Marginal Abatement Cost (MAC) curves
- the baseline emission scenarios

[1] The term 'policy choice' or 'policy-related choice' refers to variables in the calculation, the values of which cannot be based on objective ('scientific') arguments alone.

- the transaction costs and implementation factors for CDM and/or tradable units from non-Annex I.

In our analysis, we mainly focused on Annex I and non-Annex I as a group, or the world, assessing the above-mentioned impacts in a global carbon market.

2 Methodological issues

2.1 Analytical framework

We used the integrated modelling framework FAIR[2] (den Elzen and van Vuuren 2007; den Elzen et al. 2008b) for the quantitative analysis of emission reductions and abatement costs at the level of 26 regions (Table 2). We calculated the abatement costs (in 2005 US$) by assuming full use of the flexible Kyoto mechanisms such as international emissions trading (IET) and CDM, and calculated the cost-effective distribution of reductions for different regions, gases and sources. The model used baseline emissions of GHG emissions from the IMAGE land-use model and TIMER energy model. The aggregated emission credits demand-and-supply curves were derived from marginal abatement costs (MAC) curves for the different regions, gases and sources, i.e. the energy and industry-related CO_2 emissions from the TIMER energy model (van Vuuren et al. 2007). This was done by imposing a carbon tax and recording the induced reduction of CO_2 emissions, and the non-CO_2 GHG emissions based on Lucas et al. (2007). The emission credits demand-and-supply curves were used to determine the carbon price in the international trading market, its buyers and sellers, and the resulting domestic and external abatements for each region. The abatement costs for each scenario were calculated based on the marginal abatement costs and the actual reductions. They represent the direct additional costs due to climate policy, but do not capture the macro-economic implications of these costs.

We assumed that emissions could be traded freely between all of the regions that had accepted emission reduction targets. The transaction costs associated with the use of the Kyoto mechanisms were assumed to consist of a constant US$0.55 per tonne CO_2-eq emissions plus 2% of the total costs (Michaelowa et al. 2003; Michaelowa and Jotzo 2005). For countries that only participated in CDM, a limited amount of the abatement potential was assumed to be operationally available on the market, because of the project basis of the CDM and implementation barriers such as properly functioning institutions and project size (small projects are economically less viable due to the relatively higher transaction costs). Consistent with earlier studies (Criqui 2002; den Elzen and de Moor 2002; Jotzo and Michaelowa 2002), this so-called CDM accessibility was set at 20% in 2020, which is twice as high as under the Kyoto commitment period. This meant that only 20% of the total supply would be available for offsetting reductions not achieved in Annex I countries.

The model calculations did not allow banking and/or borrowing for or from future commitment periods.[3] We did not account for the expectations of the market participants in the carbon market results in 2020 (i.e., no intertemporal optimisation was considered in this analysis).[4]

The *baseline emission scenario* in this analysis was a 'median' baseline scenario developed for the ADAM project (van Vuuren et al. 2009). The ADAM baseline is a high economic growth scenario, based primarily on optimistic growth assumptions for China and India, and medium growth projections for the other regions. The population projection used was the UN medium scenario. The short-term developments for energy were calibrated against the WETO reference scenario of the World Energy Outlook (European-Commission 2007). The baseline GHG emission projection for the year 2020 was about 58 $GtCO_2$ including land use, land-use change and forestry (LULUCF) CO_2 emissions, and about 54 $GtCO_2$ excluding LULUCF CO_2 emissions.

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2 The model names in this section are acronyms. FAIR = Framework to Assess International Regimes for the differentiation of commitments; IMAGE = Integrated Model to Assess the Global Environment; TIMER = The IMage Energy Regional model.

3 As for previous commitment periods, we assumed that all banked excess emission allowances during the first Kyoto Protocol commitment period (2008 to 2012) are fully used in the second commitment period (2013 to 2018).

4 Under a stable climate policy with long-term commitments, such long-term optimisation may occur. Theoretically, in such cases the carbon price should increase at a rate near the discount rate. In addition, the increase could include a premium reflecting, among other things, the regulatory risks.

Table 2. Assumed reduction levels (in %) below baseline or business as usual scenario emissions in 2020 for the Annex I and non-Annex I countries.

Region	Configuration	Reduction
Annex I countries	Canada, USA, EU (Central and Western Europe), Russian Federation, Japan, Oceania (Australia and New Zealand) and Ukraine region (Ukraine and Belarus): Reduce below baseline emissions and can participate in IET	–35*
Non-Annex I countries		–15v
Advanced developing countries	Mexico, rest of Central America, Brazil, rest of South America, South Africa, Kazakhstan region, Turkey, Middle East, Korea region and China: Reduce below baseline emissions and can participate in IET	–20
Other developing countries	Northern Africa region, Middle East, India, rest of Southern Asia, Indonesia region, rest of South-East Asia: Reduce below baseline emissions and can participate in CDM	–10
Least developed countries	Western Africa, Eastern Africa and rest of South-Africa region: Follow baseline emissions and can participate in CDM	0

Note: * corresponds to 30% below 1990 levels; v corresponds to approximately 120% above 1990 levels.

For the *default mitigation scenario* we aimed at stabilising long-term GHG concentrations at 450 ppm, after an overshoot in concentrations to 500 ppm, which had a reasonable chance (about 50%) of meeting the 2^{o}C temperature increase target. This means that global GHG emissions (excluding LULUCF CO_2) could increase by 2020 to 15-30% below 1990 levels (den Elzen et al. 2007). For the scenario, we assumed a 30% reduction target below 1990 levels for the Annex I countries as a group in 2020 and a 15% reduction target below baseline for non-Annex I as a group. For the allocation of the emission reductions among all Annex I countries (including the USA) we assumed an equal reduction below the baseline emissions (i.e. about 35%). For the non-Annex I countries, in accordance with den Elzen et al. (2008a), we assumed differentiated reductions following on the common-but-differentiated responsibilities and capabilities principle of the UNFCCC (1992) (see Table 2). The global emission reduction in 2020 of all GHGs excluding LULUCF CO_2 was about 12 GtCO_2, or about 20% below baseline emissions, leading to approximately 46 GtCO_2 GHG emissions. The LULUCF CO_2 emissions followed the baseline, which showed a decreasing trend (see also Section 4).

2.2 Choice of scenarios

In order to explore possible scenarios for the international carbon market, we looked into a set of crucial policy choices and scientific uncertainties (see Table 1), as described briefly below. Most of these are discussed more extensively later on (in the discussion on the results of our analysis).

Ambition for emission reductions in various parts of the world – A critical factor for the future of the carbon market is the ambition for emissions reduction in different parts of the world. The EU has actively promoted the adoption of the Kyoto Protocol – and has recently put forward a set of proposals to further strengthen international climate policy, notably a 30% overall reduction target below 1990 levels for Annex I and a 15-30% reduction below baseline for non-Annex I for meeting the low concentration targets (referred to in Section 1). Obviously, broadening participation is a key priority for the EU to achieve its long-term climate objectives. For its domestic reductions, the EU has indicated that it is willing to commit to a 30% reduction (compared to 1990 levels) in 2020 as part of an international agreement if other parties commit to comparable reduction targets. If not, the EU would unilaterally still commit to a 20% reduction. So far, the response of most other parties has not been very concrete – and a wide range of outcomes still seems possible as a result of the COP-15 negotiations. Focusing on scenarios aiming at 450 ppm CO_2-eq, we therefore explored the lower and upper limit of the 25-40% range of Annex I reduction. For the reduction allocation, we assumed an equal reduction below the baseline.

In addition, we also looked at reduction rates for the USA, as this is a very significant political variable in climate negotiations, and is likely to influence the level of ambition for the entire agreement. We specifically focused on the proposal by US president Obama. According to this proposal, the USA would reduce its domestic emissions to 1990 levels by 2020. For the participation of developing countries, two issues play a key role: the emissions reduction ambition from baseline and the nature of the commitments applying to developing countries. Both are also related to participation in the global carbon market. For the former, we explored the 15-30% reduction from baseline for non-Annex I, consistent with the 25-40% reduction for Annex I, and assumed differentiated reductions for the individual non-Annex I countries. For the latter (the type of commitment), we explored two extreme alternatives. The first was that all developing countries would participate via the CDM mechanism or via full emission trading (based on binding caps), and the second was an intermediate variant for the default scenario, where only the more advanced developing countries (ADCs) participate in emission trading.[5]

The impact of forestry-related measures – A second set of critical factors in our analysis involved the contribution of *forestry-related* measures. Here, we specifically looked into the impact of including measures to reduce deforestation and degradation (REDD), and to promote AR and FM. In the various runs, these options were either included (based on the MACs of three different forestry and land-use models, which were all used in the IPCC 4th Assessment Report), or excluded. For the default case, REDD and AR were excluded, and for FM a conservative, a low estimate was used (den Elzen and de Moor 2002). More specifically, for the Annex I regions, credits were assumed to remain constant after Kyoto on the basis of FAO data and Appendix Z of the Marrakesh Accords. For the non-Annex I regions, we applied the lowest Annex I forest management credit per area unit, and multiplied this by the forest area. This led to total sinks of about 550 $MtCO_2$.

Scientific uncertainties – In terms of scientific uncertainties we focused on four issues: 1) the MAC curves, 2) baseline emissions, 3) transaction costs and 4) the CDM accessibility factor. For the MAC curves, the results of using the TIMER versus the POLES MAC curves were explored. For baseline emissions, we compared results against high and low-emission scenarios. For transaction costs, we looked into the impact of high and low estimates in the literature. Finally, for CDM accessibility, we explored a 10-30% range.

5 In reality, there are some policy uncertainties concerning the participation of countries in the global carbon market.

3 The significance of the Annex I and non-Annex I reduction ambition

3.1 Background

The reduction targets for Annex I and non-Annex I countries relate both to the demand and supply side of the international carbon market and have a major impact on the functioning of the carbon market.

In addition to the question of the overall reduction target of Annex I countries, a key political factor that has bearing on this aspect is the level of action that might be taken by the USA. In the current climate negotiations, this is likely to influence the level of ambition for the entire agreement. A stronger level of action by the USA would likely lead to more action from others, and a lower level of action to less action from others. The USA committed to reduce its emissions by 7% relative to the 1990 level in Kyoto, but ultimately did not ratify the Protocol. In the meantime, US GHG emissions increased to around 15% above 1990 levels in 2005 (UNFCCC 2008). Still, both the US Senate and House of Representatives have been actively engaged in a thorough debate on climate change legislation (e.g., Paltsev et al. 2007). Important elements included in most proposals that are debated are an economy-wide cap-and-trade system and a long time horizon (2050). Although the proposed US targets do not seem as ambitious as the EU targets, they involve significant emissions reductions relative to the business-as-usual scenarios.

On 18 November 2008, President Elect Barack Obama (USA) declared during a taped speech for the Bi-Partisan Governors Climate Summit, that he had the intention to establish an economy-wide cap-and-trade system with stringent annual targets that would set the USA on a course to reduce emissions to their 1990 levels by 2020, and to 80% below the same reference by 2050. Although the debate on climate change policy in the US Congress is primarily focused on the US, most of the bills also allow limited emission trading and project-based offsets in line with the current flexibility mechanism under the Kyoto Protocol. The most relevant bills also include provisions on REDD, which together with international trading, would link the US carbon market to the international carbon markets. A relevant issue to bear in mind is the potential difficulties at the time of ratifying an international climate change agreement in the US Senate. Such problems appeared before and after the ratification of the Kyoto Protocol. However, the debate on the climate issue has evolved considerably over the last two years, and both the new Administration and the Congress majority leaders are committed to dealing with it. Nevertheless, the time constraints imposed under the Bali roadmap and current economic crisis might make it difficult for the USA to get onboard in the near term.

