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Post2012 climate regime options for global GHG emission reduction

Analysis and evaluation of regime options and reduction potential for achieving the 2⁰ degree target with respect to environmental effectiveness, costs and institutional aspects

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Post2012 climate regime options for global GHG emission reduction

Analysis and evaluation of regime options and reduction potential for achieving the 2° degree target with respect to environmental effectiveness, costs and institutional aspects

by

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This report explores the environmental and economic effects of the pledges submitted by industrialized and major developing countries for 2020 under the Copenhagen Accord and provides an in-depth comparison with results arrived at in other model analyses. Two scenarios reflect the lower (“weak”) and upper (“ambitious”) bounds of the Copenhagen pledges. In addition, two scenarios in accordance with the IPCC range for reaching a 2°C target are analyzed with industrialized countries in aggregate reducing their CO2 emissions by 30 % in 2020 compared to 1990 levels. For all four policy scenarios the effects of emission paths leading to a global reduction target of 50 % below 1990 levels in 2050 are also simulated for 2030. In addition, a separate scenario is carried out which estimates the costs of an unconditioned EU 30 % emission reduction target, i.e. where the EU adopts a 30 % emission reduction target in 2020 (rather than a 20 % reduction target), while all other countries stick with their “weak” pledges. Not included in the calculations is possible financial support for developing countries from industrialized countries as currently discussed in the climate change negotiations and laid out in the Copenhagen Accord.</td></tr>
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Die vorliegende Studie analysiert die ökologischen und ökonomischen Wirkungen der Kopenhagen-Ziele und beleuchtet diese im Vergleich zu den Ergebnissen anderer Modellierungsaktivitäten mit gleichem Ziel. Dabei werden zum einen Politikszenarien betrachtet, die das untere („schwach“) und das obere („ambitioniert“) Ende der Bandbreite der Kopenhagen-Ziele bis zum Jahr 2020 abbilden. Zum anderen werden ergänzend zu den zwei Kopenhagen-Szenarien zwei weitere Szenarien analysiert, die laut IPCC zu einer Erreichung des 2°-Ziels führen könnten. In allen vier Politikszenarien werden für 2030 auch die Auswirkungen von Emissionspfaden simuliert, die für 2050 eine Minderung der globalen Emissionen um 50 Prozent gegenüber 1990 zum Ziel haben. Außerdem werden in einem separaten Szenario die ökonomischen Wirkungen eines Szenarios betrachtet, in dem die EU eine Reduktion ihrer Emissionen bis 2020 um 30 Prozent (statt 20 Prozent) gegenüber 1990 anstrebt, während die anderen Länder am unteren Ende ihrer “Kopenhagen-Ziele“ festhalten. Keine Berücksichtigung in den Berechnungen finden mögliche Finanzhilfen von Industriestaaten an Entwicklungsländer wie sie in den internationalen Klimaverhandlungen diskutiert werden und in der Kopenhagen-Vereinbarung zugesagt sind.</td></tr>
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Glossary

ACES	American Clean Energy and Security Act
ADC	Advanced Developing Countries
AI	Annex-I countries
APA	American Power Act
BAU	Business As Usual
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
COP	Conference of Parties
EC	European Commission
EU	European Union
EV	Equivalent Variation
GDP	Gross Domestic Product
GHG	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
LDC	Least Developed Countries
LULUCF	Land Use, Land Use Change and Forestry
NAMAs	Nationally appropriate mitigation measures
NAID	Non Annex I Developed Countries
ODC	Other Developing Countries
REDD	Reducing emissions from deforestation and degradation
REDD-Plus	Reducing emissions from deforestation and degradation, conservation of existing carbon stocks and enhancement of carbon stocks
UNFCCC	United Nations Framework Convention on Climate Change

Zusammenfassung

Dem vierten Sachstandsbericht des Weltklimarates (IPCC 2007) zufolge müssen die globalen Kohlendioxidemissionen bis 2050 um mindestens 50 bis 85 Prozent unter das Niveau von 2000 gesenkt werden, um den weltweiten Temperaturanstieg auf maximal 2° Celsius gegenüber dem vorindustriellen Niveau zu begrenzen. Der Bericht des IPCC (2007) bekräftigt darüber hinaus als Zwischenziel für 2020, dass es dazu der Minderung von Treibhausgasemissionen in Industrieländern von 25 bis 45 Prozent gegenüber 1990, sowie deutlichen Minderungen gegenüber der Referenzentwicklung in einigen Entwicklungsländern bedarf. Den Elzen und Höhne (2008) geben die nötigen Minderungen in Entwicklungsländern mit 15 bis 30 Prozent gegenüber der Referenzentwicklung an. Obwohl auf der UN-Klimakonferenz in Kopenhagen kein internationales Abkommen mit verbindlichen Zielvorgaben beschlossen wurde, hat die Mehrheit der Annex-I-Staaten im Rahmen der Kopenhagen-Vereinbarung (UNFCCC 2009) quantifizierte Emissionsreduktionsziele zugesagt. Darüber hinaus haben einige Entwicklungsländer national angemessene Emissionsminderungsmaßnahmen (NAMAs) eingereicht.

Der vorliegende Bericht stellt den Gesamtendbericht des Forschungsvorhabens „Post2012 climate regime options and potential of global GHG emission reduction: Analysis and evaluation of regime options and reduction potential for achieving the 2 degree target with respect to environmental effectiveness, costs and institutional aspects“ (FKZ 3708 41 102). Das Projekt hatte zum Ziel, das Umweltbundesamt und die Bundesregierung bei internationalen Klimaverhandlungen durch quantitative und qualitative Analysen zu verschiedenen Aspekten eines neuen Klimaregimes sowie durch die Entwicklung und Bewertung von konkreten Vorschlägen zu unterstützen.

Die vorliegende Studie analysiert die ökologischen und ökonomischen Wirkungen dieser Kopenhagen-Ziele und beleuchtet diese im Vergleich zu den Ergebnissen anderer Modellierungsaktivitäten mit gleichem Ziel. Dabei werden zum einen Politikszenarien betrachtet, die das untere („schwach“) und das obere („ambitioniert“) Ende der Bandbreite der Kopenhagen-Ziele abbilden. Die Minderungen in den Szenarien belaufen sich auf maximal 17 Prozent unter das Niveau von 1990 für Annex I-Staaten und maximal 13 Prozent unter das Referenzszenario für die großen Entwicklungsländer. Damit liegen in beiden Szenarien die Emissionen oberhalb des Emissionspfads, den der IPCC zu einer Begrenzung der Erderwärmung auf 2 °C für nötig hält. Zum anderen werden ergänzend zu den zwei Kopenhagen-Szenarien zwei weitere Szenarien analysiert, die laut IPCC zu einer Erreichung des 2°-Ziels führen könnten. Darin werden als Minderungsziele für Industrieländer einmal 30 Prozent und – im ambitioniertesten aller betrachteten Szenarien – 40 Prozent bis 2020 im Vergleich zu 1990 angenommen. Gleichzeitig bleiben die CO_2-Emissionen ausgewählter großer Entwicklungs- und Schwellenländer 15 Prozent unter der Referenzentwicklung in 2020. In allen vier Politikszenarien werden für 2030 auch die Auswirkungen von Emissionspfaden simuliert, die für 2050 eine Minderung der globalen Emissionen um 50 Prozent gegenüber 1990 zum Ziel haben. Dabei wird angenommen, dass mit Ausnahme der am geringsten entwickelten Ländern (LDC) die Emissionen aller Länder nach 2020 einer Begrenzung unterliegen. Die Reduktionsziele für die Industrieländer sind dabei annahmegemäß schärfer als für die weniger entwickelten Länder. Außerdem werden in einem separaten Szenario die ökonomischen Auswirkungen eines Szenarios betrachtet, in dem die EU eine Reduktion ihrer Emissionen

bis 2020 um 30 Prozent (statt 20 Prozent) gegenüber 1990 anstrebt, während die anderen Länder am unteren Ende ihrer "Kopenhagen-Ziele" festhalten. Keine Berücksichtigung in den Berechnungen finden mögliche Finanzhilfen von Industriestaaten an Entwicklungsländer wie sie in den internationalen Klimaverhandlungen diskutiert werden und in der Kopenhagen-Vereinbarung zugesagt sind.

Die Berechnungen werden mit dem dynamischen allgemeinen Gleichgewichtsmodell DYE-CLIP durchgeführt, das die ökologischen und ökonomischen Wirkungen von Klimapolitik auf gesamtwirtschaftliche Größen wie Einkommen, Preise, Export und Importe, sowie auf Produktionsverlagerungen in Länder, die keinen oder nur geringen Klimaschutzauflagen unterliegen („carbon leakage"), berücksichtigt.[1]

Die wichtigsten Ergebnisse der Studie lassen sich wie folgt zusammenfassen:

- Der Rückgang des Bruttoinlandsprodukts (BIP) für Industrie- und Entwicklungsländer mit Kopenhagen-Zielen beträgt unter der Annahme, dass Emissionsrechte international unbegrenzt gehandelt werden können, höchstens 0,25 Prozent im Vergleich zum Niveau in der Referenzentwicklung in 2020. Für Industrieländer bleibt das Wachstum des realen BIP zwischen 2004 und 2020 im Durchschnitt bei 27 Prozent, während es für Entwicklungsländer von einem Anstieg von 102 Prozent minimal auf einen Anstieg von 100 Prozent sinkt. Auch die ökonomischen Auswirkungen des ambitioniertesten betrachteten Szenarios haben nur minimale Auswirkungen auf das BIP-Wachstum (27 Prozent Wachstum für Industrieländer und 98 Prozent Wachstum für die großen Entwicklungsländer).
- Reduziert die EU ihre Emissionen bis 2020 gegenüber 1990 um 30 Prozent (statt um 20 Prozent), während die anderen Länder am unteren Ende ihrer "Kopenhagen-Ziele" festhalten, führt dies nur zu einem marginalen BIP-Verlust von unter 0,005 Prozent (gegenüber dem schwachen Kopenhagen-Szenario).
- In sämtlichen Politikszenarien ist der durchschnittliche prozentuale Rückgang des BIP in Industrieländern geringer als in Entwicklungsländern mit Kopenhagen-Zielen. Insgesamt liegen die jährlichen BIP-Wachstumsraten in Entwicklungsländern jedoch weiterhin deutlich über denen in Annex I-Staaten.
- Die größten Einbußen im BIP finden sich in den Ländern, die stark von ihren fossilen Ressourcen abhängen. Da die Umsetzung der klimapolitischen Ziele die Nachfrage nach diesen fossilen Brennstoffen drosselt, steigen die Weltmarktpreise im Vergleich zur Referenzentwicklung weniger stark an. Daher verzeichnet z. B. Russland Einkommensverluste, die sich auch nicht durch Einnahmen aus dem Verkauf überschüssiger Emissionsrechte, die durch neue "heiße Luft" entstehen, kompensieren lassen.
- In einigen großen Entwicklungsländern wie China oder Indien führen strengere globale Emissionsziele zu größeren BIP-Verlusten (im Vergleich zur Referenzentwicklung), da

[1] Da DYE-CLIP nur CO_2-Emissionen beinhaltet, finden die Kopenhagen-Ziele nur auf CO_2-Emissionen Anwendung. Auch Treibhausgas-Emissionen, die sich aus Änderungen in der Land- und Waldnutzung ergeben, bleiben unberücksichtigt.

ihre Industrien im weltweiten Vergleich energie- und CO_2-intensiv produzieren. Ein Anstieg der CO_2-Kosten führt daher zu einem relativ hohen Rückgang der Produktion (im Vergleich zur Referenzentwicklung) von Eisen und Stahl, Zement, Nicht-Eisen Metallen, Papier und Zellstoff oder chemischen Produkten. Trotzdem kommt es aufgrund der hohen Wachstumsdynamik in der Regel zu einer Verdopplung der Produktion in diesen Sektoren in China und Indien.

- Regionen wie Japan oder die EU, deren Industrien im weltweiten Vergleich wenig energie- und CO_2-intensiv produzieren, verzeichnen hingegen bei ambitionierteren globalen Klimazielen ein etwas höheres BIP (verglichen mit dem BIP in der Referenzentwicklung). Die Ergebnisse zeigen, dass Volkswirtschaften, die frühzeitig ihre CO_2-Intensität verringern, langfristig weniger verwundbar gegenüber stringenten zukünftigen Klimazielen sind. Insbesondere energie- und außenhandelsintensive Wirtschaftszweige in Industrie- und Entwicklungsländern können von verstärkten Investitionen in energie- und CO_2-arme Produktionsverfahren profitieren.
- Der durchschnittliche BIP-Verlust in den Szenariorechnungen für 2030, denen wesentlich ambitioniertere Emissionsziele als im Zeitraum bis 2020 zugrunde liegen, beträgt zwischen 2 und 3 Prozent (gegenüber dem Niveau in der Referenzentwicklung). Die Wachstumsverluste entsprechen global gesehen also in etwa dem Zuwachs des BIP von einem Jahr.
- Die Kopenhagen-Ziele führen in einigen großen Entwicklungsländern zwar zu einem geringeren BIP (gegenüber der Referenzentwicklung), trotzdem führen die untersuchten Politikszenarien in diesen Ländern zu Wohlfahrtsgewinnen. Die Wohlfahrtsgewinne in China und Indien sind insbesondere die Folge von verbesserten realen Austauschverhältnissen zwischen den exportierten und den importierten Gütern infolge des geringeren Anstieges der Öl- und Gaspreise, von Einnahmen aus dem Verkauf von Emissionsrechten sowie von ökonomischen Effizienzgewinnen, die sich aufgrund verminderter Klimafolgeschäden einstellen.
- Der Vergleich mit den Ergebnissen aus anderen Modellanalysen ergibt, dass in allen untersuchten Studien die mit den Kopenhagen-Zielen verbundenen Kosten relativ gering sind. Unterschiede begründen sich darin, dass unterschiedliche Modelltypen bzw. unterschiedliche Modellannahmen (z.B. in Bezug auf Substitutionselastizitäten, technologischen Fortschritt, Dynamisierung, Baselineentwicklung) zugrunde liegen. Eine Harmonisierung dieser Annahmen würde helfen, die Modellanalysen vergleichbarer zu machen. Dennoch kann festgehalten werden, dass trotz dieser Unterschiede alle Modellergebnisse in die gleiche Richtung deuten und innerhalb einer geringen Spannbreite liegen.

Summary

Global carbon dioxide emissions need to be reduced by at least 50 to 85 % in 2050 compared to 2000 levels to limit global surface temperature increase to 2°C compared to pre-industrial levels (IPCC 2007). As an intermediate greenhouse gas emission reduction target for industrialized countries in 2020, the IPCC (2007) confirmed a range of 25 % to 40 % compared to 1990, together with a substantial deviation from baseline in some developing regions, which was quantified as reductions in the range of 15 % to 30 % below baseline (den Elzen and Höhne 2008). While the climate summit in Copenhagen (COP 15) failed to come up with an international agreement involving binding greenhouse gas emissions reduction targets, under the Copenhagen Accord (UNFCCC 2009) most Annex I countries pledged quantifiable emission reductions. Similarly, several developing countries submitted nationally appropriate mitigation actions (NAMAs).

This report presents the final report of the research project „Post2012 climate regime options and potential of global GHG emission reduction: Analysis and evaluation of regime options and reduction potential for achieving the 2 degree target with respect to environmental effectiveness, costs and institutional aspects" (FKZ 3708 41 102). The goal of the project was to support the German Environmental Agency (UBA) and the Ministry of Environment by conducting quantitative and qualitative analyses on various aspects of a future climate regime.

This report explores the environmental and economic effects of the pledges submitted by industrialized and major developing countries for 2020 under the Copenhagen Accord and provides an in-depth comparison with results arrived at in other model analyses. Two scenarios reflect the lower ("weak") and upper ("ambitious") bounds of the Copenhagen pledges leading to emission reductions of 17 % below 1990 levels for Annex I countries and 13% below reference levels for Non-Annex I countries. Both scenarios do not achieve a level of emission reductions identified by the IPCC (2007) as necessary to limit the temperature increase to below 2°C. In addition, two scenarios in accordance with the IPCC range for reaching a 2°C target are analyzed with industrialized countries in aggregate reducing their CO_2 emissions by 30 % and – for the most ambitious policy scenario – by 40 % in 2020 compared to 1990 levels, respectively. In addition, CO_2 emissions of major developing countries remain 15 % below the expected emission levels in 2020. For all four policy scenarios the effects of emission paths leading to a global reduction target of 50 % below 1990 levels in 2050 are also simulated for 2030. In the scenarios for 2030, all but the least developed countries are assumed to take on emission targets, but emission caps are considerably less stringent for developing countries than for developed countries. In addition, a separate scenario is carried out which estimates the costs of an unconditioned EU 30 % emission reduction target, i.e. where the EU adopts a 30 % emission reduction target in 2020 (rather than a 20 % reduction target), while all other countries stick with their "weak" pledges. Not included in the calculations is possible financial support for developing countries from industrialized countries as currently discussed in the climate change negotiations and laid out in the Copenhagen Accord.

The analyses are carried out with the dynamic Computable General Equilibrium Model DYE-CLIP, which accounts for economic and environmental effects resulting from changes in income, prices, exports and imports, or from carbon leakage in response to climate policy.[2] The main findings are:

- Economic costs (in terms of reduced GDP compared to baseline forecast GDP) in 2020 for industrialized and developing countries with “pledges“ are - on average - no higher than 0.25 %, assuming that these countries are allowed to trade emission certificates unrestrictedly. The average GDP growth for industrialized countries with “pledges“ remains at 27 %, while for developing countries with “pledges“ it decreases slightly from 102 % to 100 % between 2004 and 2020. Economic effects for the most ambitious scenario are also rather low: the average GDP growth remains unchanged for industrialized countries (27 % between 2004 and 2020) and decreases to 98 % growth for large developing countries.
- If the EU adopts an unconditioned 30 % emission reduction target in 2020, while all other countries adopt their “weak” pledges, the reduction in GDP in the EU will be rather small (less than 0.005 %).
- All policy scenarios lead to relatively larger reductions in GDP for developing countries than for industrialized countries. However, annual GDP growth rates in developing countries remain significantly above those for industrialized countries.
- Economic losses tend to be above average in regions which depend highly on their reserves of fossil fuels, like Russia. Because climate policies result in lower global demand for these resources, their world prices fall (compared to the baseline) translating into lower incomes for the respective countries. Revenues from selling excess certificates (stemming from “new hot air“ implied by the Russian pledge) are not sufficient to compensate for these economic losses.
- Some large developing countries like China and India experience larger GDP losses for tighter global emission targets because their industrial sectors are more energy- and CO_2-intensive than in most other regions. Hence, increases in the cost of CO_2 emissions lead to larger reductions (compared to baseline) in the output of energy-intensive sectors like iron and steel, non-ferrous metals, pulp and paper, cement, or chemicals. Nevertheless, output in these sectors in China and India generally doubles by 2020.
- In contrast, because these same sectors in the EU and Japan are relatively less energy- and CO_2-intensive, the EU and Japan experience slightly higher GDP. Hence, economies which reduce their CO_2 intensities earlier are less vulnerable to tighter emission targets in later periods. Similarly, energy-intensive, trade-intensive industries in developed and developing countries alike may particularly benefit from investments, which reduce energy intensity and CO_2 emissions of their processes.

[2] Since DYE-CLIP includes CO_2 emissions only, all targets submitted under the Copenhagen Accord are applied to CO_2 emissions only. Also, the analyses abstract from LULUCF.