The Bali Action plan calls for nationally appropriate mitigation actions by DC Parties in the context of sustainable development, supported and enabled by technology, financing and capacity-building in a measurable, reportable and verifiable manner. However, the key issue for non-Annex I countries is the mitigation ambition and its relationship to their participation on the carbon market. Currently, voluntary participation in the carbon market through the CDM provides a way to engage non-Annex I countries. For the default scenario we assumed that emission credits could be traded freely between all Annex I and all advanced developing countries (ADCs) that had accepted emission reduction targets and participated in IET. For the other developing countries we assumed no reduction targets and the possibility of participating in CDM. However, the question was how to achieve the emission reduction of 15-30% compared to baseline. At this point it appeared interesting to distinguish between the ADCs and the rest of developing countries. The latter would probably need to be engaged through an enhanced project-based crediting mechanism like the CDM. However, engaging the ADCs to take on caps in the near term is going to require a proper burden sharing and the opening of developed countries' carbon markets to emission allowances from the ADCs.

3.2 Results

Table 3 presents the results for the default scenario (Table 1), and the first set of alternative scenarios. It shows emission reductions relative to 1990 levels for Annex I and relative to baseline for non-Annex I, and carbon price and abatement costs in terms of change in GDP for the global carbon market. The emission reductions are expressed in terms of anthropogenic CO_2-equivalent emissions of the six Kyoto GHGs, excluding LULUCF CO_2 emissions.[6]

In the *default scenario*, the global abatement costs in 2020 are around 0.4% of the world GDP. The abatement costs of Annex I are significantly higher than those of non-Annex I, and are obviously affected by the reduction commitments adopted by the non-Annex I countries and the related availability of carbon credits from flexibility mechanisms outlined in the Kyoto Protocol (i.e. CDM and emissions trading). Figure 1 shows the abatement by origin for Annex I and non-Annex I. It depicts domestic abatement, IET and Joint Implementation (JI), and CDM. For Annex I most of the abatement (approximately 75-80%) takes place domestically. It should be noted that in these scenarios we assumed that non-Annex I countries finance their own reduction commitments. Overall, the Annex I countries as a group act as net buyers in the market, while the ADCs (via the IET) and other developing countries (via the CDM) are net sellers. Some 80-90% of the total traded amount in the IET comes from the ADCs and among them, the largest supplier is China.

Table 3 also shows the reductions after trading and CDM for the *default scenario*. The Annex I reduction levels after trade and CDM are lowered to about 23% below 1990 levels (from 30%). Consequently, Annex I countries need to acquire an amount of emission credits through offsetting mechanisms equal to 7% of their 1990 emissions. Non-Annex I countries reduce their emissions by around 20% compared to baseline, 5% of which can be sold through the carbon market (5% of 2020 baseline emissions of developing countries is equal to 7% of 1990 emissions in developed countries). This means that 15% of reductions in non-Annex I countries would still need to come from autonomous actions that are not directly supported by the carbon market.

Table 3 presents net abatement costs consisting of the domestic abatement costs and the financial revenues or expenditure for carbon trade or CDM. The contribution of these elements and the benefits of carbon trading are shown in Table 4. Column (1) in Table 4 gives the domestic reduction costs to countries for meeting their own reduction target (therefore 15% for non-Annex I, about 93 billion US$) and column (2) the total domestic costs for meeting their reduction level after trade and CDM (therefore −20% for non-Annex I, about 155 billion US$). Column (3) gives the transfers on the carbon market (including transaction costs for Annex I): 104 billion US$ for non-Annex I (for 5% reduction below baseline).

Consequently, non-Annex I countries do implement additional domestic reductions to offset reductions in Annex I in the order of 155−93= 62 billion US$, for which they receive 104 billion US$, a gain of 42 billion US$. The price paid for the additional domestic reduction is assumed to be equal to the highest experienced marginal abatement cost for the non-Annex I countries that are selling credits. This is still below the carbon price in Annex I countries. In conclusion, emissions trading and CDM creates a gain of 42 billion US$ for non-Annex I countries, which can be used to pay part of their emission reduction costs (93 billion US$).

Annex I countries also benefit substantially from this trade and CDM with non-Annex I countries. Even though the acquisition of the credits costs them 113 billion US$, they reduce their domestic costs by 179 billion US$ from 342 billion US$ – in case of no trade – to 163 billion US$ – in case of trade. This represents a net gain of 66 billion US$.

[6] Emissions from these LULUCF sources are highly uncertain and emission estimates from various sources are often not consistent (see Section 4).

Comparing Table 4 with Figure 1 also shows that although the emission credits traded in tonnes form a relatively small part of the total abatement (Figure 1), these represent rather significant financial flows (column (3) in Table 4). This has much to do with the fact that these emissions credits are traded against the carbon price on the market, which is well above the highest MAC within the non-Annex I countries.

Table 3. The emission reductions and abatement costs of the Annex I and non-Annex I reduction cases in 2020 (Annex I 25% and 40% cases assume Annex I emissions 25% and 40% below 1990 levels by 2020; non-Annex I 10% and 20% cases assume non-Annex I emissions 10% and 20% below baseline emission levels).

Case	Annex I emissions compared to 1990 levels	Non-Annex I emissions compared to baseline	Global emissions compared to 1990	Carbon price	Annex I costs	Non-Annex I costs	Global costs
	%* (%)v	%* (%)v	%* (%)v	US$/ tCO_2-eq	% of GDP	% of GDP	% of GDP
Default case	−30 (23)	−15 (19)	28 (28)	77	0.54**	0.19**	0.42**
Annex I 25%	−25 (21)	−15 (17)	31 (31)	65	0.37	0.24	0.33
Annex I 40%	−40 (24)	−15 (20)	22 (26)	89	0.93	0.11	0.64
Non-Annex I 10%	−30 (19)	−10 (17)	32 (32)	61	0.49	−0.06	0.29
Non-Annex I 20%	−30 (26)	−19 (21)	23 (24)	112	0.61	0.55	0.59

* Excluding LULUCF CO_2 emissions; v Values in parenthesis show the reductions after trade and CDM. ** In terms of billion US$: Annex I: 275, non-Annex I: 50 and world: 325.

Table 4. Compliance costs and trading gains at the global scale and for Annex I and non-Annex I, by 2020 for the default scenario.

Case	(1) Total domestic costs (no trade)	(2) Total domestic costs (after trade & CDM)	(3) Total revenues or expenditure for carbon trade	(4) Total costs taking into account revenues or expenditure for carbon trade (= (2) + (3))	Gains from trade (= (1) − (4))
	Billion US$	Billion US$	Billion US$	Billion US$	Billion US$
World	435	326	0	326	109
Annex I	342	163	−113*	275	66
Non-Annex I	93	155	104	51	42

- Including transaction costs

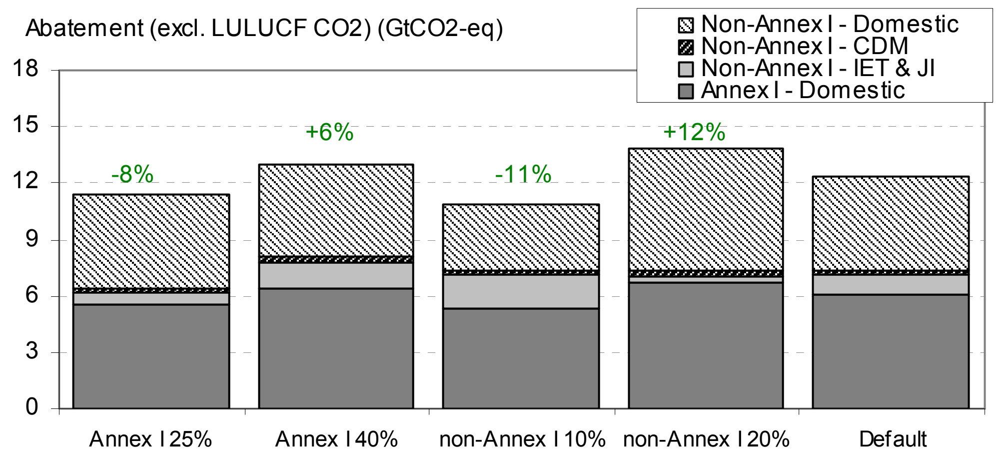

Figure 1. Overview of the Annex I and non-Annex I abatement by 2020 for the Annex I and non-Annex I reduction cases compared to the default case. Note that the IET & JI and CDM are only the transfers between Annex I and non-Annex I countries, and that not all transfers are on the carbon market, including the transfers between the Annex I countries and between non-Annex I countries.

We will now explore the alternative scenarios with different Annex I reduction targets and demand, i.e. a 25% and 40% reduction below 1990 levels (cases: *Annex I 25%* and *Annex I 40%*). These alternative targets correspond with the upper and lower limits of the Annex I reduction range under consideration by the AWG-KP, which are consistent with the Annex I reduction range for meeting the 450 ppm CO_2-eq stabilization target (lowest category) suggested by the IPCC in its latest report.
Increasing the reduction objective to 40% for Annex I countries slightly decreases the domestic abatement fraction (Figure 1). It increases the carbon price by around 15%, due to the higher demand for emission credits from the Annex I countries. The abatement costs increase by 55% (Figure 2).

Decreasing the Annex I reduction target to 25% below 1990 levels lowers the global abatement costs by 20%. However, as Table 5 shows, this translates into global emissions around 30% above 1990 levels by 2020, which would hit the upper limit of the 15% to 30% global emissions range that is consistent with stabilisation at 450 ppm CO_2-eq (den Elzen et al. 2007). As noted previously, this 450 ppm profile already allows a temporary overshoot of the concentration target. A further overshoot increases the necessary effort afterwards, shifting the burden into the future. Finally, the Annex I reductions after trade and CDM for the *Annex I 25%* and *Annex I 40%* cases show a much smaller range, only 21% to 24% below 1990 levels, instead of 25% to 40% before trade (Table 3).

Regarding non-Annex I reduction, we looked at two alternative cases: a 10% and 20% reduction below baseline levels (cases: *non-Annex I 10%* and *non-Annex I 20%*), leading to reductions below the baseline of 15% and 25%, respectively, for the ADCs, and 0% and 15% for the other developing countries. We did not explore higher non-Annex I reduction ranges here, as this would lead to higher abatement costs for the non-Annex I countries at almost the same level as Annex I (Table 3). Increasing the non-Annex I reduction target also leads to less CDM and emissions trading with Annex I, and increases the carbon price and the Annex I costs (see Figure 1). For the 10% non-Annex I reduction case, we saw an opposite pattern, i.e. lower costs for non-Annex I, a lower carbon price, more emissions trading between Annex I and ADCs, and lower Annex I costs.

In both cases, the resulting global emissions fall within the range consistent with meeting the 450 ppm CO_2-eq target. The Annex I reductions, after trade and CDM for both non-Annex I cases, show an even wider range (19-26% below 1990 levels) than in the earlier Annex I cases (21-24% below 1990 levels), indicating that other non-Annex I reduction targets have an even higher impact on the Annex I reductions after trade.

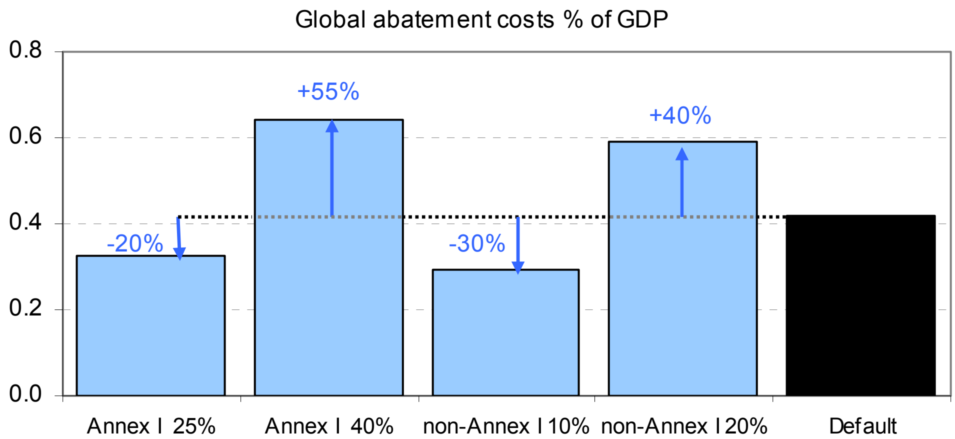

Figure 2. Global abatement costs as a percentage of the GDP for 2020 for the Annex I and non-Annex I reduction cases, compared to the default case.

Regarding the participation of the USA, we explored the case in which only the USA would adopt a domestic target aiming at 1990 levels by 2020 (*US only domestic*), and all other Annex I and non-Annex I countries would adopt the same reduction target as under the default scenario. The resulting global emissions are still compatible with meeting 450 ppm (Table 5).[7] Compared to the default scenario with a USA reduction target of −15% below 1990 levels, a return to 1990 levels is less stringent, and cuts the abatement costs for the USA in half. The global abatement costs decrease by 18% (Figure 4).

Next we explored the impact of the two extreme cases, i.e., all developing countries participating in CDM (*Only CDM DCs*) or participating in the international carbon market via IET (*Full participation DCs*). Note that for both cases in this sensitivity analysis, the developing countries adopt the same reduction target.[8] The global abatement costs decrease by 12% under Full Participation DCs and increase by 5% under the Only CDM DCs scenario (Figure 4 and Table 5). The carbon price for the only CDM DCs case is much higher than the other scenarios (Table 3). Interestingly, for the developing countries the higher carbon price compensates the lower traded volumes, as the net revenues (carbon price times traded volumes) are higher under the CDM case than under the default case. As a result, in the CDM case the costs for non-Annex I countries are lower. The full participation case also leads to lower costs for non-Annex I than the default case, but for the opposite reason: the increased traded volumes compensate the lower carbon price.

The cases do affect the Annex I reduction after trade, up to 20% below 1990 levels for the full participation case instead of −23% for the default case. In Section 5 we will analyse the robustness of these results using POLES MAC curves.

Table 5 The emission reductions and abatement costs by 2020 of the carbon-market participation cases (the Full Participation DCs case assumes that all non-Annex I or developing countries (DCs) participate in IET; the Only CDM case assumes that non-Annex I countries participate in CDM and the US Only domestic case assumes that US commits to a domestic target of returning to 1990 levels by 2020)

Case	Annex-I emissions compared to 1990 levels	Non-Annex-I emissions compared to baseline	Global emissions compared to 1990	Carbon price	Annex-I costs	Non-Annex-I costs	Global costs
	%* (%)v	%* (%)v	%* (%)v	US$/ tCO_2-eq	% of GDP	% of GDP	% of GDP
Default case	−30 (23)	−15 (19)	28 (28)	77	0.54	0.19	0.42
US only domestic	−26 (21)	−15 (18)	30 (31)	69	0.40	0.23	0.34
Only CDM DCs	−30 (26)	−15 (17)	28 (28)	112	0.61	0.14	0.45
Full participation DCs	−30 (20)	−15 (20)	28 (28)	65	0.50	0.11	0.36

* Excluding LULUCF CO_2 emissions; v Values in parenthesis show the reductions after trade and CDM.

[7] Hare et al. (2009) has also analysed this US reduction target scenario in the context of meeting the 2-degree target.

[8] In reality this is less likely; in general only countries that adopt a more stringent reduction target may participate in the carbon market.

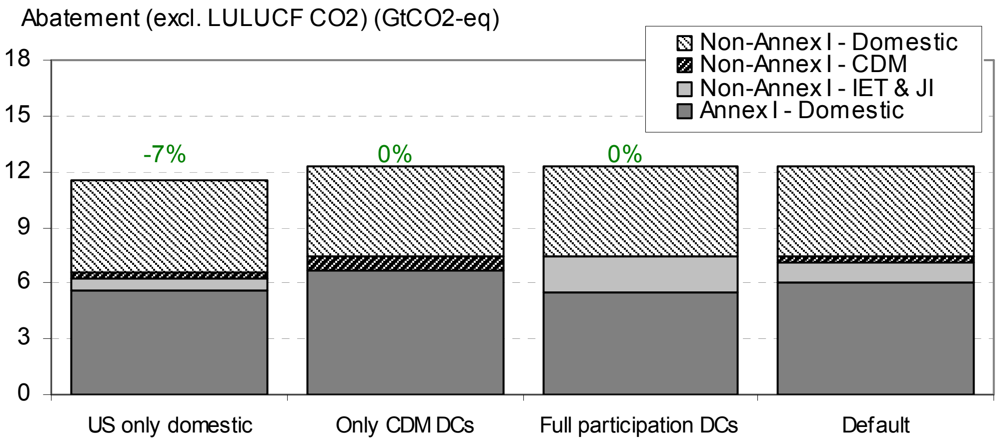

Figure 3. Overview of the Annex I and non-Annex I abatement in 2020 for the participation cases compared to the default case.

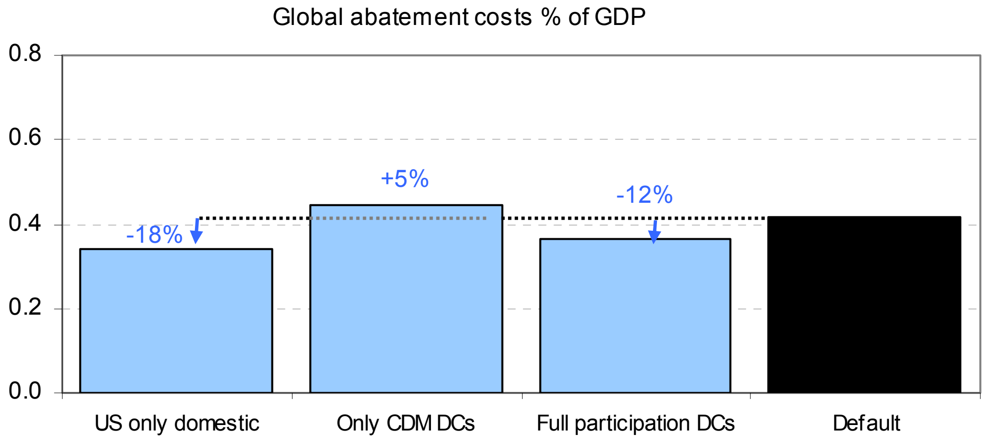

Figure 4. Global abatement costs as a percentage of the GDP for 2020 for the participation cases compared to the default case.

4 The importance of including the forestry sector in the carbon trading system

4.1 Background

The current Kyoto Protocol takes a somewhat fragmented approach to emissions and removals from forestry and other land use. So far, net removals, like those from AR and FM, can be used to offset emissions from other sectors, but the LULUCF sector is not an integral part of the "quantified emission limitations or reduction commitments" to which Annex I Parties have committed themselves (Trines et al. 2006).

However, the LULUCF CO_2 emissions are significant (15-20% of the global anthropogenic GHG emissions) and are predominantly located in non-Annex I countries. Reducing emissions from deforestation and forest degradation (REDD) could therefore significantly avoid emissions. In order to effectively reduce all greenhouse gas emissions, it would be helpful to include the forestry sector in a possible post-2012 mitigation regime. It could also create opportunities to deliver substantial funding for forest conservation and management while preventing irreversible loss of biodiversity and soil degradation.

REDD – There are different options in terms of the design and implementation to include REDD in a post-2012 climate agreement, e.g. more indirectly through a fund or fully integrated, via a market-based mechanism (e.g., Trines et al. 2006; Benndorf et al. 2007; Höhne et al. 2007; Karousakis and Corfee-Morlot 2007; Schlamadinger et al. 2007a; 2007b). In the case of fund-based mechanisms, it is often difficult to assess whether proposed sources of funding would be sufficient, especially because existing estimates of financing needs vary widely and pledges for funding (e.g. voluntary contributions) are not always fulfilled. Under the right conditions, a market-based mechanism (such as cap-and-trade) would be able to mobilise the financial resources necessary, including resources from the private sector as emphasised by Karousakis and Corfee-Morlot (2007). However, given the high uncertainty surrounding available emissions estimates from deforestation in developing countries, Karousakis and Corfee-Morlot concluded that the creation of markets for REDD by 2013 would be premature in the absence of significantly more effort to establish reliable systems for monitoring, reviewing and verifying performance. The Eliasch Review (Eliasch 2008) recommended that the inclusion of deforestation credits in carbon markets should be matched by more stringent reductions targets for Annex I countries in order to achieve a good balance between supply and demand. It should also not lead to leakage of emissions elsewhere (e.g. forestry companies relocating), and the reductions should be additional to those that would have occurred in the absence of intervention. A linking mechanism between deforestation and global carbon trading should be institutionalised as part of a wider global carbon market framework.[9]

AR and FM – Other ways to reduce forestry greenhouse gas emission are through afforestation-reforestation (AR) and forest management (FM). Currently, such activities can lead to offsets of emission reductions, thereby also influencing the functioning of the carbon market.

4.2 Results

In this section we will further analyse the costs savings of inclusion of emission credits from REDD, AR and FM in the carbon market (for earlier analysis see Rose et al. 2007; Anger and

9 The EU stated that deforestation credits could only become a realistic option if the conditions mentioned above are met. Presently, the EU is proposing a voluntary fund-based approach for REDD, i.e. the development of an international mechanism under the UNFCCC – the Global Forest Carbon Mechanism – through which developing countries will be rewarded for emission cuts achieved by REDD. The EU aims to cut global deforestation emissions by 50% (compared to present levels) by 2020, as also analysed in Kindermann et al. (2008).

Sathaye 2008; Dixon et al. 2008; Eliasch 2008; Piris-Cabezas and Keohane 2008). In its analysis, the Eliasch Review suggested that including REDD in a well-designed carbon trading system could provide incentives to reduce deforestation rates by up to 75% by 2030. With the addition of AR, this would make the forest sector carbon neutral. It would also reduce the costs of reducing global carbon emissions by up to 50% in 2030 and by up to 40% in 2050. Dixon et al. (2008) found a reduction of the Annex I costs by one-third by 2020. However, Piris-Cabezas and Keohane (2008) found that the impact of REDD on the near-term carbon prices – as a result of banking – would be more moderate than in the above-mentioned analysis.[10] Compared to a non-banking scenario, this results in higher carbon prices and abatement in the near term. In such a scenario, REDD becomes a natural candidate for banking, while becoming a cost-efficient measure for Annex-I countries and generating the necessary funding for potentially reducing the deforestation rates.