- Simulations for the 2030 emission targets imply a reduction in global GDP between 2 % and 3 % compared to baseline. This change corresponds roughly to the growth in global GDP for one year.
- While developing countries experience larger reductions in GDP, this does not necessarily translate into larger declines in net welfare. For example, both China and India experience a gain in welfare in 2020 which is due to strong terms-of-trade improvements, revenues from selling CO_2 certificates, and gains in allocative efficiency for energy commodities by taking into account the negative externality from CO_2 emissions from the use of fossil fuels.
- Comparing the results to those derived at in other modelling analyses reveals that the costs of meeting the pledges for industrialized countries are low independent of the model used. Differences occur due to model type and model specific assumptions (e.g. on substitution elasticities, technological change, model dynamics, baseline development). Harmonized baselines and model assumptions help to arrive at more comparable results. The main conclusion is, however, that despite these differences the results from all model analyses remain within a relatively narrow range and well within an order of magnitude.

1 Introduction

In the course of negotiations for a future global climate regime after 2012 there were attempts to develop a clear framework for the negotiations. Important elements in this process were the Bali Road Map and the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP) and the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (AWG-LCA) established as part of the road map and, last but not least, the EU's Climate and Energy Package with its conditional target of reducing emissions by 30% up to 2020 compared to 1990.

In preparation for the workshops and intersessional meetings initiated in these processes and the UN Climate Change Conferences in Bali, Poznan, and (in December 2009) Copenhagen, qualitative and quantitative analyses of current negotiation proposals were conducted within the scope of this research project and our own specific proposals were developed. These served to support the German Federal Environment Agency and the German government during the negotiation process.

The key component of the project was the economic analysis of differentiation strategies for reduction commitments. To this end, the DYnamic Equilibrium CLImate Policy model (DYE-CLIP) developed by the Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI) and Virginia Tech University in Blacksburg, VA/USA (Prof. Everett Peterson) was used. Key features of DYE-CLIP are:

- It is a global model encompassing 87 countries and regions, which are differentiated by country/region, aggregated or disaggregated according to the project's requirements;
- There is a great degree of sectoral detail: 57 sectors including 3 sectors from the energy industry (electricity, refined petroleum and coal, gas) and 23 sectors of manufacturing industry (including paper, chemicals, ferrous metals, non-ferrous metals); the sectors are aggregated or disaggregated according to the project's requirements;
- The model's approach is based on the GTAP-E Version of GTAP (Global Trade Analysis Project, the accepted standard model of the modelling "community"), which enables detailed mapping of energy input structures and the related CO_2 emissions;
- Data is based on the latest GTAP data set 7.0 (base year: 2004);
- It uses the standard assumptions in general equilibrium models: perfect rationality of economic agents, perfect competition; prices adjustment until market equilibrium is achieved;
- It is a dynamic recursive model optimised in five year time-steps, enabling mid-term targets to be incorporated accordingly;
- Transport costs (in particular, the energy costs) are also included, in contrast to other general equilibrium models.

In order to enable a comparison with the modelling activities of other modellers, the baseline was adjusted with regard to GDP, population development, and energy source prices. Subsequently the chosen differentiation strategies were implemented into the model and the overall economic costs were calculated compared to the baseline. A comparison of the results for the different differentiation strategies allows for statements to be made on the credibility of these strategies and on their sectoral and regional impacts from an overall economic perspective. In a further step the results were compared with those of other model activities and on this basis questions for future research questions were identified. In order to make the analyses readable internationally, the relevant sub-chapters have been written in English.

2 Environmental and economic effects of the Copenhagen pledges and more ambitious emission reduction targets

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2.1 Background

To address climate change, industrialized countries and economies in transition (Annex-I countries) originally committed in 1997 to reduce their aggregate greenhouse gas emissions by about 5.2 % during the period 2008-12 compared to 1990 emission levels in the Kyoto Protocol to the United Nations Framework Convention (UNFCCC). A major objective of the most recent UNFCCC climate summit in Copenhagen in December 2009 (Conference of the Parties COP 15) was to come up with a Post 2012 climate regime, determining long-term greenhouse gas emission targets and the future contributions of industrialized and developing countries. According to the IPCC fourth assessment report (2007) carbon dioxide emissions need to be reduced by 50-85 % in 2050 compared to 2000 levels and global emissions need to peak prior to 2020 if the increase in global surface temperature is to be limited to 2°C compared to pre-industrial levels ("2°C target"). In 2009, the G8 Summit recognized the "2°C target" and the necessity to reduce global greenhouse gas emissions by at least 50 % by 2050". The IPCC (2007) also suggested intermediate targets for 2020, including an indicative range of 25 % to 40 % emission reductions compared to 1990 for Annex-I countries and a "substantial deviation from baseline in Latin America, Middle East, East Asia and Centrally-planned Asia" (IPCC 2007, p. 776). For developing countries reductions of 15-30 % below baseline have been suggested (den Elzen and Höhne 2008). The European Commission (2009a) has also published proposals where developed countries collectively reduce emissions by 30 % in 2020 compared to 1990 and economically more advanced developing countries decrease emissions by 15-30 % below business as usual.

In the wake of COP 15, most Annex I countries have pledged voluntary emission targets for 2020. In the EU climate and energy package adopted in December 2008, the 27 EU member states promised a unilateral reduction of greenhouse gas emissions by 20 % below 1990 levels by 2020 (European Commission 2009a). In case an ambitious international climate agreement is reached, the EU will meet a more ambitious reduction target of 30 %.[3] Other countries like Australia followed the EU's lead and have also pledged to reduce emissions, with tighter targets in case an international agreement will be reached. In the US, the 'American Clean Energy and Security Act (ACES) of 2009' ("Waxman-Markey") has passed the House of Representatives in June of 2009, and the Senate has yet to decide when to vote on the "American Power Act" (APA) ("Kerry-Lieberman"). Both bills set reduction targets for the covered sources for the year 2020 at 17 % below 2005 levels and envisage greenhouse gas

[3] Originally, the more ambitious, conditional reduction target of 30 % for the EU was adopted by the March 2007 European Council Meeting under the German EU presidency (Council of the European Union 2007).

emission reductions in 2050 of 83 % below 2005 levels.[4] In addition, prior to the Copenhagen climate summit a number of developing countries, including China and India, also pledged emission reduction targets for 2020.

While COP 15 failed to produce an international agreement involving binding greenhouse gas emissions reduction targets, most Annex I countries pledged quantifiable emission reductions under the Copenhagen Accord (UNFCCC 2009). In addition, several developing countries submitted nationally appropriate mitigation actions (NAMAs) listed in Appendix II of the Accord. In total, countries which submitted pledges under the Copenhagen Accord account for about 80 % of global greenhouse gas emissions. For most countries, pledges under the Copenhagen Accord are quite similar to those made prior to COP 15.[5] The EU, for example, pledged to reduce greenhouse gas emissions by 20 % compared to 1990 levels. On condition that other major emitting developed and developing countries commit to do their fair share under a global climate agreement, the EU offered a more ambitious reduction target of 30 %. In the meanwhile the European Commission (2010) has analyzed the effects of moving unilaterally to an unconditioned 30 % reduction target but maintains that the conditions to do so are not met yet.

There are several studies, including den Elzen et al. (2009a,b), den Elzen et al. (2008), Rogelj et al. (2009), Ward and Grubb (2009) and Levin and Bradley (2009), analyzing the effects of the pledges announced prior to the Copenhagen summit on greenhouse gas emissions and their likely contribution towards meeting global climate targets. They all conclude that the announced pledges are not very ambitious and would involve more severe emission reductions later on if the “2°C target” is to be met with 50 % probability. For the emission targets submitted under the Copenhagen Accord, Rogelj et al. (2010) calculate a 50 % chance that the increase in temperatures will exceed three degrees Celsius by 2100. Den Elzen et al. (2009b) point out that the pledge made by Russia is likely to involve “new hot air, that is, emission targets are expected to be higher than expected emissions.

Previous studies analyzing the economic impacts of the “pre-Copenhagen” pledges include Amann et al. (2009), Wagner and Amann (2009) and den Elzen et al. (2009a). Based on marginal abatement cost curves to calculate mitigation costs, they find that overall costs in Annex I countries are below 0.04 % of GDP in 2020 (den Elzen et al. 2009a). Wagner and Amann (2009) analyze the impact of the economic crisis which started in the fall of 2008. According to their calculations, the crisis will result in 7 % lower GDP levels and 8 % lower emission levels in 2020 than calculated prior to the crisis. Hence, costs to meet the intended emission reduction targets are lower than assumed at the time when they were announced. De Bruyn et al. (2010) arrive at a similar conclusion.

So far, only Duscha et al. (2010), den Elzen et al. (2010a) and OECD (2010) have analyzed the economic effects of the pledges announced in the Copenhagen Accord. Allowing for international emissions trading, compliance costs for the ambitious end of the pledges in 2020

4 However, the scope and the time path for the capped emissions differ between ACES and APA. See http://energycommerce.house.gov/Press_111/20090515/hr2454.pdf for ACES and http://kerry.senate.gov/americanpoweract/pdf/APAbill.pdffor.

5 Canada altered its pre-Copenhagen pledge of “20 % reduction below 2006 levels” to “17 % below 2005 levels” in January 2010. The new target now matches the US target.

for Annex I countries are estimated to be less than 0.5% of baseline GDP in UBA (2020) and 0.2 % in den Elzen et al. (2010a). For non Annex-I countries, estimated costs are around 1 % of GDP in Duscha et al. (2010) and 0.17 % of GDP in den Elzen et al. (2010a). Countries with “hot air” or low marginal abatement costs benefit from selling certificates. In particular, the GDP of Russia is estimated to increase by up to 1.7 % in Duscha et al. (2010) and 0.3 % in den Elzen et al. (2010a).

Existing estimates for the costs of the “pre Copenhagen” pledges, such as Duscha et al. (2010) and den Elzen et al. (2010a) are primarily based on partial equilibrium models. Thus, they do not capture economic and environmental effects resulting from changes in income, prices, exports and imports, or from “carbon leakage”. Carbon leakage, which is an increase in emissions in regions without mitigation targets, may result from two channels (e.g. Paltsev 2001, Burnieaux and Martins 2000). First, because climate policy raises production costs in regions with climate targets, production may shift to regions without such targets and increase emissions globally (competitiveness effect).[6] Second, to the extent that climate policy translates into higher prices for fuels in countries with climate targets, demand for fuels declines and the world fuel prices fall.[7] In turn, lower fuel prices lead to higher demand and higher emissions (world price effect).

To analyze economic effects of unilateral and multilateral emission reduction policies, computable general equilibrium (CGE) models have recently been applied. Studies on unilateral climate policies include Böhringer et al. (2009) for the EU, Böhringer and Rutherford (2010) for Canada, and US EPA (2009) for the United States. Studies on multilateral climate policies include Kemfert and Truong (2007), Kemfert and Schumacher (2005), Gurney et al. (2009) and Peterson and Klepper (2007). These studies on (hypothetical) multilateral long term targets are based on dynamic CGE models and find that global targets consistent with the “2°C target” result in GDP losses compared to the baseline of around 5 % or less in 2050. In Kemfert and Truong (2007) these losses reach 7-8 %. Peterson and Klepper (2007) find that path towards reaching a 40 % reduction of global CO_2 emissions relative to 1990 by 2050 lowers global welfare - measured in terms of equivalent variation - by 2-4 % in 2030 relative to the baseline. Böhringer and Löschel (2003) consider hypothetical multilateral intermediate targets for 2020 based on expert judgments. Those targets, however, do not match a 2°C target path but result in even lower emission reductions (10 %) than the pledges under the Copenhagen Accord and costs in terms of consumption losses are almost negligible. Only McKibbin et al. (2010) analyze a stylized version of the Copenhagen Accord, where countries meet their pledges via domestic action, only. Simulations based on a dynamic CGE model suggest, that global GDP in 2020 is about 1 % lower than in the baseline.

In this report we apply a dynamic CGE model to explore and compare the environmental and economic effects of four multilateral emission reduction policy scenarios:

i) *“Weak Pledges”* scenario that incorporates the lower bound of the pledges as submitted by countries for 2020 under the Copenhagen Accord;

[6] See Reinaud (2008) for a recent survey of the literature on carbon leakage.

[7] The decline in world prices may be dampened however, if resource owners reacted by reducing supply in order to maintain a high price for fossil fuels.

ii) *"Ambitious Pledges"* scenario that incorporates the upper bound of those pledges;[8]

iii) *"30 %-Annex-I"* scenario that assumes a 30 % emission reduction target for Annex I countries in 2020 and that advanced developing countries reduce emissions by 15 % below their baseline emissions in 2020; and

iv) *"40 %-Annex-I"* scenario that assumes a 40 % emission reduction target for Annex I countries in 2020 and that advanced developing countries reduce emissions by 15 % below their baseline emissions in 2020.

Hence, in the "30 %-Annex-I" and the "40 %-Annex-I" scenarios, the emission reductions by Non-Annex I countries (compared to forecast) are identical. Also, in these scenarios the burden of reducing emissions is split among Annex I countries, along the lines of the European Commission proposal (2009a). In all four policy scenarios, we analyze the environmental and economic effects of emission reduction paths in 2030 that would lead to a global emission reduction target of 50 % below 1990 levels in 2050.

In addition, a separate scenario ("EU-30%") is carried out which estimates the costs of unconditioned EU 30 % emission reduction target, where the EU adopts a 30 % emission reduction target in 2020, while all other countries maintain their "weak" pledges.
In terms of environmental effects, the impact of the four policy scenarios on global CO_2 emissions is explored, including the effects of "new hot air" from Russia as well as carbon leakage[9]. The economic effects of the scenarios are captured by comparing the gross domestic product (GDP) after implementation of the policy scenarios to the forecasted GDP, and by computing the equivalent variation for a representative consumer in each region, which is a measure of the change in welfare for that region.

Similar work, but focused on the Copenhagen Accord pledges for the year 2020, has been done by the OECD (2010). Their effects on world GDP are comparable to what is found in this study. More detailed insights apart from GDP effects, however, are not provided.

The remainder of the report is organized as follows. Section 2 describes the methodology, including a description of how the targets for 2020 and 2030 are derived. In section 3 we focus on the environmental effects of the four policy scenarios, including an analysis of the effects of "new hot air" and carbon leakage. The economic effects of climate policy for the four scenarios are presented and discussed in section 4. A separate "box" presents the main findings for "EU-30 %. The concluding section 5 focuses on policy implications.

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[8] Where necessary the pledges were translated into reductions below baseline in 2020.

[9] Since the focus of the report is on the overall contribution of leakage rather than on the various sources for leakage we do not distinguish between "competitiveness effects" and "world price" effects.

2.2 Methodology

2.2.1 Computable General Equilibrium Model DYE-CLIP

The analyses are conducted employing a multi-country, multi-sector dynamic computable general equilibrium (CGE) model, DYE-CLIP[10,11], for 2004 to 2030. DYE-CLIP is based on the GDyn (Ianchovichina and McDougall 2001) and GTAP-E models (Burniaux and Truong 2002, Nijkamp et al. 2005). The current version uses the GTAP 7 database (2004 base year). Households and firms are assumed to act perfectly rational, maximizing utility and profits, respectively. Thus, the model maximizes welfare ("utility") rather than GDP. Further, the model is myopic in the sense that only information available in a given period is used by agents in their optimizing behavior. Relative factor prices drive companies' input portfolio and output prices drive demand and supply. Prices adjust instantaneously so that all markets clear in all time periods. A unique feature of the DYE-CLIP model is that it allows the supply of coal, oil, and gas to change as the prices for those commodities change, assuming a supply elasticity of 0.25.

Box 1: Bottom-up versus top down models

Traditionally, two broad types of models used to analyze the effects of climate policies are distinguished: bottom-up and top down models. Bottom-up models are engineering-based partial equilibrium models of the energy converting and using sectors which explicitly model different technologies and their (expected) development over time, capturing all energy and carbon saving possibilities. Other economic factors like GDP, demand for energy services or fuel prices are given exogenously, i.e. the interaction with other economic sectors is rather limited. Bottom-up models may be further split in optimization and simulation models. Optimization models calculate the least-cost combination of a set of available or expected technologies to meet given production and emission targets. In comparison, simulation models do not presuppose optimization. In bottom-up models, technological change depends – to a large extent – on the set and the characteristics of the technologies included a priori in the database. More recently, some dynamic bottom-up models allow for endogenous technological change via experience curves. Bottom-up models may capture so called "no regret" potentials, reflecting measures which are profitable under the economic conditions and behavioral assumptions in the model, but not implemented. In bottom-up models "costs" to meet climate targets are interpreted as the sectoral costs to achieve a particular emission target.

By contrast, top-down models are more aggregated than top-down models, represent the general economy and include all the economic effects like price changes or income and substitution effects. Since technologies or technological change are not explicitly modeled. top-down models do not allow for a direct linkage to the actual technologies responsible for the technological development. Often, a trend variable is supposed to reflect technological progress and learning-by doing or scale-effects are neglected in these models. Top-down

[10] DYE-CLIP (DYnamic Equilibrium Model for CLImate Policy Analysis) is based on GTAP-E. The current version relies on the GTAP 7 database (2004 base year).

[11] The sectors specifically modeled are electricity (ely), refined petroleum (p_c), chemicals, rubber and plastics products (crp), other mineral products (nmm), ferrous metals (is), paper products (ppp), other metal products (nfm), other manufacturing (oman), coal, oil, gas, transport (trans), agriculture (agr), other natural resources (onres), food, trade (trd) and services (serv).

models may be further split in macroeconometric models and computable general equilibrium (CGE) models. While in macroeconometric models behavioral parameters are estimated based on observed behaviour, CGE models are calibrated to match the empirical data in a particular base year. Since CGE models typically assume perfectly rational behavior (utility/profit maximization), they do not allow for “no-regret” measures. Likewise, CGE models typically assume that markets clear so that they are in equilibrium at all times. Costs of climate policy are typically expressed as losses in utility (welfare of representative consumer) or consumption or GDP, taking into account all economic interaction and feedback effects throughout the economy (including international trade),

More recent research efforts resulted in “hybrid” models, integrating (some) technologies (for selected sectors) in top-down models. Alternatively, bottom-up and top-down models may be combined via soft link, where the output of one type of model serves as an input to the other type of models.

Since the model includes only CO_2 emissions, the reduction targets specified for all greenhouse gases are applied proportionally to CO_2 emissions. Climate policies are implemented via emission quotas per region. Countries levy national CO_2 taxes on direct CO_2 emissions. Hence, a single climate policy, i.e. a CO_2 tax, is applied across all sources in a country or region. The model also includes transport margins as in Peterson and Lee (2008). The baseline simulations are based on projections for GDP growth, population/labor growth, and CO2 emission growth used in the EU ADAM-Project (PIK et al. 2008, Hulme and Neufeldt 2010, Edenhofer et al. 2010) and Poles model (Criqui 2001, Kitous et al. 2010) by country but adjusted for the current economic crisis. This baseline does not include the effects of any new policies like the climate and energy package in the EU from 2008 or the 11th or 12th five-year plan in China. Technological change is autonomous, hence the model does not allow for price- or policy-induced adjustment in the production function. The baseline simulations are identical for all policy scenarios. Results for all four policy scenarios in terms of environmental and economic effects are compared to the outcomes under the baseline. Appendix A.2 in the Annex provides specific information on the baseline level of emissions and GDP at the country and region level.

In order to have 2010 as the common starting point for all policy scenarios, the model is solved for a single, six-year period between the base year of 2004 for the GTAP 7 database and 2010. During this period, the emission reduction targets under the Kyoto Protocol are implemented for all Annex-I countries, except the United States. In addition, no emission targets are imposed on Russia and the Ukraine for 2010 to avoid introducing “hot air” from these regions. This assumption may be rationalized by den Elzen et al. (2009b) who argue that it may be in Russia’s best interest to refrain from banking “hot air” from the Kyoto-period into the next commitment period because revenues from selling certificates would be higher. In that sense, a weak pledge by Russia could be interpreted as compensation for renouncing banking hot air from the Kyoto-period. All countries/regions with emission targets are allowed to trade emissions certificates. This results in the price for CO_2 certificates (i.e. the CO_2 tax) being equalized across countries where trading of certificates is viable. Thus, the CO_2 tax for 2010 reflects the marginal costs of achieving the Kyoto-targets for all Annex-I countries, excluding Russia, the Ukraine, and the United States. The model (implicitly) permits unlimited banking within the six-year period, but not across other time periods.