So far, all allocation studies cited by the IPCC Box 13.7, as described in den Elzen and Höhne (2008), did not include LULUCF CO_2 emissions or net deforestation emissions[11], as these emissions and projections are especially uncertain, and most studies assume that these emissions will follow the baseline (no policy) developments. Also, the calculations of this study so far have only presented emission reductions excluding LULUCF CO_2. According to most studies, including the IMAGE baseline, LULUCF CO_2 emissions are likely to show a decreasing trend for the period 1990-2020 (see Figure 5). Our analysis was similar to that in the Eliasch review; we included LULUCF CO_2 emissions and marginal costs information of REDD, ARD and FM activities from three global forestry and land-use models in our FAIR model (Figure 5). The three models are the G4M model (former DIMA) (Kindermann et al. 2006; Rokityanskiy et al. 2007; Kindermann et al. 2008), the Generalized Comprehensive Mitigation Assessment Process Model (GCOMAP) (Sathaye et al. 2005; 2006) and the Global Timber Model (GTM) (Sohngen et al. 2001; 2003). A brief description of each model is given in Kindermann et al. (2008).[12]

Comparing the results from these three models allowed us to assess the sensitivity of results for using different marginal costs estimates from land use models. It provides an indication of the uncertainties surrounding the REDD and AR projections, but the actual uncertainties may be even higher. For the GCOMAP and G4M model runs, we used updated input data as described in Sathaye et al. (2008) and Gusti et al. (2008)[13], with higher baseline CO_2 emissions from deforestation due to higher carbon intensity from forests and lower MAC due to lower opportunity costs (compared to their earlier studies). For the GTM model, we used two cases (i.e. *GTM-EMF* and *GTM-2008*): one based on the Energy Modeling Forum 21 (EMF) analysis (Sohngen et al. 2001; 2003), and the other from the analysis of Kindermann et al. (2008). The endogenous deforestation baselines for the two GTM cases differ completely (Figure 5). The GTM-EMF MACs present the lowest REDD supply[14], but have the advantage of including estimates of AR and FM activities. In addition, we inferred the REDD MACs of GTM-EMF by using rising CO_2 price scenarios, which provide a better reflection of the resulting global market carbon price paths (Piris-Cabezas and Keohane 2008) than the constant CO_2 price scenarios. These were used to construct the REDD MACs in Kindermann et al. (2008), for example. Note that for GTM-2008, no ARD MACs were available which are consistent with their REDD MACs.

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[10] Their model solves for an intertemporal equilibrium of the carbon market in a case with credible and sound commitments to tackle climate change.

[11] I.e. deforestation CO_2 emissions minus the removals from forestry and other land use.

[12] The above three models were used in the IPCC AR4 overview of the potential of mitigation measures of global forestry activities (AR, REDD and FM) (see Table 9.3 in Nabuurs et al. 2007).

[13] The costs of carbon storage resulting from avoided deforestation are calculated using further land use and management simulations with carbon prices between \$0 and \$100 per ton CO_2.

[14] The baseline used in that analysis presents land-use change estimates for tropical regions that differ substantially from the rest of projections, which suggest higher initial deforestation, declining over time. In contrast the GTM-EMF baseline – by considering more conservative estimates of land use change than those reported by FAO – suggests less initial deforestation, but persisting during the century (Sohngen and Sedjo 2006).

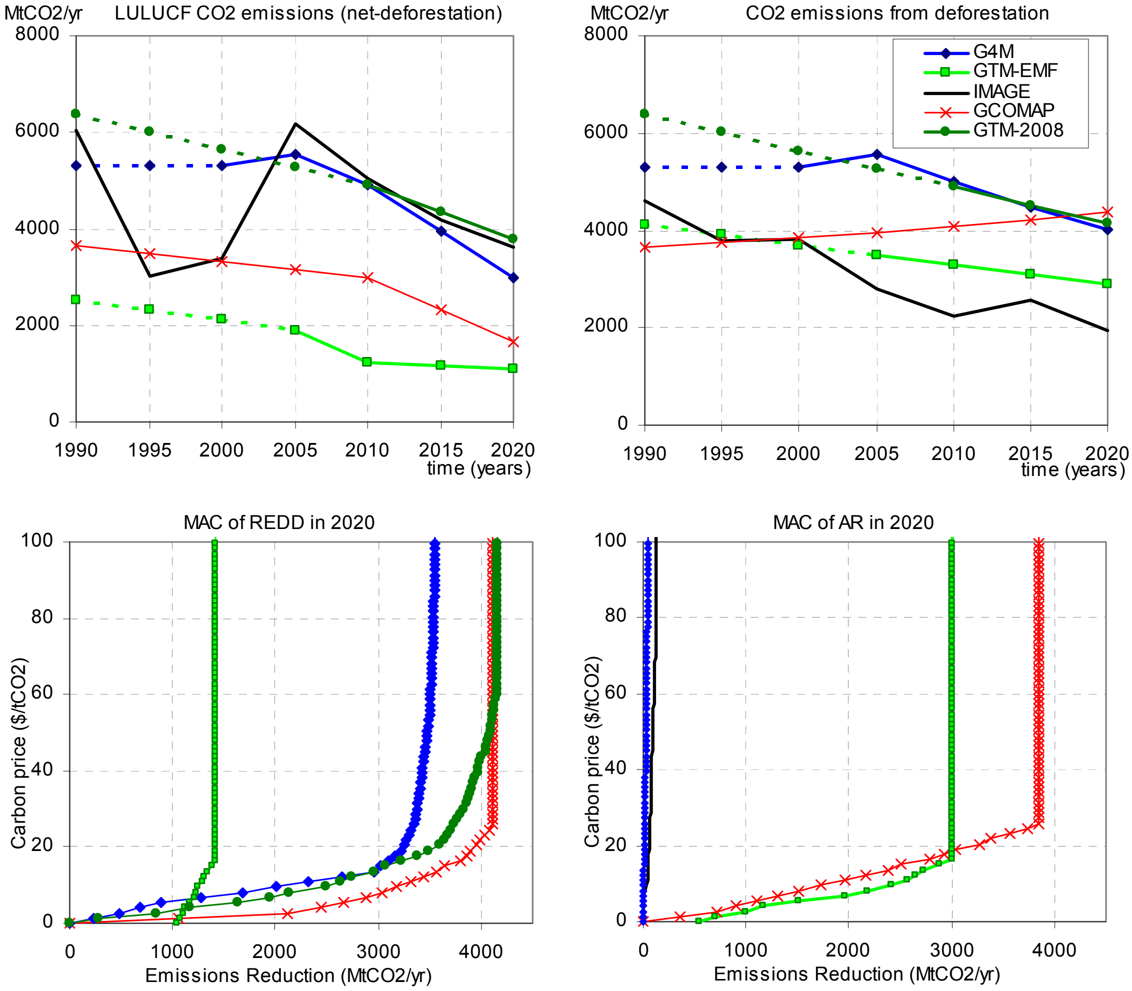

Figure 5. Baseline LULUCF CO_2 or net deforestation emissions (left upper figure), and CO_2 emissions from deforestation (right upper figure) for the time period 1990-2020 (left) and global MAC curves[15] of REDD (left lower figure) and ARD (right lower figure) of the three models (GTM, GCOMAP and G4M) and IMAGE model in 2020. Note that IMAGE does not include MAC curves for REDD, GTM-2008 does not include a MAC curve for AR or FM and only GTM includes managed forest as a LULUCF activity in the AR+FM MAC. The dashed lines in the deforestation baselines are the years for which the emissions were assumed to be extrapolated backwards to 1990, leading to emissions coherent with the decreasing deforestation emissions trend of IPCC. The dashed lines in the LULUCF, or net deforestation CO_2 emissions, are calculated by the deforestation emissions minus removals from forestry and other land use, which are assumed to remain constant in this period.

Kindermann et al. (2008) compared the REDD MAC curves of these three models, which differ across models for a number of reasons, including the input datasets (e.g., underlying estimates of the opportunity costs of land), modelling methodologies and assumptions (e.g., deforestation rates over time, land area in forest in 2000 and beyond, and land available for mitigation), drivers for land use change and ecological parameters (e.g., carbon per ha). GCOMAP and GTM-2008 generally result in the lowest MAC REDD estimates (i.e. the largest emission reduction per dollar spent) (Figure 5, left lower figure). GTM-2008 model takes into account lower land opportunity costs and higher carbon densities per ha compared to the two other models. GCOMAP considers a higher average of the annual global deforested area. G4M projects the highest global estimates of marginal costs in 2020. The three models suggest

[15] The MAC curves are in 2000 US$, and have been converted into 2005 US$ for the calculations.

unanimously that the lowest-cost region is Africa, followed by Central and South America and South-East Asia.

Figure 5 also shows the MAC curves of AR. Compared to GCOMAP and GTM-EMF, G4M shows a very low reduction potential for AR. Until now, a thorough analysis of the underlying assumptions of these models – explaining the range of outcomes – has not be made, except for REDD in Kindermann et al. (2008). Factors that play a role are uncertainties like the baseline, yield changes and biofuel demand. According to GCOMAP and GTM-EMF estimates, under a scenario with high initial carbon prices in the near term and sustained prices over time, the global carbon sequestration potential by means of AR is significant. A large share of AR activities takes place in the tropical regions but the contribution from temperate regions is also important. If climate policy is actually introduced at a later time, the time lag associated with AR activities implies that the sequestration potential would be lower. Furthermore, for GCOMAP and GTM-EMF, the deforestation baselines are lower than the estimates from the other models (Figure 5), which means, among other things, that the underlying demand for land is also lower. This explains at least partially why the supply of AR is much larger for these two models.

The AR MAC of the IMAGE model (Strengers et al. 2008) is particularly low for two reasons: 1) IMAGE only includes abandoned agricultural land in the current set of MACs; this land only becomes available later in time – when less agricultural land is needed in some regions as a result of stabilising population levels and shifting trade patterns (however, the land use scenario used here assumes expansion of agricultural land in the first decades), and 2) the criteria on net carbon uptake included in the IMAGE calculations are rather strict.

Next we will present the results for the following scenarios (see Table 6): four REDD-only cases of the three models (note that we consider both the GTM-EMF and GTM-2008); two REDD and AR (combined) cases for GCOMAP and G4M; and one REDD, AR and FM case (only for GTM-EMF) and one AR-only case for IMAGE (IMAGE-AR), based on the work of Strengers at al. (2008) using the integrated land IMAGE model. For purposes of comparison, we also calculated the default cases for each land use model, which exclude any reduction from REDD or AR, but include the LULUCF CO_2 emissions (i.e. net deforestation baselines) from each model.

Table 6. The REDD and AR cases

Case	Baselines	REDD (MAC curve)	AR (MAC curve)
GCOMAP REDD	GCOMAP	Included	Excluded
G4M REDD	G4M	Included	Excluded
GTM-EMF REDD	GTM-EMF	Included	Excluded
GTM-2008 REDD	GTM-2008	Included	Excluded
GCOMAP REDD-AR	GCOMAP	Included	Included
G4M REDD-AR	G4M	Included	Included
GTM-EMF REDD-AR-FM	GTM-EMF	Included	Included (plus FM)
IMAGE AR	IMAGE	Excluded	Included
Default IMAGE	IMAGE	Excluded	Excluded

For the calculation of all cases we assumed that the developing countries adopt the same reduction targets as indicated in Table 2 for the model-dependent baseline LULUCF or net deforestation CO_2 emissions (Figure 5). The LULUCF CO_2 emissions, together with the global GHG emissions cap excluding LULUCF CO_2, form the overall global GHG emissions cap in 2020. For all land-use models, the resulting caps differ due to the LULUCF CO_2 emissions (model-dependent). The caps are 17%, 20%, 18%, 16% and 17% above 1990 levels for IMAGE, GCOMAP, G4M, GTM-EMF and GTM-2008, respectively, all within the 15-25% global emission limit for meeting 450 pm.

Given the lead time of REDD policy development[16], we also assumed an implementation factor of REDD policies of 100% by 2020 for the ADCs that participate in IET and 20% for the other developing countries (Table 2). Given these conditions, we determined that the total reduction

[16] Given the effort needed to establish reliable systems for monitoring, reviewing and verifying performance.

of REDD implementation (Table 7) would be about 55%, 75%, 65% and 55% of the total reduction for the price level (Figure 5, and note in Table 8) for GCOMAP, G4M, GTM-EMF and GTM-2008, respectively.

Figure 6 presents the global abatement costs. Compared to the default IMAGE case[17], including REDD decreases the total abatement costs from 20% for GTM-EMF REDD up to 43% for G4M REDD (Table 7). The reduction in costs takes place mainly in the non-Annex I countries (Table 7); this ranges from around 0.25% of GDP for the default cases to small gains for the REDD cases. For the Annex I countries, including REDD only leads to a 10-15% reduction of the costs. Including REDD in the carbon and trade system leads to less domestic reduction for the Annex I countries, and more IET and CDM; consequently, there are more financial flows from Annex I to non-Annex I (Figure 7). ADCs, like Brazil, also use REDD to meet their own reduction targets.

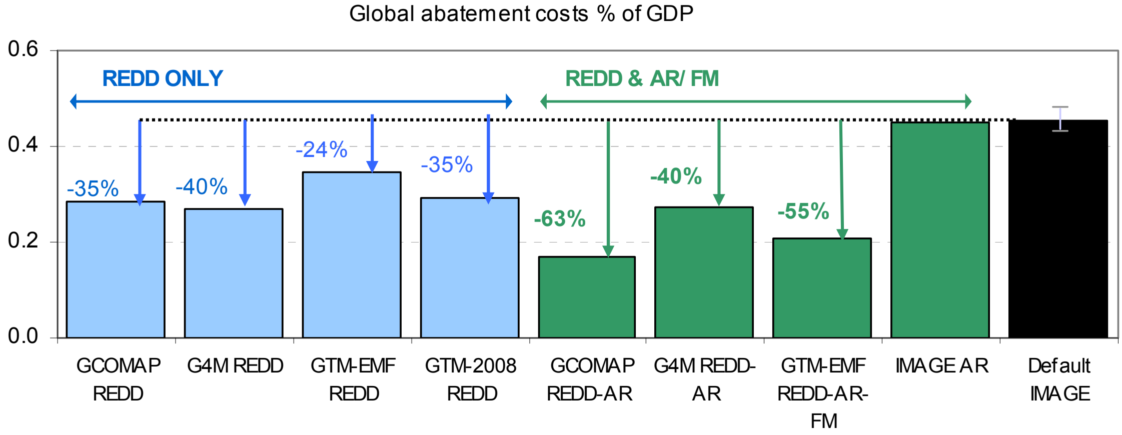

Figure 6. Global abatement costs as a percentage of GDP for 2020 for the REDD and AR cases, compared to the default case. The error bar in the default case gives the range of outcomes from the default cases from the three land-use models.

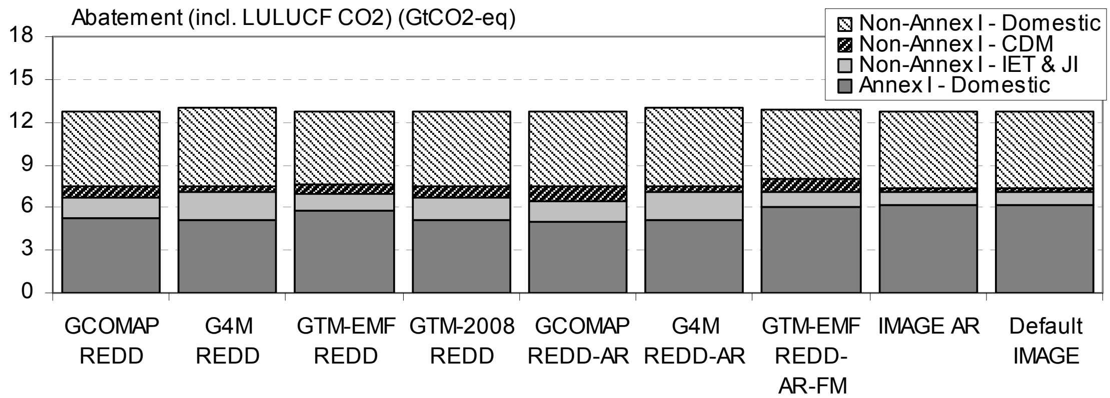

Figure 7. Overview of the Annex I and non-Annex I abatement in2020 for the REDD and AR cases, including the default case for comparison.

If AR and FM are also included, the abatement costs are reduced even more: to 55% for GTM-EMF and to 63% for GCOMAP (Figure 6). The only exceptions are G4M REDD-AR and IMAGE, due to the low reduction potentials of AR (see also Figure 5). Including AR has a limited net effect on the trade flows between Annex I and non-Annex I (Figure 7). Only for GTM-EMF is there a slight increase in the domestic abatement for Annex I countries, i.e. from 70% in the REDD case to 82% in the REDD-AR-FM case; this is due to the significant AR mitigation potential in Annex I countries.

[17] The IMAGE default case has global abatement costs of 0.45% of world GDP, and this ranges from 0.43-0.47% for the default cases, which are included in Figure 6 by means of error bars.

Table 8 shows the Annex I and non-Annex I emission reductions from REDD and AR, and the reductions in the global CO_2 emissions from deforestation and net deforestation. The G4M, GCOMAP and GTM-2008 models show the higher reductions of 2-3GtCO_2/yr from REDD and a reduction in deforestation of 50-70% compared to baseline emission developments. GTM-EMF, having the lowest baseline, shows the lowest absolute reduction in REDD and deforestation costs. If AR is included alongside REDD in the global cap and trade system, an additional 2.5 Gt CO_2 is projected to be sequestered for the GCOMAP and GTM-EMF runs, but is very limited for IMAGE and G4M. Table 8 shows that for GCOMAP there are more reductions for AR in non-Annex I than in Annex I countries. For GTM-EMF, there is the opposite pattern. The introduction of AR/FM in addition to REDD emission credits shows a total reduction in global emissions from REDD and AR/FM of between 2.8 to 4.7 GtCO_2/yr. The inclusion of AR and FM does not lead to further reduction in the deforestation emissions with respect to the REDD cases because AR and FM increase the sinks, and thus decrease the emissions from net deforestation. GTM-EMF shows a reduction of more than three times the net emissions from deforestation. GCOMAP shows a reduction of almost three times the baselines for this model in 2020.

Table 7. The emission reductions and abatement costs in 2020 of the REDD and AR cases, including the default IMAGE case and the default cases of the other land use models for comparison.

Case	Annex-I emissions compared to 1990 levels	Non-Annex-I emissions compared to baseline	Global emissions compared to 1990[a]	Carbon price	Annex-I costs	Non-Annex-I costs	Global costs
	%* (%)[v]	%* (%)[v]	%* (%)[v]	US$/t$CO_2$-eq	% of GDP	% of GDP	% of GDP
GCOMAP REDD	−32*(−20)[v]	−15*(−21)[v]	20*(20)[v]	58	0.48	−0.07	0.28
G4M REDD	−30*(−18)[v]	−15*(−21)[v]	18*(18)[v]	56	0.45	−0.06	0.27
GTM-EMF REDD	−31*(−19)[v]	−14*(−20)[v]	17*(16)[v]	70	0.52	0.02	0.34
GTM-2008 REDD	−30*(−20)[v]	−14*(−20)[v]	17*(17)[v]	58	0.47	−0.04	0.29
GCOMAP REDD-AR	−32*(−18)[v]	−15*(−22)[v]	20*(20)[v]	38	0.30	−0.08	0.17
G4M REDD-AR	−30*(−18)[v]	−15*(−22)[v]	18*(18)[v]	56	0.45	−0.06	0.27
GTM-EMF REDD-AR-FM	−31*(−24)[v]	−14*(−20)[v]	17*(15)[v]	55	0.35	−0.05	0.21
IMAGE AR	−30*(−23)[v]	−14*(−17)[v]	17*(17)[v]	82	0.55	0.27	0.45
Default IMAGE	−30*(−23)[v]	−14*(−18)[v]	17*(17)[v]	82	0.55	0.27	0.45
Default GCOMAP	−32*(−25)[v]	−15*(−18)[v]	20*(20)[v]	81	0.55	0.26	0.45
Default G4M	−30*(−24)[v]	−15*(−18)[v]	18*(18)[v]	82	0.55	0.32	0.47
Default GTM-EMF	−31*(−24)[v]	−14*(−18)[v]	17*(17)[v]	78	0.54	0.21	0.43
Default GTM-2008	−30*(−24)[v]	−14*(−17)[v]	17*(17)[v]	81	0.55	0.27	0.45

[a] The global emissions including LULUCF CO_2 differ between the models (Figure 5). The emissions excluding LULUCF CO_2 are the same for all models. * Including LULUCF CO_2 emissions; [v] Values in parenthesis show the reductions after trade and CDM.

Table 7 also shows the reductions after trading and CDM. For the default case the Annex I reduction after trade and CDM was lowered to about 23% below 1990 levels (from 30%) at the expense of higher reductions of non-Annex I, to almost 20% below baseline. For the other default cases, the variations in these numbers are only 1-2 percentage points; the higher value is for GCOMAP. Including REDD lowers the Annex I reductions after trade and CDM even further, to 18-20% below 1990 levels. This is because most REDD reductions are taking place in non-Annex I countries, and part of the reductions are used to offset the Annex I reductions via CDM and emissions trading. Consequently, non-Annex I countries will abate more, to about 20%. For example, for the GCOMAP default case, the emission reductions for Annex I decrease from about 32% below 1990 levels to 25% below 1990 levels after trade. Including REDD decreases this further – to 20%, so an additional 5% is achieved using offsets from REDD emission credits.

After the additional introduction of AR, the reductions after trade do not change for IMAGE and G4M. For GCOMAP with more reduction AR in non-Annex I, the Annex I domestic reduction (after trade) decreases even further to 18% below 1990 levels, which is much lower than the 25% for the default GCOMAP case. For GTM-EMF, with relatively more reduction of AR in the Annex I than GCOMAP, the domestic reduction of Annex I increases again, from 19% for the REDD case to 24% for the REDD-AR-FM case.

Table 8. The reductions from REDD and AR and the resulting CO_2 emissions from deforestation and LULUCF in 2020.

Case	REDD Annex-I	Non-Annex-I	AR Annex-I	Non-Annex-I	Total Annex-I	Non-Annex-I	Deforestation emissions compared to baseline	Net deforestation emissions compared to baseline
	($GtCO_2$)	($GtCO_2$)	($GtCO_2$)	($GtCO_2$)	($GtCO_2$)	($GtCO_2$)	(in %)	(in %)
GCOMAP REDD [x]	0.0	2.2	0.0	0.0	0.0	2.2	−50%	−132%
G4M REDD [x]	0.2	2.6	0.0	0.0	0.2	2.6	−69%	−93%
GTM-EMF REDD [x]	0.0	0.9	0.0	0.0	0.0	0.9	−32%	−83%
GTM-2008 REDD [x]	0.0	2.2	0.0	0.0	0.0	2.2	−54%	−59%
GCOMAP REDD-AR	0.0	2.2	1.1	1.4	1.1	3.6	−50%	−278%
G4M REDD-AR	0.2	2.6	0.0	0.0	0.2	2.6	−69%	−94%
GTM-EMF REDD-AR-FM	0.0	1.0	1.6	0.9	1.6	2.0	−36%	−322%
IMAGE AR	0.0	0.0	0.0	0.0	0.0	0.0	0%	−1%
Default IMAGE	0.0	0.0	0.0	0.0	0.0	0.0	0%	0%

* Including LULUCF CO_2 emissions. The reductions for the GHG emissions excluding LULUCF CO_2 are similar than those for the default case in Table 3. [v] Values in parenthesis show the reductions after trade and CDM. [x] The maximum reduction for the price level shown in Table 7 are: GCOMAP: 4.1$GtCO_2$, G4M: 3.5$GtCO_2$, GTM-EMF: 1.4 $GtCO_2$ and GTM-2008: 4.1 $GtCO_2$.