Because it is not necessary to obtain annual time paths to assess the impacts of the emission targets in all policy scenarios, the model is solved in five-year increments for the period 2010 to 2030. The emission targets are implemented for 2020 and 2030 with intermediate targets for 2015 and 2025 being linearly interpolated. Again, trading of emission certificates is allowed among all countries and regions with emission targets in all periods and banking is not allowed across five-year periods. In fact, when making their pledges, many countries implicitly or explicitly assumed that certificate trading was viable. However, offsets such as credits from CDM-type projects are not modeled.[12] Even though the policy scenarios considered may lead to carbon leakage and cause undesired competitiveness effects, the subsequent analyses do not include border tax adjustments or other trade measures.[13] A description of DYE-CLIP is provided in Appendix 1 of the Annex.

2.2.2 Targets and trading rules

The policy scenarios differ by the stringency of climate policy and by the type of burden sharing across and within different country groups. Financial support for developing countries to reach their reduction targets is not included in the analysis. Prices for CO_2 certificates (i.e. the CO_2 tax) will be equalized across countries where trading of certificates is viable. Regional or country-specific policies for reaching the applied targets that might already be in place like the European Emissions trading System or the European energy and climate package from 2008 are not considered but the cheapest reduction potential in each country is realized, i.e. marginal abatement costs in all sectors of an economy are equalized.[14]

2.2.2.1 Targets for 2020

In the “Weak Pledges” and “Ambitious Pledges” scenarios, Annex-I as well as major developing countries’ targets are implemented according to their reduction targets submitted under the Copenhagen Accord[15] as of 11 March 2010[16]. For 2020, emission reduction targets are implemented for six major developing countries: Brazil, China, India, South Korea, Mexico and South Africa[17]. Where a reduction range was given, the lower (more lenient) target was associated with the “Weak pledges” scenario while the higher (more stringent) target was

[12] Given that in our analyses all regions, which currently host about 85 % of registered CDM projects (http://cdm.unfccc.int/index.html/), may engage in emissions trading from 2010 on, this assumption is unlikely to be very restrictive.

[13] Such measures are foreseen, for example, in the EU ETS and in the proposals for future national greenhouse gas trading systems in the US. See, for example, Kuik and Hofkes (2010) for an analysis of the economic effects and van Asselt and Brewer (2010) for a treatment of the legal aspects for border adjustment measures.

[14] This assumption implies that cost estimates presented in this report are minimum costs. Depending on the policies implemented to reach a target these costs could be higher if policies do not lead to realisation of least-cost potentials in all sectors.

[15] http://unfccc.int/home/items/5264.php and http://unfccc.int/home/items/5265.php. See also Stern and Taylor (2010).

[16] At that time, targets from Switzerland (20-30% below 1990 levels) and Belarus (5-10% below 1990 levels) were not yet announced at the UNFCCC homepage.

[17] Data did not allow treating the Republic of South Africa separately. In CGE simulations, the Republic of South Africa is included in the ODC country group (pledges target is applied to RSA only, not to other ODC).

associated with the "Ambitious Pledges" scenario. All targets from developing countries, including the emission intensity targets submitted by China and India, have been translated into emission reductions below baseline in 2020. All reductions are assumed to exclude emissions from land use, land-use change and forestry (LULUCF) and reducing emissions from deforestation and degradation (REDD) or from deforestation and degradation, conservation of existing carbon stocks and enhancement of carbon stocks (REDD-Plus). For 2020, no emission targets exist for Other Developing Countries (ODCs) and for Least Developed Countries (LDCs) in the two pledges scenarios. For comparison, Table A-6 provides an overview of the Copenhagen Accord and the policy scenarios implemented in this report.[18]

For the "30 %-Annex-I" and the "40 %-Annex-I" scenarios, Annex-I countries as a group reduce emissions by either 30 % or 40 % below 1990 levels. A burden-sharing rule was specified which divided the reduction target among Annex-I countries according to a multi-criteria approach. Following the EC (2009b), equal weights were applied to the following four indicators: GDP per capita (in 2005) reflecting a country's ability to pay, GHG per GDP (in 2005) reflecting domestic emission reduction potential, population trend (1990 to 2005) recognizing "needs" and GDP trend (1990 to 2005) recognizing domestic "early action".[19]

For the "30 %-Annex-I" and the "40 %-Annex-I" scenarios, emission reduction targets of 15 % below baseline in 2020 are implemented for the same set of major developing countries which also submitted pledges under the Copenhagen Accord. The targets for these countries correspond to the lower end of the range suggested by den Elzen and Höhne (2008) or by the European Commission (2009a). Again, no emission targets are implemented for ODCs and LDCs for these scenarios. *Table 1* shows the average annual growth rate of emissions as implied by the policy targets, i.e. for those countries where emissions are capped. The rates are calculated for the combined emission targets of countries with targets.[20]

[18] The targets for the major developing countries implemented in this study are very similar to those calculated in Stern and Taylor (2010), In particular the carbon intensity targets by China and India are calculated based on real GDP (base is 2004, using market exchange rate). Required reductions of CO_2 emissions in "Ambitious Pledges" scenario compared to baseline emissions in 2020 are (figures for Stern and Taylor in parentheses) are then for China 9.4 % (9 %), India 10.4 % (at least 7 %). Of course, the outcomes would be different, if the pledges for India and China were interpreted in terms of nominal rather than real GDP. In this case, the emission targets would be less stringent. In contrast, if GDP was measured in purchasing power parity rather than market exchange rates, reduction targets for India and China would likely be tighter (see den Elzen et a. 2010). Den Elzen et al. (2010) further argue that the pledges by China appear less ambitious than measures currently implemented or planned in these countries.

[19] See for example, Ward and Grubb (2009) and Duscha et al. (2010) for a more detailed discussion and scenario analyses of alternative burden-sharing indicators.

[20] Note the set of countries subject to emission targets differs between the two periods. To calculate the figures for emissions in 2010 in *Table 1* we use the Kyoto-targets for countries which ratified the Kyoto Protocol (except for Russia and Ukraine). For all other countries (including the US, Russia and the Ukraine) we use the baseline emissions in 2010.

	Weak Pledges	Ambitious Pledges	30%-Annex I	40%-Annex-I
2010 - 2020	1.05%	0.39%	-0.29%	-0.85%
2020 - 2030	-2.69%	-2.63%	-2.56%	-2.11%

Table 1 *Annual average growth rates of capped emissions*

Table 1 further implies that overall emissions in 2020 are highest in the "Weak Pledges" scenario and lowest in the "40 %-Annex-I". Tighter targets after 2020 translate into more ambitious emission reduction rates for all policy scenarios (see *Table 1*). Even though emission reduction rates after 2020 are highest for the "Weak Pledges" scenario, because this scenario also has the highest emission levels in 2020, it still has the highest emissions in 2030. As in 2020 the policy scenario with the lowest emissions is the "40 %-Annex-I" scenario. By construction, the scenarios do not reflect a common probability for reaching the "2°C target" as overall emissions differ. The probability to reach the "2°C target" is highest in the "40 %-Annex-I" scenario as aggregate emissions are lowest.

Figure 1 shows the growth in emissions by countries/regions in the baseline and the targets in the four policy scenarios for 2020 compared to 2005 emission levels.[21] Arguably, the most striking difference in targets across the policy scenarios refers to the targets for Russia. Similar to the 1st commitment period under the Kyoto Protocol (Kyoto-period) (but not modeled in our policy scenarios for 2010), the targets pledged by Russia for 2020 involve substantial quantities of "hot air". The amount of hot air is the positive difference between the baseline emissions and the target emissions, corresponding to about 350 million tons of CO_2 in 2020 in the "Weak Pledges" scenario and about 150 million tons of CO_2 in the "Ambitious Pledges" scenario. For Australia, Canada and the US the targets in the "30 %-Annex-I" scenario are also significantly more ambitious than in both "Pledges" scenarios. In contrast, for a few countries/regions, namely for the EU27 and Norway, reduction targets in the "Ambitious Pledges" scenarios are more ambitious than in the "30 %-Annex-I" scenario. Interestingly, the pledges by Korea, Mexico, Brazil, and South Africa are more ambitious than the target under the "30 %-Annex-I" and "40 %-Annex-I" scenarios, i.e. the 15 % reduction compared to baseline emissions in 2020 and hence the lower end of the range suggested by EU (2009a) and den Elzen and Höhne (2008). *Table 2* summarizes the emission targets by Annex-I and Non-Annex-I countries for the policy scenarios compared to baseline for those countries with targets under the respective scenario.

[21] Compared to the baseline in 2020 the "Weak Pledges" and the "Ambitious Pledges" scenario correspond to reductions in global CO_2 emissions of about 8.5 % and 13 % respectively. These figures are in line with findings by other studies, including Stern and Taylor (2010).

	2020				2030			
	Weak Pledges	Ambitious Pledges	30%-Annex-I	40%-Annex-I	Weak Pledges	Ambitious Pledges	30%-Annex-I	40%-Annex-I
All countries (% of baseline)	-10.9%	-16.6%	-22.9%	-27.2%	-40.1%	-42.8%	-46.0%	-48.1%
All countries (% of 1990)	53.1%	43.4%	32.5%	25.2%	15.4%	8.9%	1.6%	-3.2%
Annex-I (% of 1990)	-12.1%	-17.4%	-30.6%	-40.5%	-36.4%	-39.9%	-48.8%	-55.4%
Non-Annex-I (% of baseline)	-6.9%	-13.0%	-14.3%	-14.3%	-39.7%	-42.3%	-43.5%	-43.5%

Table 2 Emission targets compared to 1990 / baseline

Hence, industrialized countries‘ “pledges“ under the Copenhagen Accord lead to emission reductions compared to 1990 emission levels of at most 17 % and developing countries‘ “pledges“ to emission reductions compared to baseline of at most 13% in 2020 (“Ambitious Pledges” scenario). Compared to the Copenhagen “pledges” the “30 %-Annex-I scenario and, in particular, the “40 %-Annex-I” scenario attribute a significantly higher reduction (compared to 1990 levels) to Annex I countries. As den Elzen et al. (2010b) point out, pursuing ambitious climate policy targets prior to 2030 may be vital in terms of reaching the 2°C target, because it is unlikely that higher emissions from earlier years can be fully counterbalanced in future decades via a “delayed action” type strategy.

2.2.2.2 Targets for 2030

For the periods between 2020 and 2030, all countries except for LDCs face emission targets in all scenarios. These targets are derived from a linear reduction path between 2020 and 2050 assuming that each Annex-I country reduces its emissions by 85 % below 1990 levels by 2050. For Annex-I countries and the six major developing countries, emission targets for 2020 were used as the starting point for the linear reduction path. By definition, emissions in the Annex-I countries in 2020 differ among the policy scenarios: the “40 %-Annex-I” scenario corresponds to the lowest overall Annex-I emission level and the “Weak Pledges” scenario corresponds to the highest overall Annex-I emission level. Since the base of the linear reduction path from 2020 to 2050 differs across the policy scenarios, the targets for 2030 also differ. As a consequence, the “40 %-Annex-I” scenario results in the lowest overall Annex-I emission level of all policy scenarios while the “Weak Pledges” scenario implies the highest overall Annex-I emission level in 2030.[22] Annual reduction rates between 2020 and 2030 in Annex-I countries, in contrast, are highest in the “Weak Pledges” scenario and lowest in the “40 %-Annex-I” scenario.

For Non Annex-I Developed Countries (NAID), for Advanced Developing Countries (ADC) and for Other Developing Countries (ODC)[23] reduction targets for 2030 are determined based on a global emission reduction target of 50 % below 1990 levels in 2050. Given the

[22] In 2050 targets would converge for all policy scenarios.

[23] See Table A-1 in the Annex for the grouping of regions.

reductions by Annex-I countries, all Non-Annex-I countries, except LDCs, will contribute the remainder to reach the 50 % global reduction target in 2050. Assuming a linear reduction path for all Non-Annex-I countries, NAID and ADCs will reduce emissions at twice the rate of ODCs. By choice, Non-Annex-I targets differ between the "Weak Pledges" and the "Ambitious Pledges" and the "30 %-Annex-I" and "40 %-Annex-I" scenarios for Brazil, China and India. Figure 1 shows the growth in emissions by countries/regions in the baseline and the targets in all policy scenarios for 2030 compared to 2005 emission levels. Overall targets are significantly more ambitious in 2030 than they were in 2020, in particular for Non-Annex-I countries (see also *Table 2*). For the period 2020 to 2030 average emission targets relative to baseline emissions for Non-Annex-I countries are still below those of Annex-I countries, but the gap has become smaller. In addition, Figure 3 shows the growth in emissions in baseline and target emissions for all four policy scenarios for 2020 and 2030 for Annex I countries compared to 1990 emission levels.

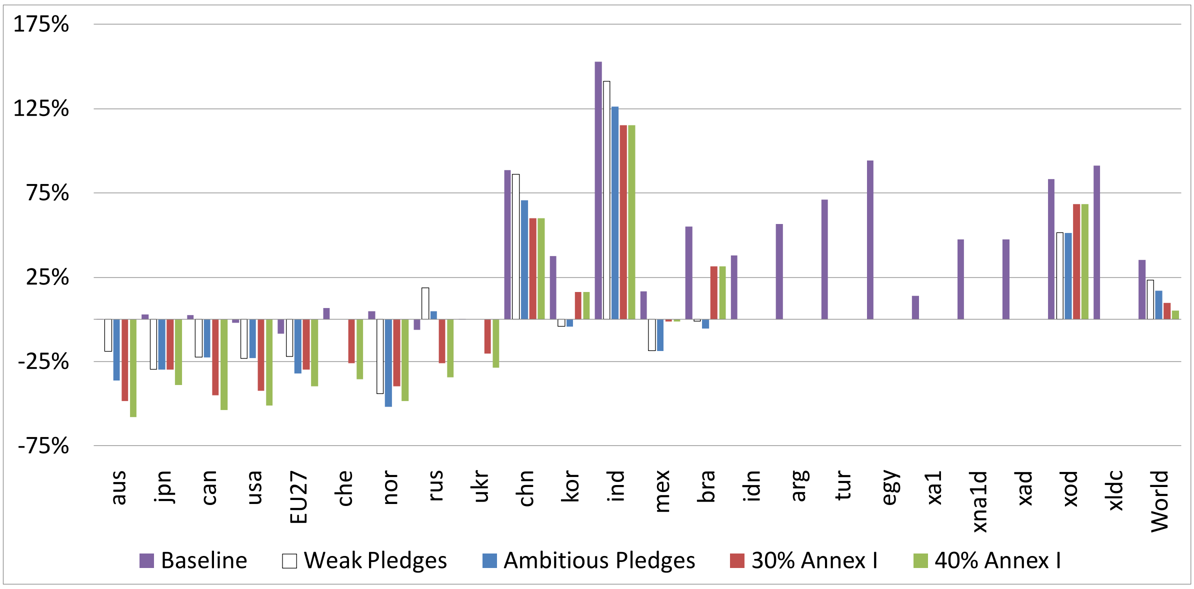

Figure 1 Growth in baseline and target emissions for the policy scenarios in 2020 compared to 2005 (in %)

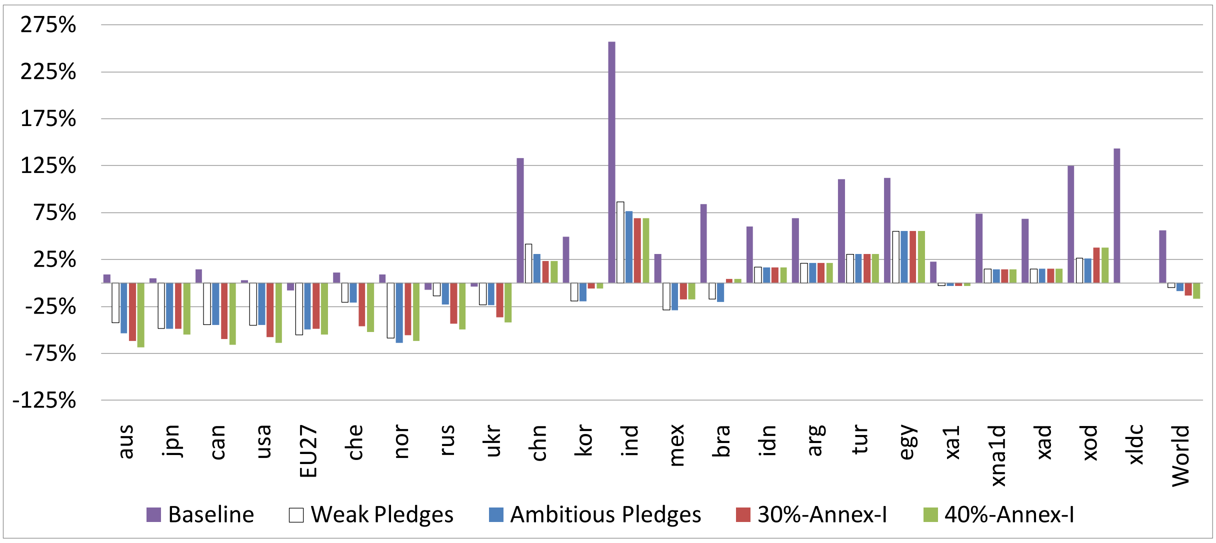

Figure 2 Growth in baseline and target emissions for the policy scenarios in 2030 compared to 2005 (in %)

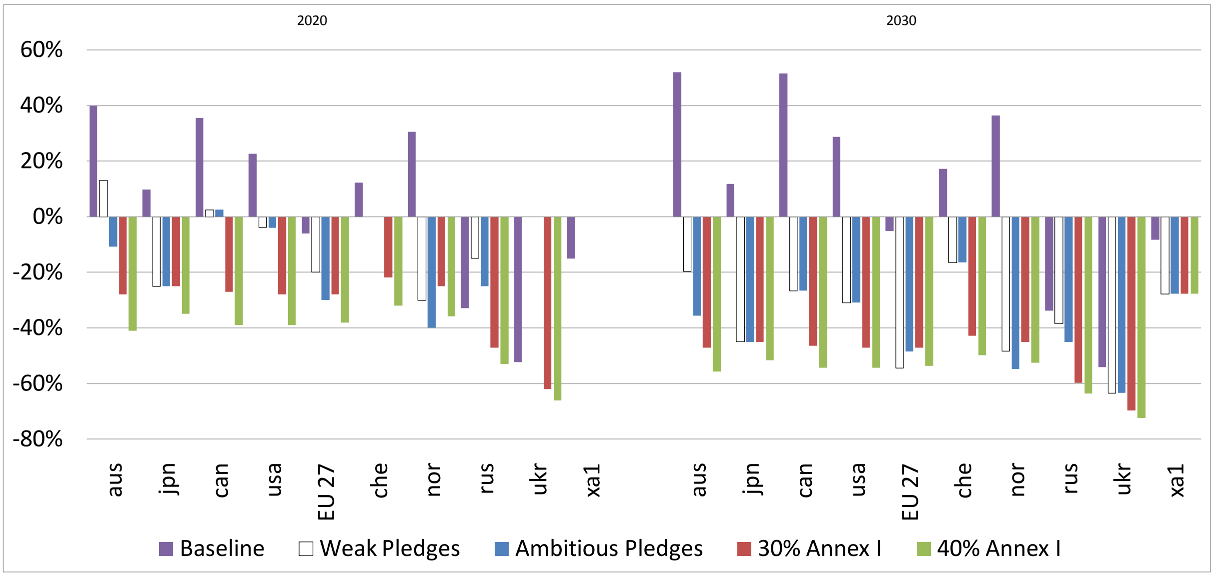

Figure 3 *Growth in baseline and target emissions of Annex I countries for the policy scenarios in 2020 and 2030 compared to 1990 (in %)*

2.3 Results of policy scenarios

For all four policy scenarios the findings in terms of environmental and economic effects are compared to the outcomes of the baseline simulations.