5 The impact of scientific uncertainties

5.1 Background

In this section we will examine the impact of a range of scientific uncertainties, i.e. the different MAC curves and baseline emissions and various assumptions on transaction costs and the CDM accessibility factor (Table 1). For the MAC curves we used those derived from the energy model POLES[18] (Criqui et al. 1999) (i.e. the POLES-Enerdata (2007) version) in combination with their associated baseline scenario.[19] This baseline is consistent with our default IMAGE/TIMER baseline (van Vuuren et al. 2009). For the model analysis of the MAC curves we focused on the Annex I and non-Annex I reduction cases, as analysed in Section 3. For baseline emissions, we used a high and low-emission scenario, i.e. updated IMAGE implementations of the IPCC SRES B1 and A1b scenarios.[20] For the CDM accessibility, which is 20% for the default case, we used a 10-30% range, based on the value assumed for the Kyoto period and three times this value. For the transaction costs, we looked at the impact of two extreme variants: zero costs and costs five times as high as the default values.

Table 9. The emission reductions and abatement costs in 2020 of the Annex I and non-Annex I reduction cases using POLES-Enerdata MAC curves.

Case	Annex-I emissions compared to 1990 levels	Non-Annex-I emissions compared to baseline	Global emissions compared to 1990	Carbon price	Annex-I costs	Non-Annex-I costs	Global costs
	%* (%)v	%* (%)v	%* (%)v	US$/ tCO_2-eq	% of GDP	% of GDP	% of GDP
Default case	−30*(−16)*	−15*(−23)*	23*(23)*	39	0.34	−0.02	0.21
Annex I 25%	−25*(−14)*	−15*(−21)*	26*(26)*	34	0.25	0.02	0.17
Annex I 40%	−40*(−19)*	−15*(−26)*	17*(19)*	48	0.55	−0.12	0.31
Non-Annex I 10%	−30*(−13)*	−10*(−21)*	27*(27)*	32	0.30	−0.11	0.16
Non-Annex I 20%	−30*(−19)*	−19*(−26)*	19*(19)*	47	0.37	0.11	0.28

* excluding LULUCF CO_2 emissions.

5.2 Results

MAC curves – For all cases Table 9 shows a lower carbon price and lower costs for the POLES MAC curves than for the TIMER MAC curves (compare Table 9 with Table 3). The costs results even show small gains for non-Annex I. The differences between the POLES and TIMER models are not straightforward. While the two models start from a common baseline, there are differences in the assumptions about technology development (induced or otherwise), abatement potential and the ability to substitute different technologies. Some clear differences may play a role. TIMER uses a multinomial logit function mechanism[21] to describe substitution among end-use energy carriers, different forms of electricity generation (coal, oil, natural gas, solar/wind and nuclear) and substitution between fossil fuels and bio-energy. In contrast, POLES uses full optimisation, possibly leading to lower costs. Secondly, inertia (technology lifetimes) might be longer in TIMER. It should be noted that in the long term (2030-2050), the TIMER MAC curves lead to lower abatement costs due to more optimistic assumptions on

18 The POLES model is a world simulation model for the energy sector. It works in a year-by-year recursive simulation and partial equilibrium framework, with endogenous international energy prices and lagged adjustments of supply and demand by world region.

19 For a sensitivity analysis of TIMER MAC curves with different assumptions on the costs and potential of carbon capture and storage, bio-energy and non-CO_2 abatement, see den Elzen et al. (2008b).

20 We used the information from a recent study by den Elzen et al. (2008b), scaling the costs for Annex I and non-Annex I and globally for the their B2, A1b and B1 scenarios; these scenarios were based on the information from the World Energy Outlook 2004, instead of 2006 (which is the case here).

21 This function assigns market shares based on production costs and preferences (cheaper, more attractive options get a larger market share; but there is no full optimisation).

learning effect and technological improvements in TIMER. Another important distinction is that in TIMER there is more convergence in abatement costs curves across regions.

If we compare Figure 8 with Figure 1, we also see that the carbon credits traded via the IET and reductions off-sets by CDM are much higher (almost by a factor of two) for the POLES MAC curves than for TIMER. This is a direct result of the more pronounced differences in the marginal abatement costs between the Annex I and non-Annex I countries for POLES. This also leads to a lower domestic abatement fraction (60-65%). Also, the Annex I reductions after trade and CDM are lowered to about 16% below 1990 levels I (23% for TIMER) at the expense of higher non-Annex I reductions, at almost 23% (20% for TIMER) below baseline (Table 3). Again, the reason is that in TIMER, the technology mix between Annex I and non-Annex I countries already converges more in the baseline.

Finally, Annex I and non-Annex I reduction cases under the POLES MAC curves result in a comparable increase or decrease in global costs compared to the default case as under the TIMER MAC curves. For example, we also see a 20% decrease in the costs for the 25% Annex I reduction case, which is the same for TIMER (Figure 9).

Table 10 presents the build-up of the costs for the default case for the POLES. The benefits of trading for both Annex I and non-Annex I countries are even higher, i.e. 93 and 42 billion US$ respectively (instead of 66 and 42 billion US$ for the TIMER MAC curves, see Table 4). In particular, the Annex I countries cost benefits are higher. Table 10 also shows that the global costs for the no-trade case and default case differ by a factor two, which is much higher than under TIMER. This is a result of the greater convergence in the abatement costs across regions in TIMER, as mentioned above.

Table 10. The costs in the world, and in the Annex I and non-Annex I counties, and trade in emission rights in 2020 for the default scenario for the POLES MAC curves.

	(1) Total domestic costs (no trade)	(2) Total domestic costs (after trade & CDM)	(3) Total revenues or expenditure for carbon trade	(4) Total costs taking into account revenues or expenditure for carbon trade (= (2) + (3))	Gains from trade (= (1) − (4))
	Billion US$	Billion US$	Billion US$	Billion US$	Billion US$
World	298	165	0	165	133
Annex I	265	71	−101*	172	93
Non-Annex I	33	89	95	−7	40

* Including transaction costs

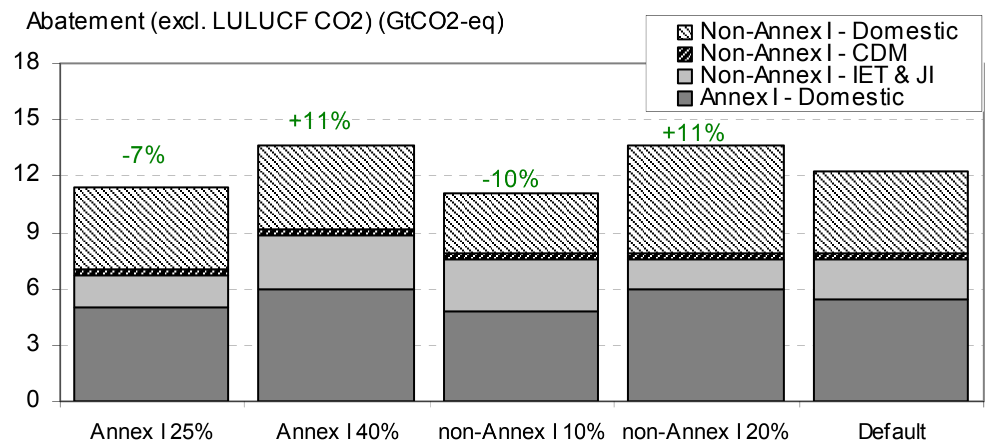

Figure 8. Overview of the Annex I and non-Annex I abatement in 2020 for the Annex I and non-Annex I reduction cases compared to the default case using POLES MAC curves.

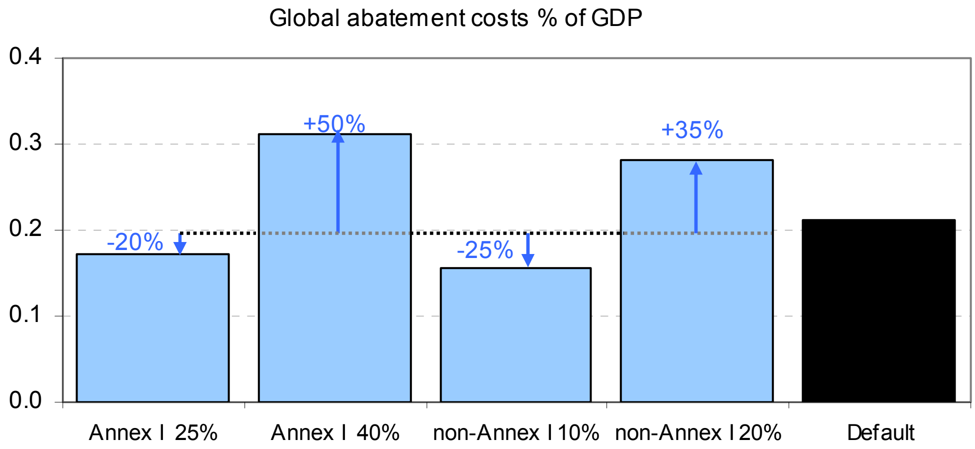

Figure 9. Global abatement costs as a percentage of the GDP for 2020 for the Annex I and non-Annex I reduction cases compared to the default case using POLES MAC curves.

In Figure 10 and 11 we consider the influence of other key scientific uncertainties on costs; we also compare these directly to the influence of key policy choices for the TIMER and POLES MAC curves Figure 10 for the global abatement costs and Figure 10 for the Annex I and non-Annex I abatement costs). In each case, we compare high and low values as summarised in Table 1, but the ranges have been chosen in such a way that the resulting global emissions in 2020 are still compatible with meeting the 450 ppm CO_2-eq concentration stabilisation target.

Baseline – The main factor influencing the costs is the alternative baseline scenarios. The baselines not only directly influence the abatement costs via the reduction burden (i.e. the differences between the baseline and reduction target), but also via the GDP, as the costs are represented as percentage of GDP. The latter effect is less dominant than the former in the short term, as the differences between the GDP for high and low economic growth are not significant.

CDM accessibility and transaction costs – The other factors concerning CDM accessibility and transaction cost have a limited impact.

From Figure 10 it can be concluded that the main policy choices determining the global abatement costs – ranked according to importance – are the following:
1. Annex I and non-Annex I reduction targets;
2. Including the forestry sector in the carbon market;
3. Participation of developing countries or the US in the carbon market.

Figure 10 also shows that this finding is robust for another set of MAC curves, i.e. those for POLES, as illustrated by comparing the right graph with the left graph. From the scientific uncertainties, the baseline emission has by far the largest impact on the abatement costs. The MAC curves are also important for the abatement costs.

Figure 10 (upper) shows that for Annex I abatement costs the sequence in importance of key factors remains the same, except that the baseline and Annex I reduction ambition are by far the main factors. The non-Annex I reduction target has a limited impact on the Annex I costs. These findings are robust for the POLES MAC curves.

The findings for the non-Annex I abatement costs were similar (Figure 10, lower), except that including REDD in the global market greatly influences the non-Annex I costs. Both REDD, POLES MAC curves and a lower non-Annex I reduction target can change the costs of non-Annex I countries into gains. Both cases of participation of developing countries, i.e. full trade and only CDM, lead to lower costs for non-Annex I, as explained in Section 3.