2.3.1 Certificate prices

Prices for CO_2 certificates (in 2004[24] US$ per ton of CO_2) for the trading regions in the respective periods appear in Table 3 for all policy scenarios. The certificate price of 17.3 $/ton (13.90 €/t CO_2 in 2004 €[25]) in 2010, which is the same across all scenarios, represents the marginal abatement costs of achieving the Kyoto targets in the model (abstracting from the Kyoto emission targets by Russia, the Ukraine or the US). In 2015, the price of certificates falls relative to the 2010 price in all scenarios. This occurs due to the new “hot air” for Russia and because China and India are allowed to sell emission permits, which lowers the global marginal cost of abatement. In 2020, certificate prices for both Pledges scenarios remain at or below the 2010 certificate price. Only for the 30 % Annex-I scenario, where larger emission reduction targets for the Annex-I countries lead to higher global marginal abatement costs, does the certificate price in 2020 exceed the 2010 price.

To meet the 2030 targets, marginal abatement costs rise substantially in all policy scenarios. Certificate prices increase between 73$/ton (58.70 €/ton) in the “Weak Pledges” scenario to 87.2$/ton (70.10 €/ton) in the the “40 %-Annex-I” scenario. Because of differences in certificate prices in 2020 across the difference scenarios, the increase in certificate prices averages from 13 % annually between 2020 and 2030 in the “40 %-Annex-I” scenario to 23 % annually in the “Weak Pledges” scenario. Overall, certificate prices in 2030 are approximately 15$/ton to 40$/ton lower in the pledges scenarios that for the more ambitious scenarios.

[24] The current GTAP 7 database uses 2004 as base year. Therefore all results are given compared to 2004 levels.

[25] The average exchange rate for 2004 of 1€ = 1.2438$ as given by the US Federal Reserve is used to convert $-prices into €-prices.

Year	Weak Pledges	Ambitious Pledges	30%-Annex-I	40%-Annex-I
2010	17.3	17.3	17.3	17.3
2015	5.6	8.5	12.8	16.6
2020	10.2	17.1	26.9	34.9
2025	39.1	47.8	59.8	68.8
2030	83.2	94.9	110.5	122.1

Table 3 CO_2 certificate prices in the policy scenarios (in 2005 $/ton)

2.3.2 Emissions trading, hot air and leakage

In all policy scenarios, countries with targets are allowed to trade emission certificates. Figure 4 and Figure 5 show the traded volumes of certificates for the different countries and regions in 2020 and 2030 respectively. Traded volumes are endogenously determined and depend on a country's emission target (compared to baseline emissions) and on its marginal abatement costs. Optimal trading and abatement strategies imply that countries facing tight targets and high abatement costs will purchase certificates from countries with low marginal abatement costs and/or excess certificates resulting from lenient targets.

Results for 2020

Figure 4 shows that, except for the "Ambitious Pledges" scenario, the US will be the major buyer of certificates in absolute terms in all policy scenarios in 2020. In the Ambitious Pledges scenario, the EU27 commits to a 10 percentage point larger reduction in emissions while the US commitment remains unchanged. This larger abatement effort by the EU27 causes it to purchase more certificates than the US in the Ambitious Pledges scenario. Because Brazil, Mexico, and South Korea have much larger emission reduction commitments in the two Pledges scenario than in the "30%-Annex-I" scenario, these regions purchase significant quantities of certificates in both Pledges scenarios.[26] China and India are two of the largest sellers of certificates across all policy scenarios. In the Pledges scenarios, South Africa (part of Rest of ODC – xod - in Figure 4) also commits to larger emission reductions in the Pledges scenarios, but does not actively buy or sell certificates in these scenarios. However, in the "30 %-Annex-I" scenario, its smaller emission reduction target allows it to be a major seller of certificates in 2020.

Russia is also a major seller of certificates in both "pledges" scenarios since projected emissions by Russia are below its target. In the "Weak Pledges" scenario, total emission reductions, including "hot air," are approximately 3.2 billion tons of CO_2 in 2020, compared to base-

[26] Brazil's position, however, would likely be different, if REDD and REDD-plus were included in the analysis, since these measures have a high potential and are relatively cheap.

line emissions. Since baseline emissions in Russia are about 0.35 billion tons of CO_2 below its “Weak Pledges” target,[27] emission reductions net of “hot air” are about 3.55 billion tons CO_2. The total share of “new hot air” in 2020 is about 9.7 % in the “Weak Pledges” Scenario.[28] Similarly, the share of “new hot air” for the “Ambitious Pledges” scenario is approximately 3 %. In contrast, the “30 %-Annex-I” and the “40 %-Annex-I” scenarios do not result in new “hot air” for Russia. In fact, Russia becomes a net buyer of certificates in the “30 %-Annex-I” and the “40 %-Annex-I” scenario.

Across all policy scenarios, a substantial share of required reductions in emissions for regions with targets is achieved via emissions trading. In relative terms, more certificate trading occurs in scenarios with lower certificate prices, because higher certificate prices render domestic abatement more cost effective. In 2020, about three quarters of the total reduction in emissions (net of hot air) is achieved via emission trading in the Weak Pledges scenario. This share drops to 56 % in the “Ambitious Pledges” scenario and to under 45 % in the “30 %-Annex-I” and the “40 %-Annex I” scenarios (see also Table 4).

	Weak Pledges	Ambitious Pledges	30%-Annex-I	40%-Annex-I	Weak Pledges	Ambitious Pledges	30%-Annex-I	40%-Annex-I
Global emissions (in % of 2005 emissions)	23.7%	17.8%	11.0%	6.5%	-4.0%	-8.0%	-12.8%	-15.9%
Share of certificate trading in reductions	72.8%	47.5%	41.4%	44.6%	17.3%	15.9%	16.2%	18.1%
Leakage rate in % of baseline emission	0.3%	0.6%	0.8%	1.0%	0.4%	0.4%	0.4%	0.5%
Leakage rate	4.3%	4.4%	4.6%	4.8%	1.0%	1.0%	1.1%	1.1%

Table 4 Overview of emission reductions, role of certificate trading, and leakage

In terms of environmental effectiveness, no policy scenario will reduce global CO_2 emissions in 2020 compared to 2004 emission levels. Global CO_2 emissions in the “Weak Pledges” and in the “Ambitious Pledges” scenarios will increase by about 20 % and 14 %, respectively. While the voluntary “pledges” scenarios limit global emission growth to about half the growth in the baseline (29 % in 2020 compared to 2005) at best, they are unlikely to be compatible with an emission path allowing to achieve the “2°C target” (Ecofys and PIK 2009, Stern and

[27] For comparison, den Elzen et al. (2009b) estimate the magnitude of hot air from Russia in 2020 at 0.42 Gt.

[28] Clearly, if Russia was assumed to transfer “hot air” from the Kyoto phase and the pledges remained the same, certificate prices would be substantially lower than 10$/ton or 17$/ton in 2020 in the “Weak Pledges” and the “Ambitious Pledges” scenarios, respectively.

Taylor 2010).[29] Global emissions also rise in the “30 %-Annex-I” and the “40 %-Annex-I” scenarios, but the growth rates of 11 % and 6.5 % are significantly lower. Hence, no policy scenario considered is likely to be consistent with the intermediate target proposed by the IPCC (2007).

To some extent, emission reductions in the policy scenarios (compared to baseline) are offset by emission increases in regions which do not take on mitigation action (“carbon leakage”). Ceteris paribus, these additional emissions rise with higher prices of CO_2 certificates. If leakage is measured relative to the reductions in countries with targets (as in IPCC 2007), the leakage rate in 2020 ranges between 4.3 %[30] in the “Weak pledges” scenario and 4.8 % in the “40 %-Annex-I” scenario (Table 4). If leakage is measured as a share of global baseline CO_2 emissions in (and hence based on the same “denominator”) across all policy scenarios, leakage increases from 0.35 % in the “Weak Pledges” scenario to 1.03 % in the “40 %-Annex-I” scenario (see Table 4). In general, the reported leakage rates are rather small.[31]

Results for 2030

Targets for 2030 are significantly more ambitious than for 2020. For example, 2030 global emissions are approximately 4 % less than 2004 emissions in the “Weak Pledges” scenario and about 16 % lower in the “40 %-Annex-I” scenario. Compared to baseline emissions, the reductions range between around 39 % in the “Weak Pledges” scenario and 46 % in the “40 %-Annex-I” scenario. As was the case for 2020, the US is the largest buyer of certificates in all but the “Ambitious Pledges” policy scenario (see Figure 5). Certificates are mostly sold by China, with India, with other developing countries (ODC) supplying much lower levels. Compared to 2020, developed countries engage more heavily in “domestic” emission reductions with certificate trading accounting for about 17 % of the total required emission reductions. Hence, for more ambitious targets, domestic abatement becomes relatively more cost-efficient. In absolute terms, though, the (minimum) traded volume increases by about 20% in the “Pledges” scenarios, by about 8 % in the “30 %-Annex-I” scenario and remains about the same as in 2020 in the “40 % Annex-I” scenario..

Unlike in the policy scenarios for 2020, in the simulations for 2030 all regions (except for LDCs) are assumed to commit to limit their emission. Consequently, the leakage rate in the policy scenarios for 2030 is substantially smaller than in the scenarios for 2020 even though certificate prices are much higher in 2030.

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29 According to PIK (2010), the pledges under the Copenhagen Accord would lead to a temperature increase of around 3.5°C.

30 This means, that 4.3 % of the respective reductions in Annex-I countries and in the six major developing countries with capped emissions are offset with emissions in LDCs and other regions without emission targets.

31 When leakage rates are compared to findings from other studies, the level of aggregation needs to be taken into account. If leakage rates are measured at the sectoral level (including sectoral targets), rather than at the country level, the calculated leakage rates are higher (e.g. Bernard and Vielle 2009).

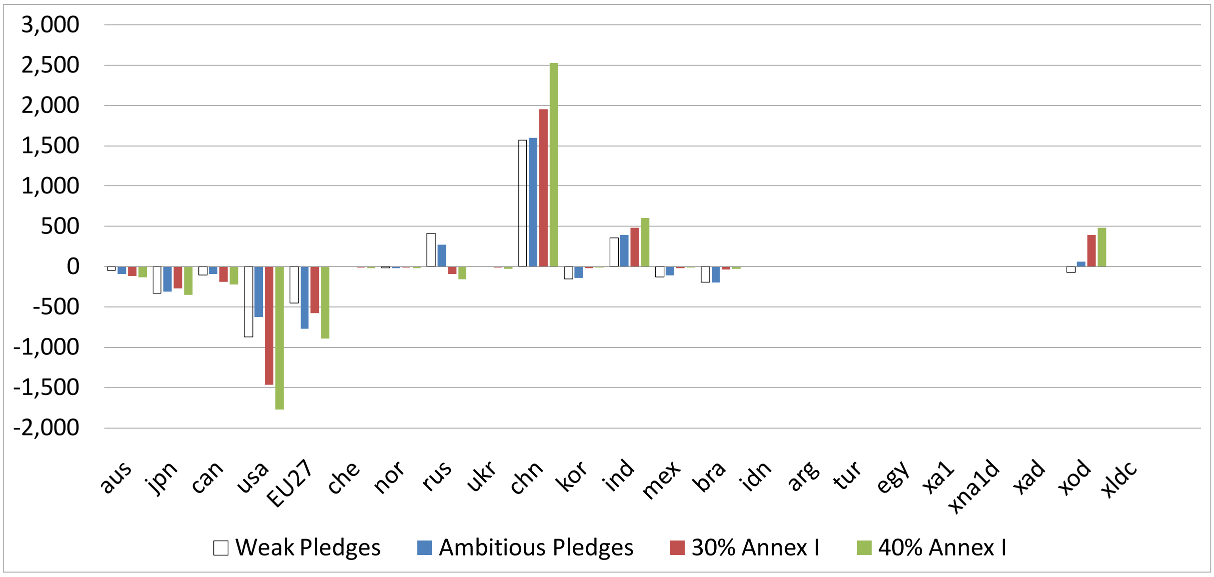

Figure 4 Volume of certificate sales (+) and purchases (-) in 2020 (in million tons)32

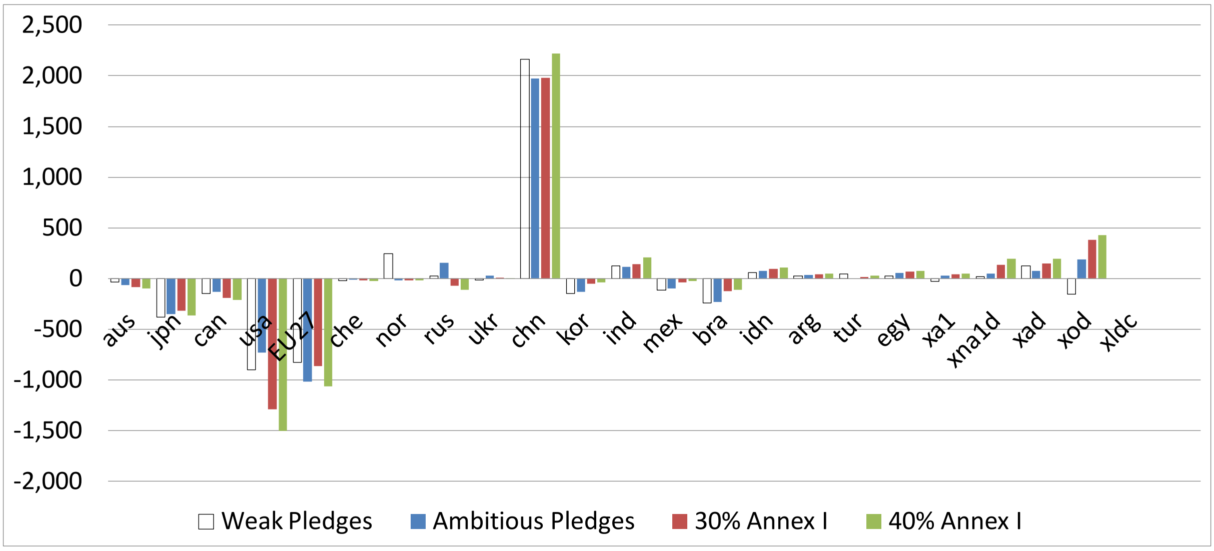

Figure 5 Volume of certificate sales (+) and purchases (-) in 2030 (in million tons)

2.3.3 Gross domestic product

One of the concerns of implementing climate change policy is its potential impacts on economic activity and whether those effects vary across countries or regions. Unlike bottom-up

32 Note that results for South Africa are included in the xod region in Figure 4 and Figure 5.

engineering or partial equilibrium models, where GDP is typically given exogenously, a CGE model allows GDP, input and output prices, production levels, and trade flows to change endogenously in response to climate policy.

Figure 6 and Figure 7 show for 2020 and 2030 the level of GDP for the four policy scenarios and the baseline (normalized at 2004 levels) at the country and regional level. Results for “EU-30 %” are presented and discussed in Box 1.

Results for 2020

Relative to GDP in the baseline, the reductions in global GDP in 2020 amount to around 0.2 % for the “Weak Pledges” scenario, 0.3 % for the “Ambitious Pledges” scenario, 0.5 % for the “30 %-Annex-I” scenario, and 0.7 % for the “40 %-Annex-I” scenario. Overall, global GDP growth decreases by 1 percentage point from 43 % between 2004 and 2020 in the baseline to 42 % in the “Ambitious Pledges” scenario. However, there are variations in the changes in GDP between Annex-I countries, Non-Annex-I countries with emission targets, and countries without emission targets. In Annex I countries, the differences between GDP growth in the baseline and policy scenarios are small. Reductions in GDP compared to baseline for Annex I countries with targets[33] are fairly modest, averaging under 0.1 % in the “Weak Pledges”, 0.1 % in the “Ambitious Pledges” scenario, 0.2 % in the “30 %-Annex-I” scenario, and 0.3 % in the “40 %-Annex-I” scenario. For Russia, while GDP growth remains above the average Annex I GDP growth (58 % between 2004 and 2020), reductions in GDP in the policy scenarios relative to baseline are above average, ranging from 0.9 % to about 3 % in the “40 %-Annex-I” scenario. The lower growth in GDP for Russia compared to the baseline mainly results from a smaller increase in private consumption due to lower growth in factor income (e.g. wages and returns on capital). All policy scenarios lead to a decline in the output of fossil fuels (coal, oil, gas) commodities (relative to the baseline) because of lower domestic and export demand. Because climate policies result in lower global demand for fossil fuels, their world prices fall (compared to the baseline).[34] Given the size of these sectors in Russia, this leads to a strong decline in the demand for labor and capital and to a decrease in the price of those factors (relative to baseline). The profits received by Russia from selling “new hot air” in the “Pledges” scenarios are not sufficient to compensate the loss in factor income.[35]

For Non-Annex-I countries with emission targets, the reduction in GDP is much larger than for Annex-I countries, averaging 0.9 % in the “Weak Pledges” scenario, 1.4 % in the “Ambitious Pledges” scenario, 2.2 % in the “30%-Annex-I” scenario, and 2.8 % in the “40 % Annex-

[33] Note that in this report not all Annex-I countries are associated with targets under the Copenhagen Accord (notably Switzerland and the Ukraine).

[34] This finding is typical for climate policy analyses based on CGE models.

[35] Qualitatively similar findings for Russia can be found, among others, in Böhringer and Vogt (2003), for the impact of the Kyoto Protocol, which also involves substantial amounts of hot air for Russia.

Scenario."[36]. China and India experience the largest reduction in GDP, relative to the baseline, ranging from 1.1 % to 2.9 % for China and from 1.2 % to 2.2 % for India. The larger reductions in GDP from tighter emission targets occur because the industrial sectors in China and India are more energy- and CO_2-intensive than most other regions. As tighter emission targets raises the price of CO_2 certificates, CO_2 emissions become more costly leading to higher output prices and larger reductions in the production of energy-intensive sectors in China and India. Even though China and India have the largest reductions in GDP in 2020, their real GDP growth will remain very strong, being 2.6 and 2.7 times higher in 2020 than in 2004, compared increasing 2.7 and 2.8 times in the baseline.[37]

While tighter emission targets lead to larger reductions in GDP for some large developing countries like China and India, some Annex-I countries, notably the EU and Japan[38] experience an increase in GDP. This occurs due to the relative differences in energy and CO_2 intensities between regions. Whereas China and India are relatively more energy- and CO_2-intensive than other regions, the EU and Japan are relatively less energy- and CO_2-intensive. Thus, a higher cost of CO_2 emissions will have less effect on the prices and make EU and Japanese firms more competitive, leading to increases in output.

For example, in the "Ambitious Pledges" scenario steel production in China and India in 2020 is still more than twice as CO_2-intensive as in the EU. Hence, CO_2-intensive production sectors are much more vulnerable to higher CO_2 prices in countries such as China or India than in Japan or the EU. Besides costs for direct emissions, higher CO_2 prices also affect the costs of intermediaries, in particular of electricity. Thus, higher CO_2 prices may significantly increase production costs for electricity-intensive sectors like chemicals, rubber and plastic products or other metals such as aluminum. Because coal is the main fuel used to generate electricity in China and India, electricity prices rise more in both regions than in other regions (compared to baseline). These price increases are larger for tighter emission targets.[39] For example, the electricity price increase in China is twice as high for the "30 %-Annex-I" scenario compared with the "Ambitious Pledges" scenario and about three times as high compared with the "Weak Pledges" scenario in 2020. In this respect, it should be noted that the dynamic nature of the model allows capturing "early action" effects in the sense that it recognizes the effects of climate policy on CO_2 intensity of the economy in past periods.

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[36] If REDD and REDD-plus measures were included, the reduction in GDP for Brazil would probably be much smaller compared to baseline in all policy scenarios. Brazil could even become a net seller (rather than buyer) of certificates and GDP may increase.

[37] Even though growth will be larger in developing countries, per capita GDP in developing countries will still be substantially below per capita GDP in industrialized countries.

[38] Peterson and Klepper (2007) find qualitatively similar results for Japan, but do not offer further insights.

[39] Of course, these analyses implicitly assume that carbon (opportunity) costs will be passed on to electricity consumers.

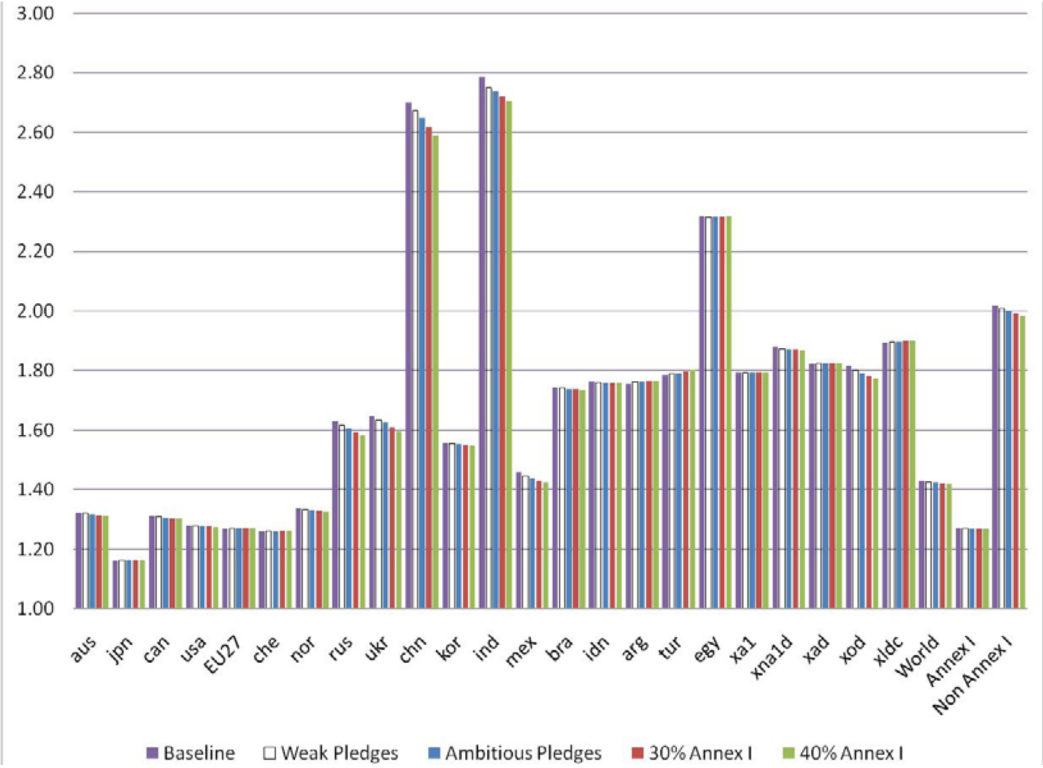

Figure 6 GDP in baseline and policy scenarios in 2020 (relative to 2004)

Table 5 provides an overview of output changes in selected sectors and regions for allscenarios compared to baseline. In general, gains and losses in production (relative to baseline) in all policy scenarios are usually small and below 1 % in the EU27, the US and Japan. In contrast, production losses (relative to baseline) in China and India are significantly higher and tend to range between 3 % in the “Pledges” scenarios to more than 10 % in the “Annex I” scenarios. More specifically, the sectors iron and steel, other mineral products (i.e. mostly cement) and other manufacturing in the EU27, the US and Japan tend to benefit from higher prices for CO_2 certificates. These (positive) output effects are rather marginal for the “Pledges” scenarios and range up to around and above 1 % in the “40 %-Annex-I” scenario. In contrast, output in China and India in these sectors decreases significantly (compared to baseline). Typically, these losses range between around and below 3 % in the “Weak Pledges” scenario to around and above 10 % in the “40 %-Annex-I” scenario. While China and India experience the largest output reductions in these sectors, output growth will remain quite strong. In the baseline steel output almost doubles in China and increases by more than 140 % in India by 2020 compared to 2010, In the “40 %-Annex-I” scenario, output in the steel sector in China still increases by 80 % and in India by 114 % over that period.

	EU27	US	Japan	China	India
Iron and steel					
Weak Pledges	0.39	0.20	0.48	-2.87	-4.34
Ambitious Pledges	0.63	0.20	0.63	-4.69	-6.35
30%-Annex-I	1.15	0.82	0.87	-7.12	-9.00
40%-Annex-I	1.55	1.28	1.16	-9.08	-11.33
Other metals					
Weak Pledges	-0.23	-0.59	0.44	-3.36	-10.23
Ambitious Pledges	-0.32	-1.14	0.53	-5.50	-15.12
30%-Annex-I	-0.60	-1.04	0.62	-8.49	-21.34
40%-Annex-I	-0.60	-0.94	0.92	-11.01	-26.42
Chemicals, rubber, plastics					
Weak Pledges	0.18	-0.29	0.02	-4.26	-3.42
Ambitious Pledges	0.32	-0.59	-0.12	-6.88	-5.15
30%-Annex-I	0.43	-0.60	-0.37	-10.32	-7.58
40%-Annex-I	0.54	-0.66	-0.48	-12.97	-9.73
Paper					
Weak Pledges	-0.05	-0.15	0.03	-2.68	-3.61
Ambitious Pledges	-0.11	-0.28	0.00	-4.34	-5.35
30%-Annex-I	-0.20	-0.41	-0.07	-6.55	-7.59
40%-Annex-I	-0.29	-0.54	-0.12	-8.21	-9.28
Other mineral products					
Weak Pledges	0.35	0.06	0.49	-2.98	-2.29
Ambitious Pledges	0.53	0.03	0.70	-4.83	-3.28
30%-Annex-I	0.78	0.12	0.96	-7.22	-4.45
40%-Annex-I	0.93	0.16	1.18	-8.91	-5.17
Other manufacturing					
Weak Pledges	0.13	0.14	0.15	-2.38	-2.76
Ambitious Pledges	0.24	0.13	0.10	-3.88	-3.96
30%-Annex-I	0.28	0.58	-0.01	-5.95	-5.65
40%-Annex-I	0.44	0.94	0.08	-7.70	-7.16

Table 5 Difference in output in selected industry sectors in the policy scenarios compared to the baseline in 2020 (in % of baseline)

For other metals, only Japan benefits from higher certificate prices, while the EU and the US experience small output reductions compared to baseline. Reductions in China and, in particular, India are significantly larger. The EU27 is the only region where output in the sector chemicals, rubber and plastics increases in response to tighter emission targets, while the US and Japan face minor reductions in output (compared to baseline). As for all other sectors, the decline in production (relative to baseline) in chemicals, rubber and plastics is relatively more significant in China and India. Output effects in the paper sector are quite small in the EU27, the US and Japan in all policy scenarios. Apart from Japan in the "Pledges" scenario output in the paper sector decreases in all scenarios in all regions. China and India experience similar relative reductions (compared to baseline) of up to around 9 % in the "40 % Annex-I" scenario. Output growth in the paper sector remains strong though in these countries. In the baseline sector output almost doubles between 2010 and 2020 in both countries.

To sum up, tighter targets for Annex-I countries render sectors in regions with emission targets and which produce relatively energy-intensively less competitive. As a consequence energy- and trade-intensive sectors in these regions lose market shares (relative to baseline) to regions where production is less energy intensive.

The effect of climate policies on GDP for countries and regions without emission targets is mixed. For Argentina, Turkey, and LDCs, climate policy leads to small GDP gains in all policy scenarios. However, countries like Indonesia and Egypt with relative large domestic energy sectors, suffer from lower world prices for their products and experience a reduction in GDP.

Box 2: Findings for unconditioned EU 30 % target

This box presents findings for changes in GDP in the "EU-30 %" scenario compared to "Weak Pledges". In the "EU-30 %" scenario the EU is assumed to adopt a 30 % emission reduction target in 2020 compared to 1990 levels as in "Ambitious Pledges" scenario, while all other countries adopt the same emission targets as in the "Weak Pledges" scenario.

The results imply that the price of certificates increases by approximately 15 % to 11.70 $/ton (9.40 €/ton) of CO_2 compared to the "Weak Pledges" scenario. Hence, the environmental and economic effects of the "EU-30 % scenario will be very similar to the "Weak Pledges" scenario. The EU achieves the additional emission reductions primarily via purchasing certificates from other countries. Approximately 95 % of the extra reductions will be met via purchasing certificates from abroad. In particular, China and to a lesser extent also India expand certificate sales in response to the increase in certificate prices. Our calculations indicate that the net effect of an unconditional EU 30 % emission reduction target compared to the "Weak Pledges" scenario involves a small reduction in GDP of less than 0.005 % for the EU.

In general, these findings are in line with the results of a similar analysis carried out on behalf of the European Commission (2010), even though under somewhat different assumptions.[40] Accordingly, additional total costs for the EU to go from a 20 % to a 30 % target are approximately 0.2 % of GDP in 2020.[41]

Results for 2030

Results on the effects of the policy scenarios on the growth of real GDP in 2030 are displayed in Figure 7. In 2030 the reduction in global GDP equals 1.9 % for the "Weak Pledges" scenario, 2.3 % for the "Ambitious Pledges" scenario, 2.8 % for the "30 %-Annex-I" scenario, and 3.2 % for the "40 %-Annex-I" scenario. For regions which faced emission targets in 2020, the economic effects for 2030 follow the pattern described for 2020 but they are more pronounced because targets are significantly tighter and certificate prices substantially higher. The EU, Japan and Switzerland experience an increase in GDP as targets become tighter. All other regions with targets in 2030 experience a reduction in GDP, while LDCs benefit from carbon-leakage effects. On average, the reductions in GDP are relatively higher for Non-Annex-I countries, ranging from 5.0% to 8.0%, than for Annex-I countries, which range from 0.3% to 0.8%. However, as was the case in 2020, even with the larger reductions in GDP due to climate policy, Non-Annex-I countries still grow much faster than Annex-I countries. In 2030, GDP in Non-Annex-I countries is approximately twice as large as in 2010, while GDP in Annex-I countries is only about 40% larger than in 2010. Results for selected sectors and regions in 2030 are presented in Table 6.

Qualitatively, the effects are similar to those observed for 2020 in Table 5, but – because prices for CO_2 certificates are much higher – output gains and losses (relative to baseline) are also more significant in 2030 than in 2020. In China and India, output losses tend to range between 15 % and 30 % for most sectors and scenarios – even higher losses occur primarily in India in the sector other metals. As is the case for 2020, in 2030 in the EU27 the largest output gains (relative to baseline) can be observed in the sectors iron and steel and in other mineral products, and the largest relative output losses in the sector other metals. The US experiences the largest relative output losses in the sector other metals and the largest

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[40] For example, unlike in this report, the CGE-based calculations in EU (2010) assume that the amount of certificates from abroad that can be used for compliance is limited. More specifically, countries cannot use more than 1/3 of the distance between the emission targets and the baseline emissions. Assuming that these certificates can be used without restrictions – as in this report – tends to dampen the effects of a tighter emission target in the EU on GDP in the EU. At the same time though, the more ambitious targets in the EU, which accounts for about ¼ of all required emission reductions in 2020, also raise the costs of CO_2 in China and elsewhere.

[41] It should be kept in mind that as before the target is applied without taking into account further policies like the European Emissions Trading System or the European energy and climate package from 2008. Including these policies would result in more domestic action and thus fewer purchases of emission certificates by the EU from other regions. Since emission reduction measures in the EU tend to be more expensive for the EU than importing certificates, explicitly modelling the policies from the EU package is expected to result larger reductions in GDP in the EU compared to baseline GDP in all scenarios.

relative gains in the iron and steel sector. Finally, production in Japan increases above all in the sectors iron and steel and other mineral products, but decreases slightly in the sectors paper sector and in other manufacturing in 2030.

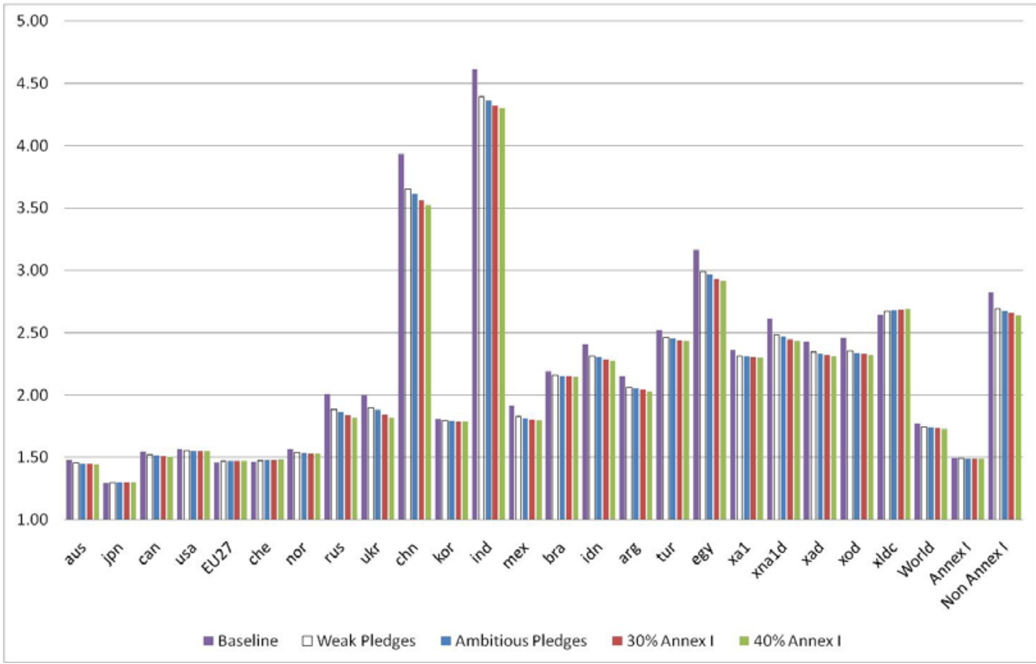

Figure 7 GDP in baseline and policy scenarios in 2030 (relative to 2004)

	EU27	US	Japan	China	India
Iron and steel					
Weak Pledges	4.47	1.60	2.90	-15.12	-16.97
Ambitious Pledges	5.33	1.53	3.26	-17.94	-19.77
30%-Annex-I	6.24	3.52	3.71	-21.66	-23.52
40%-Annex-I	7.31	4.78	4.59	-24.56	-26.74
Other metals					
Weak Pledges	-2.09	-5.96	0.98	-16.87	-36.71
Ambitious Pledges	-2.09	-7.24	1.16	-19.99	-41.82
30%-Annex-I	-2.69	-6.12	1.34	-24.34	-48.14
40%-Annex-I	-2.51	-5.58	2.18	-28.01	-53.23
Chemicals, rubber, plastics					
Weak Pledges	3.88	-0.34	0.83	-20.74	-16.08
Ambitious Pledges	4.56	-0.89	0.75	-24.30	-19.03
30%-Annex-I	4.98	-0.16	0.46	-28.90	-23.06
40%-Annex-I	5.48	0.09	0.55	-32.34	-26.37
Paper					
Weak Pledges	-0.32	-1.17	-0.17	-14.89	-16.70
Ambitious Pledges	-0.43	-1.46	-0.24	-17.52	-19.40
30%-Annex-I	-0.60	-1.70	-0.35	-20.93	-22.76
40%-Annex-I	-0.77	-1.93	-0.44	-23.37	-25.15
Other mineral products					
Weak Pledges	3.16	0.43	2.85	-15.97	-9.20
Ambitious Pledges	3.58	0.32	3.26	-18.91	-10.97
30%-Annex-I	4.10	0.69	3.78	-22.52	-13.01
40%-Annex-I	4.45	0.85	4.26	-24.91	-14.13
Other manufacturing					
Weak Pledges	0.54	0.60	-0.31	-13.83	-11.07
Ambitious Pledges	0.79	0.43	-0.41	-16.17	-12.98
30%-Annex-I	0.81	1.85	-0.60	-19.46	-15.68
40%-Annex-I	1.22	2.75	-0.21	-22.23	-18.04

Table 6 Difference in output in selected industry sectors in the policy scenarios compared to the baseline in 2030 (in % of baseline)

2.3.4 Welfare Effects

While the changes in GDP provide insight into the change in overall economic activity from implementation of emission targets, it is not necessarily a good indicator of how emission targets affect the well-being (or welfare) of individuals in a given region. For example, a decrease in the price of imported products will improve that regions terms-of-trade, leading to an increase in welfare.[42] However, because consumers substitute imported for domestic products, GDP may be lower even as welfare increases. Likewise, when negative production or consumption externalities are present, a reduction in consumption will reduce GDP but may lead to an increase in welfare.

The change in economic welfare from the implementation of emission targets will depend on how this policy affects the efficient use of resources (e.g., labor and capital) in a region's economy (allocative efficiency), the level of resources available to that economy, whether it will affect that region's terms-of-trade with other regions, and whether that region buys or sells CO_2 certificates. In this report, equivalent variation (EV) is used to measure the economic welfare of a representative consumer in a given region. EV is defined as the amount that the representative consumer would need to be paid to be as well off after the implementation of emission targets as it would be if no climate policy was implemented (using baseline prices).

In the DYE-CLIP model, EV is decomposed into its constituent components of allocative efficiency, terms-of-trade, factor endowments, and revenues from CO_2 certificate trading. In determining the change in allocative efficiency for the energy commodities, we take into consideration that climate policy is being implemented to address a negative (global) externality from CO_2 emissions associated with the use of fossil fuels. Without implementing climate policies and assuming perfectly competitive energy markets, the price of the energy commodities is equal to their marginal production costs. However, CO_2 emissions from the use of energy commodities cause economic and environmental damages (e.g., social costs). Thus, the market price of energy commodities is less than the total social cost (marginal production costs plus marginal social cost of the CO_2 emissions), implying that a larger quantity of energy commodities is consumed relative to what is socially optimal. However, when part or all of the marginal social cost is "internalized" through the use of carbon taxes (e.g., price of CO_2 certificates), the use of energy commodities will be reduced which will lead to an increase in allocative efficiency. Because increases in atmospheric CO_2 levels from higher CO_2 emissions will affect all regions, the externality is assumed to exist in all regions in the model.

One limitation to accounting for the externality in the use of energy commodities is that the marginal social cost of CO_2 emissions is not known with certainty. As noted, among others, by Tol (2009), there is a large range of estimates of the social cost of climate change. One reason for large divergence in estimates is the use of different pure rates of time preference

[42] A region's terms-of-trade is determined by the prices it receives for its exports compared to the prices it must pay for its imports. If a region must pay more for its imports relative to what it receives for its exports, then that region experiences a decline in its terms-of-trade and a reduction in welfare.

(e.g., discount rates). If more of the costs associated with climate change will occur in the future, then using a larger rate of time preference will more heavily discount those costs, leading to a lower present value of the social cost of CO_2 emissions. In order to take into consideration the costs of climate change on future generations, a 0 % pure rate of time preference is assumed in this study. This is the same assumption made by Stern (2007, p. 344), who estimated an $85/ton social cost of CO_2 emissions, in 2000 $. Converting the Stern estimate to 2004 dollars using the US GDP deflator, yields a social cost of carbon of $92.15/ton of CO_2.[43] In 2020, the price of CO_2 certificates is less than marginal social costs of carbon all of the reduction in the use of energy commodities represents a gain in allocative efficiency. However, in 2030, the certificate prices in all scenarios except "Weak Pledges," exceed the marginal social cost of carbon. For these cases, the difference between the certificate price and the marginal social cost represents a decrease in allocative efficiency compared to the social optimum. Thus the gain in allocative efficiency from internalizing the negative externality is partially offset by the loss in allocative efficiency from price of CO_2 certificates exceeding the marginal social cost.