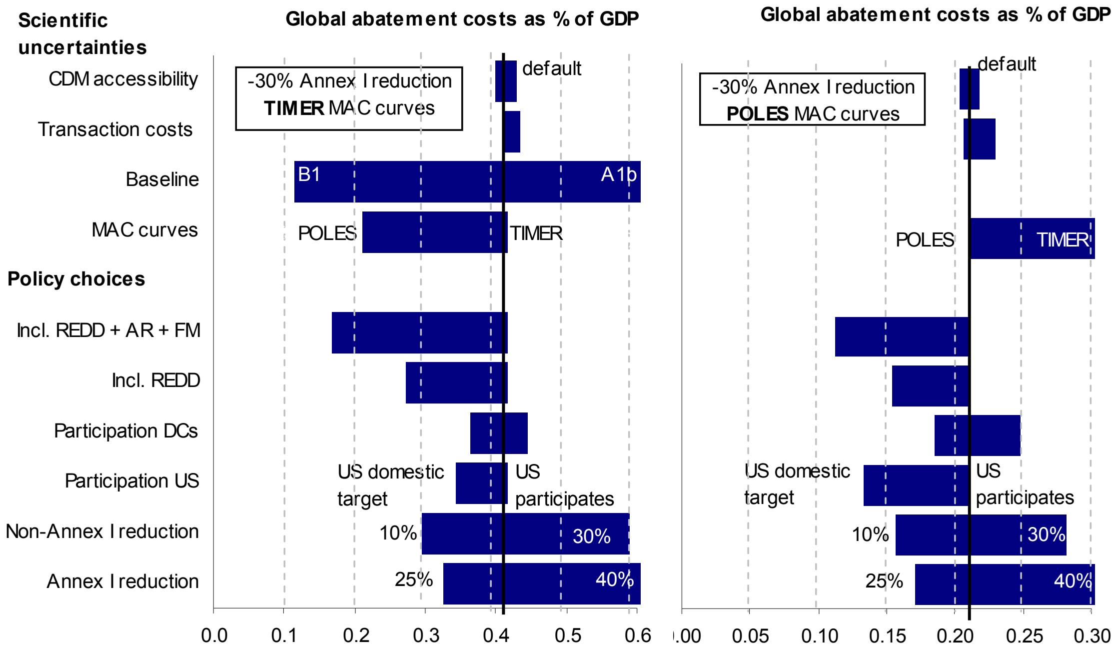

Figure 10. The impact of the key factors on the Annex I (upper) and non-Annex I (lower) abatement costs by 2020 for the TIMER MAC curves (default calculations) (left-hand figure) and POLES MAC curves (right-hand figure). Note: for the POLES model no alternative baseline was available.

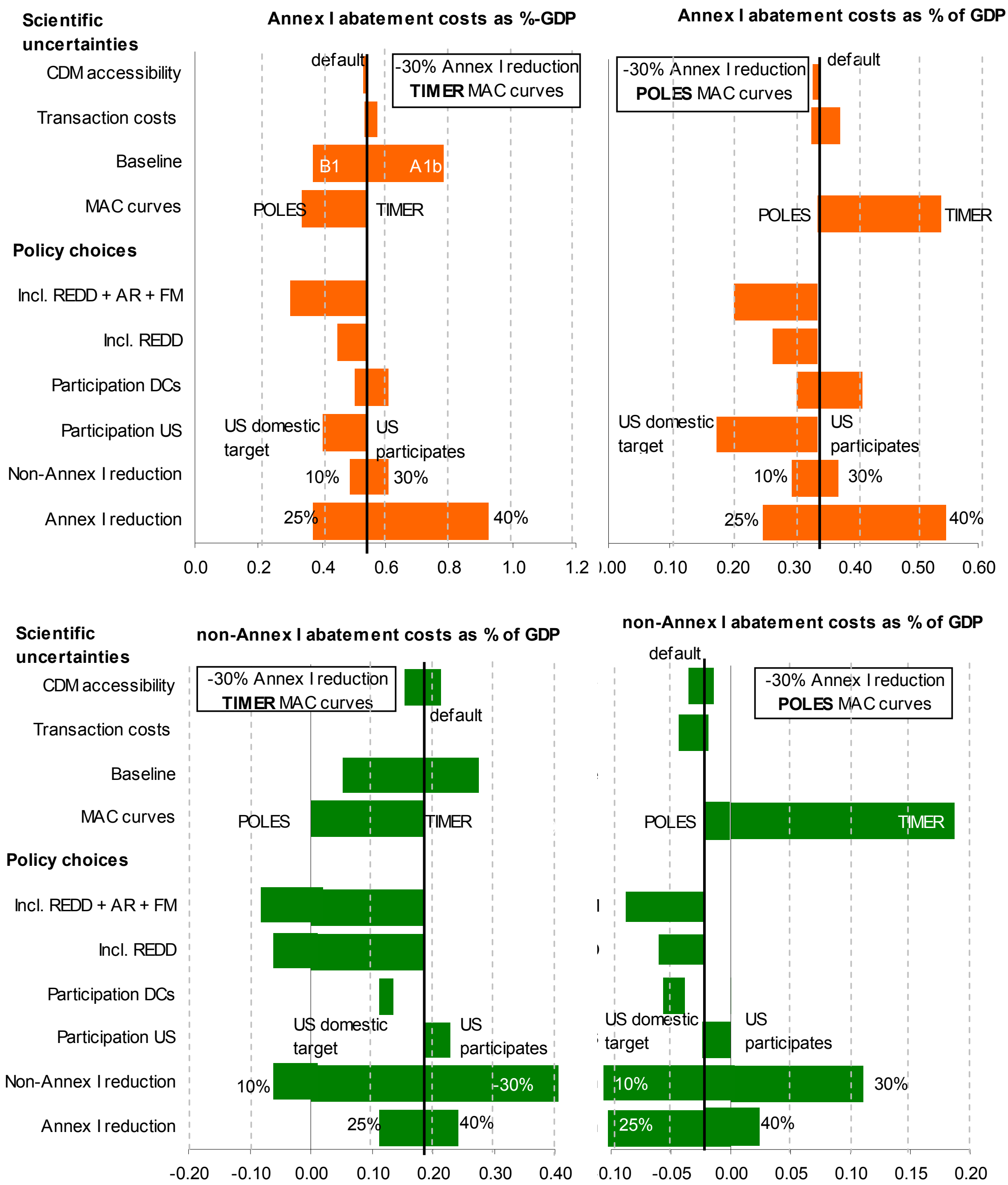

Figure 11. The impact of the key factors on the Annex I (upper) and non-Annex I (lower) abatement costs by 2020 for the TIMER MAC curves (default calculations) (left-hand figure) and POLES MAC curves (right-hand figure). Note: for the POLES model no alternative baseline was available.

6 Conclusions

In our study, we analysed the impact of various policy choices and scientific uncertainties on the carbon market and abatement costs in 2020 for meeting long-term greenhouse gas concentrations at 450 ppm CO_2-eq. The main findings are the following:

- *The level of ambition for reductions by the Annex I and non-Annex I countries, in a future international agreement on climate change, is one of the most important policy choices influencing the carbon price on the carbon market and abatement costs in 2020*. For the default case, assuming a 30% emission reduction below 1990 levels for Annex I in 2020 and a 15% reduction below baseline emissions for non-Annex I, compatible with stabilising GHG concentration at 450 ppm CO_2-eq, the global abatement costs are 0.5% of GDP. A higher Annex I and non-Annex I reduction of 40% and 30% increases the global costs by about half. Reducing the Annex I and non-Annex I reduction lowers the global abatement costs by 20-30%, but leads to global emissions in 2020 at the upper limit of emission corridors that can still attain the 450 ppm CO_2-eq target in the long term.
- *Including REDD in the carbon market could decrease the global abatement costs significantly (by 25 to 40%). This could lead to low costs or even net gains for the non-Annex I countries. With the addition of AR, the global abatement costs could even be reduced by 40-65% in 2020.* The inclusion of the forest sector in the global carbon market could lower the abatement costs of meeting stringent reduction targets. Emission credits from REDD can offset part of the Annex I reduction, and increase the financial flows from Annex I to non-Annex I countries. ADCs, like Brazil, would also use REDD to meet their own reduction targets. The final abatement costs for non-Annex I decline, and may even turn into gains. It also has the benefit of reducing deforestation by 30-70% in 2020. It should be noted, however, that it is uncertain to what extent REDD, AR and FM measures can actually be implemented. Previous attempts to reduce deforestation rates for biodiversity purposes have had a very mixed result. From a climate policy perspective, issues related to the various stakeholders in forest preservation and the permanency of these measures are still subject to debate. Obviously, the outcomes presented here are highly dependant on these implementation issues. In that context, another concern about allowing the forest sector (in particular REDD) to be part of a single carbon market is that it could flood the market and lead to a collapse of the carbon price; this is because it is a potentially abundant source of relatively less expensive, but uncertain, abatement. However, by establishing stringent and sound national baselines, which would be used to determine REDD credits, a ceiling could be set on the amount of credits generated. Furthermore, in a scenario with clear long-term commitments, market participants might have the incentive to intertemporally optimise their carbon purchases, thus decreasing the risk of flooding the market through the banking provisions, as noted by Piris-Cabezas and Keohane (2008). This is an important transitional issue and requires consideration of the relationship between supply and demand in the carbon market as well as appropriate design features at the point of linking forests to carbon markets, as discussed in the Eliasch Review (Eliasch 2008).
- *The main policy choices determining the abatement costs are: 1. Annex I and non-Annex I reduction targets; 2. including the forestry sector in the carbon market; 3. the participation of developing countries or the USA in the carbon market. This finding is robust for other MAC curves. The most important scientific uncertainty by far concerns the baseline emissions, followed by the MAC curves.* Important scientific uncertainties are the baseline emissions and the MAC assumptions. The baseline emissions have a high impact on the carbon price and abatement costs; a high baseline doubles the price and costs . The MAC assumption can also double the costs, i.e. the TIMER MAC curves lead in 2020 to abatement costs that are twice as high as the POLES MAC curves. Another aspect is that the TIMER curves are more similar across regions, so they lead to a lower incentive for emission trading. The Annex I costs are mainly influenced by the baseline and Annex I reduction target. The non-Annex I costs are also mainly influenced by the non-Annex I reduction target, the MAC curves and including REDD in the global market. More optimistic assumptions concerning these factors can convert the costs of non-Annex I countries into gains.

- *A gradual participation of non-Annex I or developing countries in the carbon market can lead to benefits for both Annex I and non-Annex I.* Emission trading and CDM can decrease the costs of meeting the reduction targets considerably. The global benefits can be on the order of 100-150 billion US$ by 2020. IET and CDM also lower the actual reduction targets of Annex I to about 20-25% below 1990 levels (from the Annex I reduction ambition of 30%). The remaining 5-10% is achieved through offsetting mechanisms that generate credits for reductions in Annex I countries. Non-Annex I countries need to reduce their emissions compared to baseline by around 15-20%, of which 5% can be sold through the carbon market via CDM and IET. This would take place under gradual participation of the developing countries in the global market, i.e. ADCs would participate via IET and the other developing countries via CDM. With full participation of the developing countries via IET, the benefits would be even higher.

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Appendix A The baseline scenario

As a reference for possible developments in the absence of climate policy, we used a scenario that, overall, should be considered as a 'median' baseline projection. The socio-economic and the energy sector projections represent the reference scenario developed for the ADAM project (van Vuuren et al. 2009). The main characteristics of the scenario are shown in Table 11.The ADAM baseline is a high economic growth scenario, based primarily on optimistic growth assumptions for China and India. Outside these regions, growth assumptions are considered to be comparable with other more moderate economic growth projections. The population projection used is the UN medium scenario.

The outcomes, in terms of energy, are broadly similar to those of the WETO reference scenario (European-Commission 2007). Oil production is not expected to decrease, where a decreasing production of oil from conventional sources is offset by an increased production from unconventional sources. The oil price shows a more or less constant price level at 2005 levels (about 55 US$(2005)/barrel of oil) over the period 2005 to 2020. Non-fossil energy sources provide a more or less constant contribution to the total demand (about one-fifth). Coal continues to supply to the largest part of energy demand. The resulting total GHG emissions are expected to increase from 37 $GtCO_2eq$ in 2000 to 54 $GtCO_2eq$, by 2020, with energy-related emissions remaining dominant. The energy-related CO_2 emissions in the ADAM scenario also compare well to those depicted in IEA's World Energy Outlook 2008 (IEA 2008).