Two additional assumptions are made regarding the gains in allocative efficiency from internalizing the externality associated with CO_2 emissions. First, by using the same social cost of carbon in the determination of allocative efficiency across all regions, we assume all representative consumers realize the global nature of the externality and care about the global costs, not just the costs incurred in their region. Hence, our EV estimates would differ if regions' representative consumers only cared about the damages in their regions. Second, we do not include any other benefits from a reduction in CO_2 emissions, such as a reduction in local air pollution due to smaller quantities of fossil fuels being burned.

The change in allocative efficiency is computed in the DYE-CLIP model using the same procedure as in the GDyn and GTAP-E models. With no externalities, allocative efficiency will decrease from an increase in a production or consumption tax (or subsidy). However, in the presence of an externality, an increase in a production or consumption tax, up to the point where the tax-inclusive price equals the marginal total social costs will reduce consumption of the commodity associated with the externality in the post-tax equilibrium. For the same tax increase and initial equilibrium, the absolute value of the loss in allocative efficiency in the no externality case is equal to the absolute value of the gain in allocative efficiency with an externality. The only difference between these two cases is the sign of the change.

As shown in Figure 8, the EV in 2020 from implementing the three climate change policies is relatively small for most regions, with absolute values of less than $10 billion (2004 dollars). Globally, EV increases by $8.9 billion to $125.9 billion across the four scenarios. Welfare increases because the gains in allocative efficiency from a reduction in fossil fuel consumption and CO_2 emissions offset losses in allocative efficiency for non-energy commodities and losses from lower stocks of primary factors available globally. Note that if the application of a

[43] Tol (2009) reports an unweighted sample median and mean of $23.16/ton and $63.22/ton of CO_2 in 1995 dollars. Converting to 2004 $ yields a median and mean estimate of $27.49 and $75.03/ton of CO_2 respectively. Using a lower social cost of carbon would reduce the gains in allocative efficiency from climate policy.

carbon tax had been treated like any other production or consumption tax in the computation of EV (as for example in Peterson and Klepper 2007), implying that a carbon tax leads to a reduction in allocative efficiency and welfare, the opposite conclusion regarding global welfare would have been reached. As a comparison, computing EV using this approach would have yielded a global loss in EV ranging from $98.1 billion in the Weak Pledges scenario to $358.2 billion in the "40 %-Annex-I" scenario. Including the externality in the computation of EV leads to a welfare gain instead of a loss for China, EU27, India, Japan, South Korea, and the *Rest of Other Developing Countries (xod)*.

China, India, and the EU27 enjoy the largest gains in EV. For China and India, the welfare gain is due to improvements in their terms-of-trade, sales of emission certificates, and improvement in the allocative efficiency of energy commodities (see Table 7). The improvement in the terms-of-trade for China and India is mainly due to a lower price of imported oil. For the EU27, the sources of welfare gain are allocative efficiency for both energy and non-energy commodities, and their terms-of-trade, again mainly from lower oil prices. The Rest of Developing Countries region, which includes South Africa, also has a relative larger gain in EV in the "30 %-Annex-I" and "40 %-Annex-I" scenarios. This is due to a lower emissions target in the Annex-I scenarios compared with the Pledges scenarios, which lead to larger sales of emission certificates.

The regions with the largest loss in EV are Rest of Non-Annex-I Developing countries (xna1d), Rest of Advanced Developing countries (xad), and Russia. These regions are major exporters of energy commodities (e.g., oil and gas) and experience large declines in their term-of-trade as well as decreases in the returns to capital owned by these regions.[44] That is, these countries receive lower prices for their exports of fossil fuels in relation to the prices of their imported goods. Even the sale of CO_2 certificates by Russia could not offset the decline in their terms-of-trade.

44 The xna1d region includes the Middle Eastern oil producing countries while xad includes Venezuela.

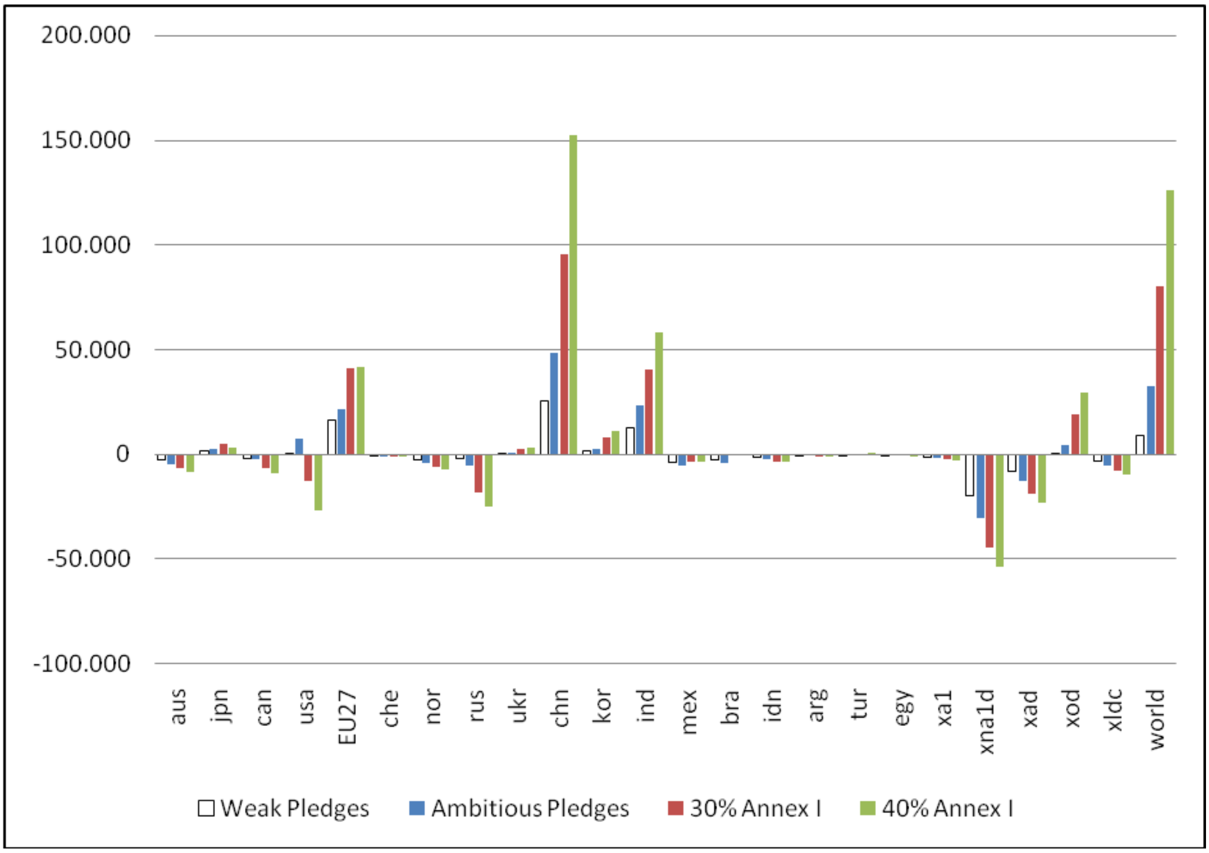

Figure 8 Equivalent variation in 2020 (in million 2004 US$)

The United States is the only country or region where the welfare implications are different for the “Pledges” scenarios versus the “30 %-Annex-I” and “40 %-Annex-I” scenarios. In the Pledges scenarios, the US enjoys a welfare gain due to a gain in allocative efficiency from a partial internalization of the externality, from a gain in its terms-of-trade; and an increase in the returns to capital owned by the United States. The improvement in the terms-of-trade occurs mainly for agriculture, other manufacturing, and services. These gains offset the cost of purchasing CO_2 certificates. In the “30 %-Annex-I” and “40 %-Annex-I” scenarios, the cost of purchasing CO_2 certificates increases substantially, by $29.0 billion to $51.4 billion. This increase more than offsets the gains in allocative efficiency in the energy markets, leading to a $12.5 billion welfare loss for the US in the “30 %-Annex-I” scenario and a $26.6 billion loss in the “40 %-Annex-I” scenario.

Region	Allocative Efficiency Non-Energy	Allocative Efficiency Energy	Terms of Trade	Emission Trading	Other[a]	EV
	($millions, 2004)					
Australia	-429.2	1,177.5	-2,911.3	-444.6	34.4	-2,573.2
Japan	1,115.8	2,752.3	3,109.0	-3,393.4	-2,102.3	1,481.4
Canada	-513.6	1,344.9	-1,184.5	-1,094.5	-304.3	-1,752.0
USA	-1,358.3	8,578.7	2,607.2	-8,893.3	-522.1	412.2
EU27	7,362.3	8,563.4	6,981.4	-4,563.7	-1,959.6	16,383.8
Switzerland	96.5	-107.9	62.0	0.0	-542.9	-492.3
Norway	-105.3	143.9	-1,732.8	-171.6	-547.4	-2,413.2
Russia	-1,060.2	2,085.8	-3,354.3	4,272.0	-3,703.9	-1,760.6
Ukraine	117.5	-21.6	275.4	0.0	-26.4	344.9
China	-14,435.6	14,708.0	13,767.5	16,123.7	-4,825.8	25,337.8
South Korea	-149.1	1,360.4	2,170.0	-1,591.9	-172.0	1,617.4
India	-2,080.3	6,857.2	3,776.4	3,628.7	224.6	12,406.6
Mexico	-3,728.2	3,012.3	-1,197.2	-1,271.6	-402.3	-3,587.0
Argentina	135.4	-85.8	-433.8	0.0	155.0	-229.2
Brazil	-491.9	848.4	-774.0	-1,983.9	28.1	-2,373.3
Indonesia	-141.6	26.0	-1,005.4	0.0	-600.2	-1,721.2
Turkey	73.4	-573.3	640.4	0.0	-81.9	58.6
Egypt	-53.7	-7.2	-73.1	0.0	-221.6	-355.6
Rest Annex-I	-307.7	266.3	-827.1	0.0	-276.5	-1,145.0
Rest Non-Annex-I, Developing	-825.7	-520.2	-12,086.0	0.0	-6,380.0	-19,811.9
Rest of Advanced Developing	19.2	-240.5	-5,797.4	0.0	-2,216.7	-8,235.4
Rest of Other Developing	-3,400.7	3,531.6	607.0	-669.9	420.9	488.9
Rest of Least Developed	104.0	-209.0	-2,708.3	0.0	-371.1	-3,184.4

[a] Includes changes in EV due to changes in factor endowments and ownership, and investment.

Table 7 Decomposition of 2020 equivalent variation for the "Weak Pledges" scenario

Because of differences in income levels across the regions, it is also instructive to consider the change in welfare relative to baseline GDP in 2020. As shown in Figure 9, the EV from implementing the Pledges scenarios is less than 1.0 % of the 2020 baseline GDP for most regions. The average absolute EV relative to baseline GDP is 0.3% and 0.5% for the “Weak Pledges” and “Ambitious Pledges” scenarios. Hence, welfare changes relative to GDP are rather small for most countries. The exceptions are China, India, and xna1d, which also have the largest changes in EV in dollar terms. It is interesting to note that while the absolute value of EV for Norway is less than $5.5 billion, given the relative size of Norway’s economy, the welfare change is relatively large. Also note that while the EU27 had relatively large absolute change in EV, given the size of its economies, that change is a relatively small percentage of 2020 baseline GDP. In the “30 %-Annex-I” and the “40 %-Annex-I” scenarios, the average absolute EV relative to baseline GDP is 0.9% and 1.2% for all regions. Russia, Ukraine, and Rest of Developing Countries experience much larger relative welfare change in these scenarios than in the Pledges scenarios. For Russia, the elimination of “hot air” lowers their sales of CO_2 certificates in the “30 %-Annex I” scenario by about $7.1 billion, compared to the Ambitious Pledges scenario. For the “40 %-Annex I” scenario, this difference is almost $10 billion. In addition, the larger reduction in emissions further reduces the world prices of energy commodities, leading to larger terms-of-trade losses for Russia. For the Ukraine, the relative larger gain in EV in the “Annex-I” scenarios is mainly due to an improvement in its terms-of-trade in oil, chemicals, rubber and plastics products (crp), and ferrous metals (is). Finally, because the Rest of Developing Countries includes South Africa, which faces much smaller emission reduction targets in the “Annex-I” scenarios, it sells about $9.3 billion more in CO_2 certificates in the “30 %-Annex I” scenario than in the Ambitious Pledges scenario. For the “40 %-Annex I” scenario, this difference is about $15.6 billion.

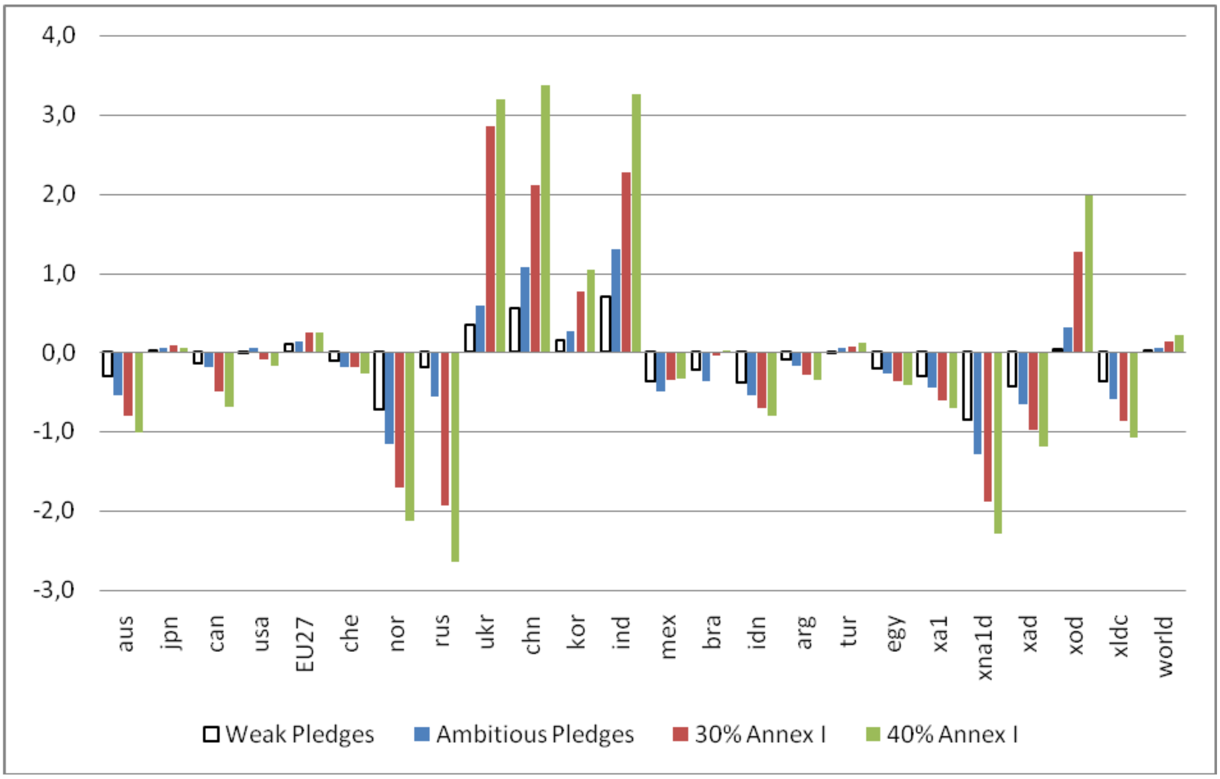

Figure 9 Change in welfare in 2020 (in % of baseline GDP)

Stricter emission targets in 2030 lead to higher carbon taxes and, on average, also to larger welfare changes compared to 2020. Otherwise the relative results are quite similar to the results for 2020. For completeness equivalent variation in absolute and relative terms is reported in the in the Annex.

The welfare results for 2030 illustrate the sensitivity of the assumption about the social cost of carbon, and in particular the discount rate. In the "Weak Pledges" scenario, the certificate price in 2030 remains below the assumed marginal social cost of carbon. Thus, all of the reductions in the use of energy commodities represent a gain in allocative efficiency. However, this is not the case for the remaining scenarios. In the "Ambitious Pledges" scenario, the certificate price is just slightly more than the marginal social cost of carbon, implying virtually all of the reduction in energy use is a gain in allocative efficiency. The global EV for this scenario increases relative to the "Weak Pledges" scenario. In the "30% Annex-I" and "40% Annex-I" scenarios, the certificate prices exceed the marginal social cost of carbon between \$18 and \$30/ton of CO_2. For these scenarios, the portion of the certificate price above the marginal social cost of carbon represents a loss in allocative efficiency, reducing the net gain from internalizing the externality. If the assumed marginal social cost of carbon was higher, this would not have been the case. So the result that 2030 global welfare is lower in the "30% Annex-I" and "40% Annex-I" scenarios than the "Pledges" scenarios is entirely due to the assumption on the value of the social cost of carbon.

2.4 Conclusion on the modelling analysis

Several policy implications emerge from the analyses presented in the previous sections on the environmental and economic effects of various climate policies. In particular, the “pledges” announced by several industrialized and large developing countries are neither ambitious in terms of global emission reductions required to stay on an emissions path towards the 2°C target, nor costly in terms of average global GDP losses or average changes in welfare (EV) – but significant differences exists across countries and regions. Compared to cost estimates for the Copenhagen pledges which are based on partial equilibrium models, the costs in this report, which are calculated with a CGE model, are generally higher. Environmental effectiveness is also tarnished by new hot air from Russia, but revenues from selling hot air cannot compensate for economic losses in Russia. Somewhat more ambitious 30 % and even 40 % reduction targets for Annex-I countries along with the 15 % below baseline target for major developing countries in 2020, also imply only moderate average reductions in GDP and changes in EV.

The reduction in GDP in 2020, relative to the baseline, is not evenly distributed across regions. Although in all policy scenarios and in particular in the “30 %-Annex-I” and “40 %-Annex-I” scenarios, major developing countries (with emission targets) have relatively larger reductions in GDP compared with Annex-I countries, the effects on the growth of real GDP are relatively small leading to a decrease in the growth of GDP in developing countries from 102 % in the baseline to 98 % in the “40 %-Annex-I” scenario between 2004 and 2020. Since major developing countries tend to produce relatively energy-intensively, they lose market shares in sectors like iron and steel, non-ferrous metals, pulp and paper, cement, or chemicals to regions where production is less energy intensive. Nevertheless future output growth will generally remain quite strong in these sectors in all policy scenarios.

Consequently, some Annex-I countries like the EU or Japan experience even small GDP gains which increase with tighter emission targets. Hence, economies which commit to climate targets earlier and reduce their CO_2 intensities sooner are less vulnerable to tight emission targets in later periods. Similarly, energy-intensive, trade-intensive industries in developed and developing countries alike may particularly benefit from investments leading to lower energy intensity and CO_2 emissions of their production processes. Considering a scenario where the EU unilaterally moves from a 20 % to a 30 % emission reduction target, while all other countries stick with their “weak” pledges, the calculations show that additional costs for the EU are negligible (0.005 % compared to the “weak” pledges scenario).

While in all policy scenarios many developing countries (with emission targets) experience larger reductions in GDP than developed countries, this does not necessarily translate into larger declines in net welfare (EV) as well. For example, both China and India experience a gain in welfare in 2020. This is due to strong terms-of-trade effects, the sale of CO_2 certificates, and gains in allocative efficiency for energy commodities because the price on CO_2 results in a more efficient use of energy commodities by taking into account the negative externality from CO_2-emissions. Consequently, global welfare increases in all policy scenarios, but relative to GDP in 2020 global EV is below 0.3 % in all policy scenarios and hence rather small.

The policy scenarios involve substantially more ambitious emission targets for 2030, including all regions but LDCs. Qualitatively, the effects are similar to those found for 2020, but more pronounced since the tighter emission targets imply higher CO_2 prices. On average, the reduction in global GDP is below 3 % while global EV relative to GDP remains low (below 0.7 %). The welfare results for 2030 illustrate the sensitivity of the findings to the assumption on the value of the social cost of carbon.

Given the differential effects on the reduction in GDP and net welfare across regions, particularly among developing countries, the chosen emission burden-sharing criteria may have to be reconsidered in order to better address the situation of many developing countries and the possibility of options to compensate their financial burden due to their mitigation efforts. However, because some developing countries enjoy a gain in welfare, any changes in the burden-sharing criteria or monetary compensation should be targeted towards the developing countries with welfare losses.

In terms of carbon-leakage, the findings suggest that the environmental effectiveness of the sub-global climate agreements considered in this report is hardly challenged by higher emissions in regions which are not committed to climate targets. Carbon leakage effects would be more severe if targets were tighter or if less countries committed to limit their emissions.

When interpreting the results, some caveats apply. In particular, quantitative effects on emissions and costs would differ from the findings presented in this report, if other greenhouse gases, LULUCF and the corresponding mitigation measures and financial support from industrialized countries for developing countries were also included. These differences would vary across regions, depending on the significance of other greenhouse gas emission sources in terms of mitigation potential and costs and the extent to which they are included in countries' emission reduction targets. It should also be kept in mind that the analyses presented assume unlimited certificate trading across countries with emission targets. While this implies that tighter targets in some regions translate into higher CO_2 costs in all regions with emission targets, unrestricted emission trading contributes to achieving climate targets at lowest global costs. Similarly, the analyses presented do not allow for offsets generated in non-trading countries. While this option is expected to also reduce overall mitigation costs, this cost-containment effect vanishes once more countries take on binding emission targets. Similarly, if banking was allowed, reduction costs over time would be lower since countries may choose to reduce more emissions than required in early periods and transfer unused certificates in future periods. Unless the time path of targets takes into account cost differences over time (and hence does not require banking or borrowing to achieve the inter-temporal optimum), an optimizing strategy would require that future targets are known to investors well in advance. At last, technological change is modeled as being exogenous. That is, the rate of technological progress is not affected by policies. Allowing for price-induced technological progress would lower mitigation costs.

Finally, the four policy scenarios represent very different emission paths and hence imply different probabilities of achieving the “2 degree target”. Thus, they should not be interpreted as alternative ways of reaching the same target.

3 Impact of the Copenhagen Accord Pledges on the Economic Competitiveness of the EU27: An Analysis of Economic Modelling Outputs

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The environmental and economic effects of the Copenhagen Pledges have been analyzed by various model groups with differing model approaches and implementation techniques. The interpretation and comparison of these model results prove to be quite challenging as the range of results varies and require a more detailed investigation of the type of the model chosen and the underlying model assumptions and scenario setups that drive the results. This chapter aims to shed light on some of the model analysis conducted in the aftermath of the Copenhagen conference. It focuses on the analysis presented in Section 2 using a multi-region, multi-sector dynamic CGE model and the analysis presented in the European Commission report on moving beyond 20% for the EU which was published in May 2010 (EC, 2010). To keep the comparison straightforward we limit the overview to include only full economy models and their economic results in terms of GDP or value added effects and to pointing out the effects on GHG emissions reductions.

3.1 Copenhagen Accord Pledges: Range of GHG Emission Reductions

According to the analysis presented in Section 2 the Copenhagen Accord Pledges of the industrialised countries will achieve a maximum emission reduction of **17%** below 1990 levels. It is further anticipated that the Copenhagen Accord Pledges of the developing countries will deliver a maximum emission reduction of **13%** compared to baseline in 2020 (Table 9 provides more information about the 2020 baseline). In Section 2 the range of emissions reductions expected from the Copenhagen Accord Pledges are calculated using the following assumptions in the DYE-CLIP Model:

- The emission reduction targets in the 'Weak' and 'Ambitious' scenarios correspond to, if applicable, the high and low pledges of a Party in the Copenhagen Accord.
- For 2020, emission reduction targets are implemented for six major developing countries (Brazil, China, India, South Africa, Mexico and South Korea)
- All targets from developing countries have been translated into emission reductions below baseline in 2020 and are assumed to exclude emissions from LULUCF and REDD (i.e. China have a target ranging from -1.1 to -9.3% below 2020 baseline)

In the Commission report a quantitative analysis of the Copenhagen Accord Pledges has also been conducted by Den Elzen et al using the TIMER/IMAGE model. Assuming that all of the Copenhagen Accord Pledges are fully implemented by the Parties, the low pledges would reduce emissions to **50 Gt CO_2e** and the high pledges would lower emissions to **48.7 Gt CO_2e** in 2020. Den Elzen et al. assume that the 'safe' stabilisation target to remain within the 2°C trajectory is approximately 44Gt **CO_2e** of global emissions in 2020 (i.e. representing a considerable departure from the 55.9 Gt **CO_2e** baseline in 2020). Although a direct comparison between these two studies is difficult, given the different metrics, baseline emissions in 2020 and interpretations of the developing country pledges, both approaches imply that the Copenhagen Accord Pledges are insufficient to meet recommended stabilization targets informed by the science on climate change.

3.2 Global Economic Recession: Reassessing the Cost of GHG Abatement

Table 8 provides an overview of the different economic model approaches of the several economic models (i.e. DYE-CLIP, GEM E3, E3MG, PACE) that are under consideration in this review paper. Table 9 illustrates the underlying assumptions and policy scenarios that are associated with each model and Table 10 provides a comparison between the output of each model for a specific model run (i.e. a policy scenario based upon free allocation or full auctioning of emission allowances). Each model's output contributes to the discussion on the cost of GHG abatement with varying insights into the impact of climate policy from a national and sectoral perspective. In the following sections each model will be discussed individually.

3.2.1 Results from the DYE-CLIP Model

According to the analysis presented in Section 2 the differences between GDP growth in the baseline and policy scenarios are small for Annex I Parties under the assumption that there are no limits on carbon trading. It is anticipated that the reductions in GDP compared to the 2020 baseline for Annex I Parties range from an average of **0.1%** in the 'Weak Pledges', **0.1%** in 'Ambitious Pledges', **0.2%** in the '30% Annex I Scenario' and **0.3%** in the 40% Annex I Scenario'. Given that the DYE-CLIP model is designed to allow GDP, input and output prices, production levels and trade flows to change endogenously in response to climate policy it is evident that Russia experiences considerable GDP losses relative to the other Annex I Parties. Russia sustains higher GDP losses due to a smaller increase in private consumption reflecting the lower demand for fossil fuels from the implementation of climate policy in the four scenarios. Furthermore, the selling of 'new hot air' does not fully compensate for this loss in GDP. Table 10 provides an overview of the expected gains and losses in production (relative to baseline) in all policy scenarios are usually small and **below 1%** in the EU27, the US and Japan. For example in the iron and steel sector these regions/countries benefit from climate policy experiencing a increase from the baseline ranging from **0.39-1.55%** (EU27), **0.20-1.28%** (US) and **0.48-1.16%** (Japan). It is important to acknowledge that the auctioning of allowances and no limit on carbon trading considerably reduces production losses (Table 9).

With regards to the Non Annex I Parties the reduction in GDP is relatively larger than for Annex I Parties and the output from the DYE-CLIP model ranges from **0.9%** in the 'Weak Pledges Scenario', **1.4%** in the Ambitious Pledges Scenario, **2.2%** in the 30% Annex I scenario, and **2.8%** in the '40% Annex Scenario'. China and India experience the largest reduction in GDP relative to baseline in 2020 due to the higher intensity of their industrial sectors (i.e. tighter targets lead to higher certificate prices, higher output prices and larger reductions in the production of energy intensive sectors in China and India). Production losses in China and India are significantly higher and tend to range between **3-10%.** The large production losses of the Non Annex I Parties reflect the fact that the DYE-CLIP model considers not only the direct cost of emissions, but also the cost of intermediaries (i.e. electricity) with the introduction of climate policy. Given that coal is the main fuel used to generate electricity in China and India, electricity prices rise more in both countries than in other regions (compared to baseline). Therefore, the policy scenarios in DYE-CLIP capture the 'early action' effects of climate policy on CO_2 intensity of the economy in past periods.

3.2.2 Results from GEM E3 Model

In comparison to the DYE-CLIP model, the GEM E3 model uses alternative policy scenarios with GDP or production output changes measured against a reference scenario whereby the EU implements its low end pledge of a 20% GHG reduction below 1990 emission levels while the remaining Parties stayed at their baseline level of emissions in 2020. In contrast to the DYE-CLIP model, the GEM E3 imposes a limitation on the use of international credits (i.e. set at 1/3 of the distance between pledge and baseline) and for each of the three policy scenarios (i.e. low pledges, mixed_EU 30% other countries remain with low pledge and high pledge) are modelled with and without access to the carbon market. The GEM E3 Model anticipates that the % difference in GDP for the EU27 from the reference scenario will range from **-0.2% to -1%** of GDP in 2020. The effect on GDP for the other Copenhagen Accord Pledges include: US (**-0.5% to -0.9%)** Japan (**-0.4% to -0.9%)** China (**-0.7% to -1.8%)** and India (**-0.2% to -1.5%**).

GEM E3 models the impact of both free allocation and auctioning on the cost of climate policy for only three sectors (ferrous and non ferrous metals, chemical products and other energy intensive industries) and Table 9 provides a summary of the assumptions used for both forms of allocation. Under the assumption of free allocation and access to the international carbon market, the EU27 experiences either production gains or losses depending on the policy scenario. Under the 'Low Pledges' Scenario, the EU27 production output increases by **0.5%, 0.3%** and **0.4%** for ferrous and non ferrous metals, chemical products and other energy intensive industries respectively. The EU27 experiences the largest production losses in the 'Mixed Pledges' Scenario with output decreasing by **-0.4, -0.9** and **-0.6%** for ferrous and non ferrous metals, chemical products and other energy intensive industries respectively (Table 10). Under all scenarios Japan, China and India experience production losses as a consequence of the implementation of climate policy. India suffers the largest production losses under the 'High Pledges' scenario of **-8.9%** (ferrous and non ferrous metals), **-3.4%** (chemical products) and **-12.6%** (other energy intensive industries). In contrast, under the assumption of auctioning for the power sector only and access to the international carbon market, the EU27 experiences either a production gain or loss ranging from **0.5% to -1.1%** (ferrous and non ferrous metals), **0.4% to -1.1%** (chemical products) and **0.5% to -0.7%** depending upon the climate policy scenario implemented. Assuming auctioning for all ETS sectors the costs of implementing climate policy in the EU27 reduces further demonstrating how the effective recycling of auctioning revenues can reduce the costs of GHG abatement.

3.2.3 Results from E3MG Model

The E3MG model also analyses alternative policy scenarios compared to a reference scenario whereby the EU implements its low end pledge of a 20% GHG reduction below 1990 emission levels while the remaining Parties stayed at their baseline level of emissions in 2020. The E3MG is a macro-econometric model, thus of a different model type than the GEM E3 and DYE-CLIP model. Similar to the runs by the DYE-CLIP model (Section 2), the E3MG does not impose a limitation on the use of international credits for each of the three policy scenarios (i.e. low pledges, mixed_EU30% other countries remain with low pledge and high pledge) with and without access to the international carbon market. The E3MG model anticipates that the % difference in GDP for the EU27 from the reference scenario will range from **-0.1% to -1.5%** of GDP in 2020. The effect on GDP for the other Copenhagen Accord Pledges include: US (**-0.4% to -0.6%)** Japan (**-0.1% to -0.3%)** China (**0.2% to -0.8%)** and India (**0% to -0.3%**). It is likely that the lack of a restriction on the use of international credits contributes to lower abatement costs compared to the output from the GEM E3 model.

E3MG models the impact of both free allocation and auctioning on the cost of climate policy and the assumptions used in the model runs are illustrated in Table 9. Under the assumption of free allocation (except for the power sector) and access to the international carbon market, the EU27 experiences small production losses in all of the policy scenarios. Under the ‘Low Pledges’ Scenario, the EU27 production output decreases by **-0.1%,** -**0.4%, -0.0** and -**0.3%** for chemicals, rubber & plastics, non-metalic mineral products and basic metals respectively. The EU27 experiences the largest production losses in the ‘High Pledges’ Scenario with output decreasing by **-0.2%,** -**0.5%, -0.4** and **-0.3%** for chemicals, rubber & plastics, non-metalic mineral products and basic metals respectively. Given that the E3MG model only considers the industry of two regions (i.e. EU27 and Outside EU27) it is difficult to compare the model’s output with alternative economic modelling attempts where there is a greater coverage of regions and countries. However, the E3MG model shows that the production losses for the ‘Outside EU27’ region were similar for all sectors except for non-metalic mineral products whereby the EU27 region experienced higher losses in production output.

3.2.4 Results from PACE Model

The PACE model uses alternative policy scenarios with changes measured against a reference scenario whereby the EU implements both its low end pledge of a 20% GHG reduction below 1990 emission levels and the 20% renewables target while the remaining Parties stayed at their baseline level of emissions in 2020. A key feature of the PACE model is that it allows for endogenous technological change. In contrast to the DYE-CLIP and E3MG model, the PACE imposes a limitation on the use of international credits (i.e. a CDM use is set in the non-ETS sectors up to 3% of 2005 non-ETS emissions and in ETS sectors of up to 50% of the reduction requirements) and each of the three policy scenarios (i.e. low pledges, mixed_EU30% other countries remain with low pledge and high pledge) are modelled with two different variants: one with free allocation to the energy intensive sectors and one with full auctioning in these sectors (summary of these model run assumptions are provided in Table 9).

Under the assumption of full auctioning and limited access to the international carbon market, the EU27 experiences either production gains or losses depending on the policy scenario. Table 10 shows the production gains and losses for the EU27 for the different scenarios and the different sectors under the assumption of full auctioning. The EU27 experienced production losses compared to the reference scenario regardless of the policy scenario for the cement (**-0.2% to -0.4%**), construction (**-0.2% to -0.6%**) and iron and steel (-**0.4% to -0.9%**). The PACE model projects production gains or losses within a range of -1% to 1% compared to the reference scenario for the all of the sectors under the assumption of full auctioning. However, the PACE model demonstrates that under the assumption of free allocation and limited access to the international carbon market these production losses are minimized further and therefore implies that free allocation will remain an important means of enhancing the competitiveness of industry in the EU27.

3.3 Lessons learned from the model comparison

This chapter presents a comparison for a selected number of economic models on the environmental and economic effects of the Copenhagen pledges. The focus is on the model employed in the current report as well as the models presented in the European Commission report on moving beyond a 20% target for the EU which was published in May 2010 (EC, 2010). To keep the comparison light we limited the overview to include only full economy models and their economic results in terms of GDP or value added effects and to pointing out the effects on GHG emissions reductions.

In summary, it can be concluded that the costs of meeting the pledges for industrialized countries are low independent of the model used. Differences occur, however, as shown in Table 10. These differences are due to model type and model specific features (such as the model philosophy, optimality assumptions, specification of functional forms and underlying parameters, implementation of model dynamics and technological change etc.). To better understand these differences, an overview table was assembled to provide an immediate comparison (compare Table 8). Furthermore, different model assumptions and implementation of scenarios lead to varying results. For example, the DYE-CLIP model provides a comparison to a baseline that reflects business as usual. The models employed in the Commission analysis, however, provide a comparison to a reference scenario which already includes the 20% target set for the EU. This naturally results in different ambitions that are additionally needed and in differences in associated costs. Moreover, differences can be attributed to whether emissions from all GHG are accounted for or whether only CO_2 (or only energy-related CO_2) has been taken into consideration. As LULUCF options can be accounted for in an all-

GHG setting, the associated costs can be expected to be lower. Another important and influential aspect relates to the recycling of auctioning revenues as it potentially leads to (positive) double dividend effects as well as whether offsets are allowed within the trading system and banking of allowances which also dampens costs.

A perfect comparison of model results is thus not possible. Harmonized baselines and model assumptions help to arrive at more comparable results. Differences would still remain based on the model type specific set-up. The main conclusion is, however, that despite these differences the results from all model analyses remain within a relatively narrow range and well within an order of magnitude.

Future research may be devoted to shed further light on some of the more urgent policy related aspects that aim to address the three-fold questions of i) when to act and what are the effects when sudden drastic reductions are needed, ii) what to include: all GHG or CO_2, only in terms of mitigation or also adaptation, and iii) where to act in terms of sectoral coverage: which sectors to include (emissions trading sectors and non emissions trading sectors; and regional coverage: which countries commit to reductions and how to provide remedies for regional differences in associated costs (border adjustment or other measures, sectoral approaches in form of no-lose targets, sectoral trading, sectoral benchmarks, ex-post adjustment).

The economic models compared in this overview all seem well equipped to address these questions. At best such an analysis would be conducted in a harmonized way to allow for a comparison and an assessment of the range of the results.

Table 8 Comparison of model types

	DYE-CLIP	E3MG	GEM E3	PACE
Model Type	CGE	Macroeconometric Model	CGE	CGE
Base Year	The model is based on GTAP-E. The current version relies on the GTAP 7 database (2004 base year)	For each economic region historical measures of consumer and government spending, production and consumption are collected for all sectors annually from 1970 to 2006.	The current GEM-E3 version has been updated to the GTAP7 database (2004 base year)	The underlying data base for the PACE model is GTAP7 with the base year 2004.
Dynamics	The model is dynamic recursive: it is solved in steps of five-year periods with myopic expectations (in the sense that only information available in a particular five year period will be used for the optimization).	The model simulates the global economy, representing it as 20 interacting regions. Relationships between variables such as production and consumption are estimated based on panel data, so that the model can be used to project future economic trends and therefore the impact of mitigation policies.	The model is dynamic, recursive over time, driven by accumulation of capital and equipment.	The model is dynamic, recursive over time, driven by accumulation of capital and equipment and technological change as well as labor supply.
Technology Change	Technological change is autonomous, hence the model does not allow for price or policy induced changes in the production function.	E3MG models the development of technology in response to changes in investment and policy represented within the model.	Technology progress is explicitly represented in the production function, either exogenous or endogenous, depending on R&D expenditure by private and public sector and taking into account spill over effects.	The model features the technological explicitness of bottom-up (engineering) energy system models for the electricity sector while production technologies in other sectors are described in a conventional top-down aggregate manner, i.e. by means of CES (CET) functions.