Table 11. Global population, GDP per capita and anthropogenic GHG emissions for 1990, 2000 and 2020 for the ADAM baseline (van Vuuren et al. 2009)

	Population (in million inhabitants)			GDP (1000 US$(2005) per capita)			GHG emissions ($GtCO_2eq$ per year)		
	1990	2000	2020	1990	2000	2020	1990	2000	2020
Annex I regions									
Canada	28	31	36	26.6	31.7	43.0	0.62	0.73	0.77
USA	256	284	338	31.2	38.6	53.2	6.59	7.74	8.86
Western Europe	376	391	407	26.1	31.1	47.6	4.48	4.62	4.57
Central Europe	131	129	123	4.5	5.0	13.3	1.54	1.29	1.31
EU27*	507	519	530	19.4	23.4	36.5	6.02	5.91	5.87
Ukraine region	67	63	53	2.4	1.2	6.0	1.08	0.56	0.57
Russian Federation	165	163	150	5.3	3.6	13.3	3.84	2.52	2.94
Japan	124	127	127	30.7	34.4	53.2	1.36	1.53	1.66
Oceania	23	26	31	22.7	27.9	40.7	0.53	0.64	0.82
Non-Annex I regions									
Mexico	84	100	125	6.0	7.1	8.9	0.47	0.58	0.76
Rest of Central America	62	73	96	3.1	3.5	6.1	0.22	0.22	0.41
Brazil	149	174	219	3.7	4.2	5.9	0.67	0.88	1.32
Rest of South America	148	176	227	2.9	3.6	4.8	0.81	1.03	1.40
Northern Africa	118	142	194	1.4	1.5	2.4	0.35	0.44	0.72
Western Africa	241	316	504	0.6	0.6	0.6	0.35	0.43	0.87
Eastern Africa	156	201	330	0.4	0.4	0.4	0.25	0.31	0.50
South Africa	37	46	48	4.6	4.6	5.5	0.37	0.44	0.63
Rest of Southern Africa	84	108	152	0.6	0.6	0.7	0.17	0.22	0.37
Turkey	57	68	87	3.7	4.4	10.1	0.23	0.30	0.58
Kazakhstan region	50	55	68	1.6	1.1	3.5	0.69	0.48	0.64
Middle East	136	174	259	4.4	4.9	7.2	0.93	1.43	2.41
India	849	1021	1332	0.4	0.6	2.1	1.53	2.07	3.95
Korea region	63	69	73	5.6	9.1	23.1	0.49	0.72	1.25

	Population			GDP			GHG emissions		
	(in million inhabitants)			(1000 US$(2005) per capita)			($GtCO_2$eq per year)		
	1990	2000	2020	1990	2000	2020	1990	2000	2020
China region	1158	1276	1427	0.6	1.4	8.2	3.78	5.67	13.15
Mekong region	258	310	397	1.1	1.6	4.0	0.67	1.01	1.79
Indonesia region	186	214	263	0.8	1.1	3.0	0.41	0.56	0.97
Southern Asia	269	342	503	0.4	0.5	1.0	0.36	0.49	0.94
World	5273	6078	7569	5.6	6.4	10.3	32.77	36.89	54.16

* It is assumed that the EU27 covers Western and Central Europe.

Appendix B Datasets assumptions and extrapolation of the REDD and AR data of GTM and GCOMAP towards the 26 IMAGE regions

GTM-EMF, GTM-2008

The data for GTM is aggregated at the level of nine regions plus the world total: North America, South America (assumed as Latin America including Mexico and Brazil), Europe (EU and EE), Former Soviet Union (FSU), China, India, Australia/New Zealand, Asia-Pacific and Africa.

It is important to note that GTM is a model designed to show sequestration and emissions from managed and unmanaged land and changes in the “stocks” of these two categories of land; therefore REDD and AR must be inferred from GTM. The data for managed forest was assumed to be sinks and removals, and the data from un-managed forest was assumed to be deforestation emissions. From the difference between the managed and un-managed forests, we calculated the net deforestation emissions. We conducted this procedure for two scenarios under two carbon prices and for the baseline; the first scenario assumes a price of US$20/tC in 2010 and rises by 3% per year. The second one assumes a price of US$75/tC in 2010 and rises by $5 per year through 2050. This provides a high and a low carbon price scenario and the consequent changes in managed and unmanaged land. Furthermore, we used a linear interpolation between these two scenarios to find the final MAC curves for REDD, AR and Forest Management.

For developing regions it is possible to make a differentiation between what can be called afforestation-reforestation (everything that grows in addition to the baseline) and possible reduction of deforestation (remainder of unmanaged land). For the case of developed nations, we assumed that there is indeed no deforestation, hence no possible reduction of deforestation emissions. This means that all the unmanaged forest reduction accounts for afforestation/reforestation. For the managed forest, we assumed that all the increment of land in the managed forest corresponds to possible Forest Management sinks. These new managed areas could be due to afforestation/reforestation or due to unmanaged forest changing to managed forest. It was not possible to differentiate between what part of the increment in managed forest corresponds to a change of unmanaged forest to managed forest and what part corresponds to possible afforestation/reforestation activities. Hence we allocated the emissions from the increment in managed forest land to a category that we call AR+FM.

In the case of the REDD MAC curves, for scaling from GTM’s regions towards the IMAGE regions, we used allocation factors (Table 12) derived from the LULUCF CO_2 emissions for 2000 in $MtCO_2$ found in the CAIT[22] database. These factors were applied to the extrapolation of the MAC curves from 2010-2050 and the baseline deforestation and net deforestation or LULUCF CO_2 emissions. For the AR+FM MAC curve, the allocation factors were calculated based on the IMAGE MAC for AR (Strengers et al. 2008). We used the highest price per tonne of carbon for each year with available data, and then derived the allocation factors for the GTM regions. In addition, the total forest area from IMAGE was used to find allocation factors for the GTM AR+FM data for Africa. This is because the method (i.e. using the AR MAC from IMAGE) provides zeros as scaling factors for the year 2020; we therefore used the forest area. The distribution of emissions for the AR+FM MAC curves was the same as for the REDD MAC curves previously described.

[22] Climate Analysis Indicators Tool. World Resources Institute. http://cait.wri.org/

Table 12. Allocation of the GTM regions to the IMAGE regions. Allocation factors.*

GTM Regions	IMAGE Regions	REDD Allocation factors	AR allocation factors for 2020
North America	USA	1	
South America	Mexico	0.04	0.79
	Brazil	0.58	0
	Rest of South America	0.29	0
	Rest of Central America	0.09	0.21
Europe (EU & EE)	OECD Europe	0.71	0.94
	Eastern Europe	0.29	0.06
FSU	FSU	1	1
China	China	1	1
India	India	1	1
Australia/New Zealand	Oceania	1	1
Asia-Pacific	Indonesia	0.66	0.12
	Japan	0.001	0.88
	South East Asia	0.34	0
Africa	North Africa	0.01	0.01
	East Africa	0.12	0.13
	West Africa	0.61	0.60
	South Africa	0.001	0.26
	Rest of South Africa	0.26	0

* The following IMAGE regions were not allocated any data from the GTM regions: Canada, Turkey, Ukraine, Asia-Stan, Middle East, Korea and the Rest of India.

GCOMAP

GCOMAP data was aggregated in 15 regions: Southern, Eastern and Western Africa, Central America, South East Asia, South America, Canada, East Asia, Eastern Europe, Former Soviet Union, Japan, Middle East, Northern Africa, Oceania, OECD Europe, South Asia and United States. We used the same method to find allocation factors as for GTM in the case of REDD data (i.e. CAIT database) and also in the case of AR data (i.e. IMAGE MAC for AR and IMAGE total forest area for African regions).The REDD and ARD MAC curves were constructed with the GCOMAP model, assuming a linear increasing carbon tax. The allocation of GCOMAP regions to IMAGE regions is shown in Table 13 .

Table 13. Allocation of the GTM regions to the IMAGE regions. Allocation factors.*

GCOMAP Regions	IMAGE Regions	REDD allocation Factors	AR allocation factors for 2020
Southern, Eastern and Western Africa	South Africa	0.05	0.26
	East Africa	0.62	0.13
	West Africa	0.33	0.60
Central America	Mexico	0.32	0.79
	Rest of Central America	0.68	0.21
South East Asia	Indonesia	0.66	1
	Rest of South East Asia	0.54	0
South America	Brazil	0.67	0
	Rest of South America	0.33	1
Canada	Canada	1	1
East Asia	China	1	1
Eastern Europe	Eastern Europe	1	1
FSU	FSU	1	1
Japan	Japan	1	1
Middle East	Turkey	0.5	0
	Middle East	0.5	1
Northern Africa	North Africa	1	1
Oceania	Oceania	1	1
OECD Europe	OECD Europe	1	1
South Asia	India	1	1
United States	USA	1	1

* The following IMAGE regions had no allocation from GCOMAP regions: Rest of South Africa, Turkey, Ukraine, Asia-Stan, Korea and Rest of India.

Appendix C Overview of REDD and AR MAC curves

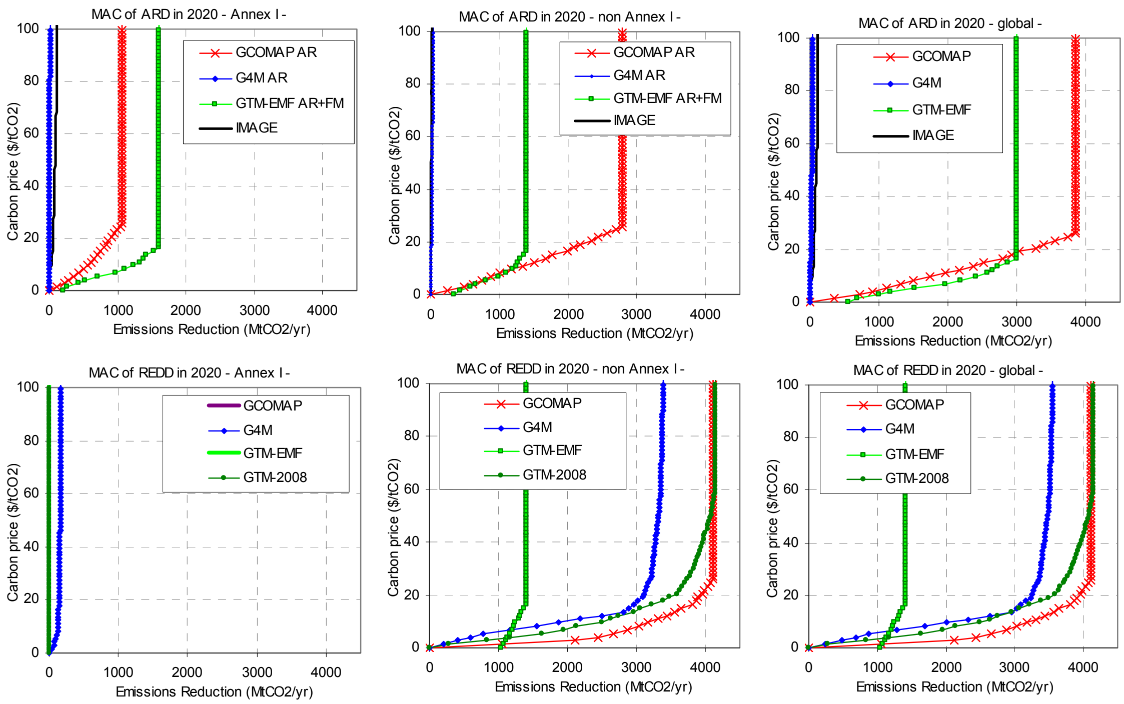

Figure C.1. Overview of the Annex I, non-Annex I and global marginal abatement cost curves in 2020 for REDD and AR.