Sectoral Coverage	The sectors specifically modelled are electricity, refined petroleum, chemicals, rubber and plastics products, other manufacturing, coal, oil, gas, transport, agriculture, other natural resources, food, trade, and services.	42 industrial sectors based on the NACE classification, including 16 service sectors and disaggregation of the energy sectors	Agriculture, Solid Fuels, Liquid Fuels, Natural Gas, Electricity, Ferrous and Non Ferrous Ore and Metals, Chemical Products, Other Energy Intensive Industries, Electrical Goods, Transport Equipment, Other Equipment Goods Industries, Consumer Goods Industries, Building and Construction, Telecommunication Services, Transports, Services of Credit and Insurance, Other Market Services and Non Market Services.	Food, Agricultural and Wood / Energy (Crude Oil, Natural Gas, Coal, Petroleum and Coal Products, Electricity and Heat) / Energy Intensive (EIS-ETS besides Electricity and Petroleum and Coal Products, Cement, Basic Iron and Steel, Aluminium, Bricks Tiles and Construction Products, Remaining Iron and Steel, Paper Products, Mineral Products, Metals without Aluminium, Air Transport, Fertilizers and Other Nitrogen Compounds, Organic Chemicals, Inorganic Chemicals, Chemical Rubber Plastics) / EIS-NETS (Transportation excluding Air and Sea), Mining, Construction, Machinery and other Manufacturing) / Rest of Industry (Textiles, Dwelling, Commercial and Public Services).
Regional Coverage	Australia, Japan, Canada, USA, EU15, EU12, EU27, Switzerland, Norway, Russia, Ukraine, China, Korea, India, Mexico, Brazil, Indonesia, Argentina, Turkey, Egypt, Rest AI, Rest Non AI, Developing, Rest of ADC (inc. RSA), Rest of ODC, LDC, and World.	20 world regions, including explicit treatment of the US, Japan, India, China, Mexico, Brazil and the four largest EU economies	The world version of GEM-E3 distinguishes 21 world regions: Canada, USA, Australia, New Zealand, Japan, United Kingdom, Germany, Nordic countries of the EU, Rest of the EU, Other European OECD countries, Central European Associates, Former Soviet Union, Latin America, Sub-Saharan Africa, North Africa, Middle East, South East Asia Dynamic Economies, South Asia, India, China, and Rest of the World Countries.	EU-27, China, Japan, India, Canada, United States, Mexico, Brazil, Russia, Ukraine, Australia and New Zealand, South Korea, Indonesia and Malaysia, and Rest of the World

Table 9 Comparison of modelling assumptions and policy scenarios

		DYE-CLIP	E3MG	GEM E3	PACE
Model Type		CGE	Econometric Model	CGE	CGE
Model Assumptions	Emission Reduction Pledges	All the pledges from the Copenhagen Accord have been analysed. All targets from developing countries have been translated into emission reductions below baseline in 2020. All reductions are assumed to exclude emissions from LULUCF and REDD. No emission targets are imposed on Russia and Ukraine for 2010 to avoid introducing 'hot air' into these regions. All of the pledges refer to CO_2 emissions.	All the pledges from the Copenhagen Accord have been analysed. All of the pledges refer to CO_2 emissions.	All the pledges from the Copenhagen Accord have been analysed. In addition to CO_2 emissions, the model considers non CO_2 emissions from agriculture.	All the pledges from the Copenhagen Accord have been analysed. All of the pledges refer to CO_2 emissions.
	Carbon Market Participation	All countries or regions with emission targets are allowed to trade emission certificates resulting in the price of CO_2 certificates being equalized across countries where trading of certificates is possible.	Only those countries with a pledge participate in the carbon market and generation of credits for the carbon market would come from reductions on top of reductions made to meet the pledges themselves.		
	Access to International Carbon Markets	No limit on the use of international carbon markets. No banking is allowed across five year periods.	There is no limit on the use of international credits. It was assumed that no surplus AAUs are allowed to be banked into the period post 2012 and also no new surplus AAUs are generated for the years up to 2020.	There is a limit on the amount of credits from third countries (1/3). It was assumed that no surplus AAUs are allowed to be banked into the period post 2012 and also no new surplus AAUs are generated for the years up to 2020.	Each scenario assumes a CDM use in 2020 set at 42% of the reduction efforts of the Annex I regions besides EU27. In PACE, for the EU27, a CDM use is set in the non ETS sectors up to 3% of 2005 non ETS emissions and in ETS sectors of up to 50% of the reduction requirements.

	Allocation of Allowance Revenues	Climate policies are implemented via emission quotas per region. Countries levy national CO_2 taxes on direct CO_2 emissions. Therefore a single climate policy i.e. a CO_2-tax is applied across all sources in a country or region which is equivalent to assuming full auctioning for each sector.	In E3MG allowances are allocated for free to EU industries with the exception of the auctioning of the power sector. The recycling of revenues was done through reductions of social security contributions of employers (50%) subsidizing RE (35%) and increasing R&D expenditures (15%).	GEM E3 assumes full allocation to all sectors. In GEM E3 revenues were fully used to reduce labour costs.	Auctioning only in the power sector with a shift from 100% free allocation (distributed according to a benchmark) to full auctioning by 2020 for energy intensive industries. The allocation of free allowances reflects the existing ETS provisions. Revenues from auctioning are not recycled through a reduction in labour costs but through a lump sum payment to households.
Reference Scenario		Output changes for all policy scenarios compared to 2020 baseline.	The policy scenarios are compared to a reference case where only the EU implemented its low-end pledges (20%) and the others stayed at baseline.		
Policy Scenarios	Policy Scenarios	Weak Pledges	Low Pledges		
		Ambitious Pledges	Mixed Pledges (EU 30% other countries remain with low pledge)		
		30% Annex I Scenario	High Pledges		
		40% Annex I Scenario			
		Weak Pledges_EU 30%			
	Alternative Allocation Scenarios	-	Inclusion of taxation in the non ETS in the high pledge policy scenario	Auctioning in the ETS power sector and free allocation in non-ETS	Full auctioning for all sectors in the ETS.
		-		Auctioning all ETS sectors and free allocation in non-ETS	
		-		Auctioning all ETS sectors and a tax in non ETS sectors	

Table 10 Estimating the Cost of GHG Abatement: Range of CGE Modelling Results

		EU27	US	Japan	China	India
		% Change in output energy intensive industries in 2020 (% change from baseline)				
DYE-CLIP	Iron and steel	0.39 to 1.55	0.2 to 1.28	0.48 to 1.16	-2.87 to -9.08	-4.34 to -11.33
	Other metals	-0.23 to -0.6	-0.59 to -1.14	0.44 to 0.92	-3.36 to -11.01	-10.23 to -26.42
	Chemicals, rubber and plastics	0.18 to 0.54	-0.29 to -0.66	-0.48 to 0.02	-4.26 to -12.97	-3.42 to -9.73
	Paper	-0.05 to -0.29	-0.15 to -0.54	-0.12 to 0.03	-2.68 to -8.21	-3.61 to -9.28
	Other mineral products	0.35 to 0.93	0.06 to 0.16	0.49 to 1.18	-2.98 to -8.91	-2.29 to -5.17
	Other manufacturing	0.13 to 0.44	0.14 to 0.94	-0.01 to 0.15	-2.38 to -7.7	-2.76 to -7.16
		% Change in output energy intensive industries in 2020 (% change from reference scenario)				
GEM 3*	Ferrous and non ferrous metals	-0.4 to 0.5	-0.6 to 0.2	-2.2% to -1.3	-7.0 to -1.8	-8.9 to -5.0
	Chemical products	-0.9 to 0.3	-1.8 to -1.1	-2.5 to -1.3	-3.6 to -0.8	-3.4 to -1.6
	other energy intensive industries	-0.6 to 0.4	-0.5 to 0.0	-0.9 to -0.4	-8.6 to -3.5	-12.6 to -6.7
E3MG**	Chemicals	-0.2 to -0.1	-0.1 to -0.1			
	Rubber and plastics	-0.5 to -0.4	-0.5 to -0.4			
	Non metallic mineral products	-0.4 to -0.0	-0.1 to -0.1			
	Basic metals	-0.3 to -0.3	-0.2 to -0.1			
PACE***	Mineral products	-0.3 to 0	Although regional data is not publically available, it can be obtained from the author.			
	Iron and steel (further processing)	-0.5 to 0				
	Non ferrous metals	0 to 0.2				
	Paper products, publishing	-0.1 to 0				
	Cement	-0.4 to -0.2				
	Bricks, tiles and construction products	-0.6 to -0.2				
	Iron and steel	-0.9 to -0.4				
	Aluminium	-0.3 to 0.1				
	Fertilizers	-0.5 to 0.1				
	Organic chemicals	-0.5 to 0.1				
	Inorganic chemicals	-0.4 to 0.1				
	Chemicals, rubber and plastics (other)	-0.7 to 0.3				

Key	
% Output Gain	(blue)
% Output Uncertain	(yellow)
% Output Loss	(red)

* GEM E3: % Change in output refers to free allocation assumption ** E3MG: % Change in output refers to free allocation (except for power sector) assumption *** PACE: % Change in output refers to full auctioning in ETS sectors assumption

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5 Annexes

A1-Appendix 1: Model description DYE-CLIP

DYE-CLIP is a multi-country, multi-sector dynamic computable general equilibrium model for 2004 to 2030. It is based on the dynamic version of GTAP, GDyn, (Ianchovichina and McDougall 2001) and the static GTAP-E Model (Burniaux and Truong 2002, Nijkamp et al. 2005) which are themselves based on the perfectly competitive, multi-region, multi-sector GTAP model (Hertel and Tsiagas 1997). Because GTAP-E explicitly models substitution possibilities between energy inputs and between energy and capital, and also tracks CO2 emissions, it has frequently been used in the analysis of climate change policies (e.g. Kremers et al. 2002, Nijkamp et al. 2005, Kemfert et al. 2006, Burniaux and Chateaux 2008, Dellink et al. 2010). DYE-CLIP extends the standard GTAP-E model by allowing the supply of coal, oil and gas to change as the prices for those commodities change, assuming a supply elasticity of 0.25.

A.1.1 Structure of an economy in GTAP

Figure shows the markets and value flows in DYE-CLIP. Each region consists of a representative regional household, a regional government and regional producers.

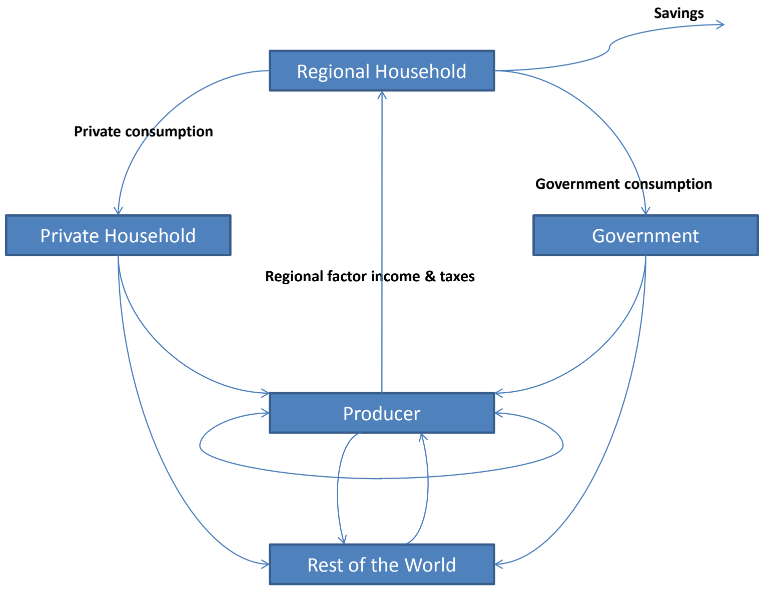

Figure A-1: Multi region open economy without government intervention in GTAP-Dyn

A.1.2 Regional Household Demand

In each region, there is a single aggregate household that represents the consumption side of the model. This regional aggregate household collects all of the factor income and tax receipts and spends this income on private consumption of goods and services, government consumption, and savings. The utility function for the aggregate regional household consists of two levels. At the top-level, a Cobb-Douglas utility function is specified such that shares of private consumption, government consumption, and savings remain constant. At the second-level, a non-homothetic Constant Difference Elasticity of substitution utility function is used to represent preferences for private consumption. Also at the second-level, a Cobb-Douglas utility function is used to represent preferences for government consumption.

A.1.3 Production

Similar to the GTAP-E model, a nested Constant Elasticity of Substitution (CES) production structure, as illustrated in Figure , is specified in the model. Each sub-nest in the production structure represents the potential for substitution between individual or composite inputs. Each composite input is composed of the commodities at the next lower level in the tree structure of Figure . Beginning at the top of the production structure, firms produce output by using non-energy intermediate inputs and a primary factor composite (or value added). Typically, the elasticity of substitution between the primary factor composite and non-energy intermediate inputs (σ_T) is assumed to equal zero. This implies a constant per-unit-of-output input use of all non-energy intermediate inputs and the primary factor composite. The primary factor composite is composed of land, skilled labor, unskilled labor, natural resources, and a capital-energy composite with a constant elasticity of substitution (σ_{VA}) between them. Within the capital-energy composite, there are three inter-fuel substitution possibilities: (a) electricity versus non-electricity composite (σ_{ELY}); (b) coal versus non-coal composite (σ_{COAL}); and (c) between oil, gas, and petroleum products (σ_{FU}). For example, producers may substitute coal for non-coal fuel (a composite of oil, gas and petroleum products) when coal becomes more expensive than non-coal fuels. Firms may also substitute the energy composite (σ_{KE}) for capital when the aggregate energy price decreases relative to the capital rental rate. As pointed out by Burniaux and Truong (2002), the advantages to this specification is that it allows for substitution between fuels and the potential for capital and energy to be either substitutes or complements, depending on the values of the elasticities of substitution chosen.

In contrast to GTAP-E model, the endowments of oil, gas and coal are not assumed to be fixed. Instead the supply of these factors reacts to the price with a supply elasticity of 0.25 for all three factors. This reflects the adjustment in hauling capacity that can be observed in reality.

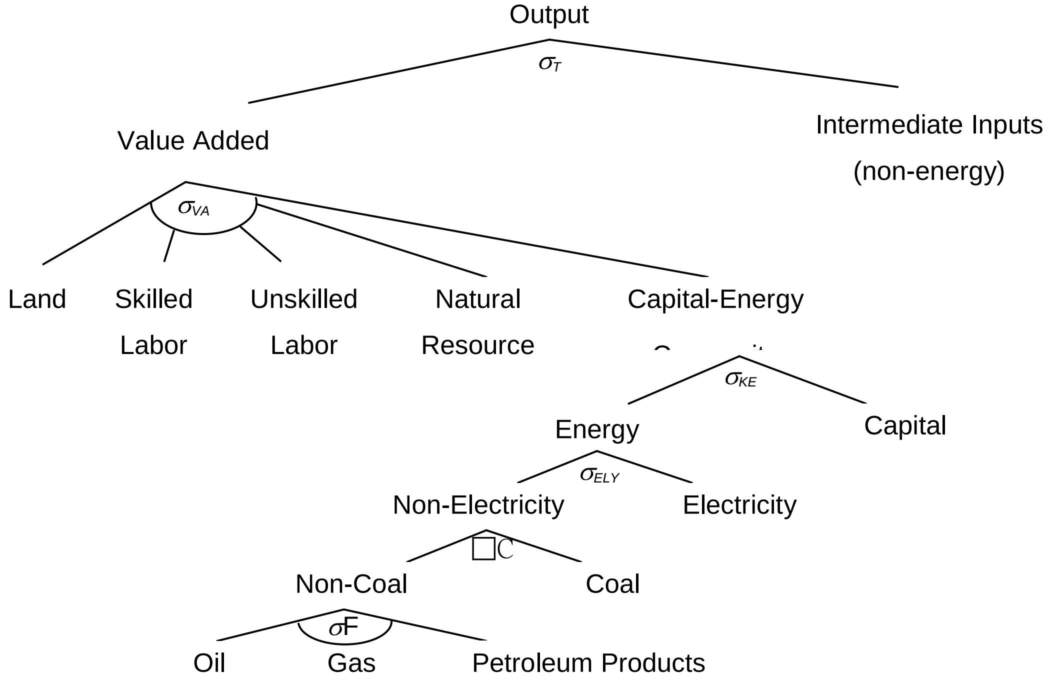

Figure A-2: Structure of production

A.1.4 Capital flows in DYE-CLIP

The representation of capital flows in DYE-CLIP follows the GTAP-Dyn model by Ianchovichina and McDougall (2001). It relies on a highly stylized representation of the financial markets shown in Figure which consists of one financial asset, equity, only and where a "global trust" is introduced that covers all investments into foreign firms. The regional household can invest into local firms or the global trust only. The global trust receives investments from all regional households and invests in all regional firms. Income flows from equity are modelled accordingly.

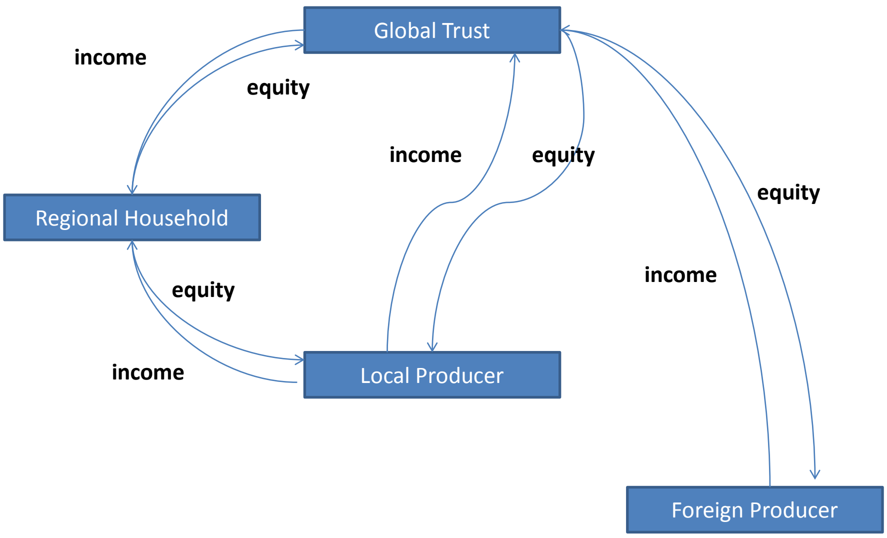

Figure A-3: Financial market in GTAP-Dyn

A.1.5 Dynamics in DYE-CLIP

DYE-CLIP tracks the accumulation of capital over time in each region by adding the level of net investment in each time period and region to the beginning level of the capital stock in each region. The level of investment in each region and time period is based on a lagged adjustment, adaptive expectations theory of investment used by Ianchovichina and McDougall (2001). Investors expectations about the return to capital in a region is based on whether the rate of growth in the capital stock is equal to or differs from a normal growth rate in the capital stock. If the observed growth exceeds the normal growth rate, investors will expect the return on capital to decrease. The actual rate of return is base on the capital rental rate and the price of capital goods. Any deviation between the actual and expected rates of returns on capital is eliminated progressively through time through changes in the level of investment. This reflects the assumption that investors' expectations do not change instantaneously because they are unsure whether an observed change in the rate of return is transient or permanent. Over a long enough period of time, the expected and actual rates of return are equalized across all regions in the model. Because of the assumption of adaptive expectations, the model may be solved one time period at a time (e.g., a recursive model) rather than solving for all time periods simultaneously.

A.1.6 Representation of CO_2 emissions and mitigation costs

A carbon tax is used to represent the marginal abatement costs in the model. Its level is endogenously determined and depends on the quantitative restrictions on CO_2 emissions in

Annex B countries. Emission of CO_2 per unit of energy commodity used is assumed to be constant across users and regions, but varies by energy commodity (coal, oil, gas, and petroleum and coal products). The change in CO_2 emissions is:

$$\begin{aligned} CO2(r,e)*gco2(r,e) = \sum_j \Big[EDINT(e,j,r)*qfd(e,j,r) + EMINT(e,j,r)*qfm(e,j,r) \Big] + \\ EDHH(e,r)*qpd(e,r) + EMHH(e,r)qpm(e,r) + \\ EDGV(e,r)*qgd(e,r) + EMGV(e,r)*qgm(e,r), \end{aligned} \tag{1}$$

where *gco2* is the percentage change in CO_2 emissions; *EDINT*, *EMINT*, *EDHH*, *EMHH*, *EDGV*, and *EMGV* are the amount of CO_2 emitted from domestic and imported intermediate energy inputs, domestic and imported energy commodities consumed by the private household, and domestic and imported energy commodities consumed by the government households; and *qfd*, *qfm*, *qpd*, *qpm*, *qgd*, *qgm*, are the percentage changes in the use of domestic and foreign energy commodities by firms, private households, and the government. Other greenhouse gases than CO_2 are not modelled. When emission trading is permitted, the carbon tax (marginal abatement costs) is equalized across trading countries.

A.1.7 Domestic Margins

In contrast to most applied general equilibrium models, including the GTAP-E model, DYE-CLIP explicitly associates the domestic transportation, wholesale, and retail trade services that facilitate the flow of goods from producers to buyers with individual commodities. The domestic margins are specified using a nested CES structure, as shown in Figure , following the work of Dixon, et al. (1982), Dixon and Rimmer (2002), Bradford and Gohin (2006), and Peterson (2006). At the top of this structure is a composite commodity that is purchased by the private household, government household, or firms. This composite commodity is a combination of the margin inclusive composite imported commodity and a margin inclusive domestic commodity, where σ_D is the elasticity of substitution between the composite import and the composite domestic commodity. In the next level, the composite imported commodity and the domestically produced commodity are combined with a composite marketing service.[45] Based on the work of Holloway (1989) and Wohlgenant (1989), the potential for substitution between the composite commodity and composite marketing service is denoted as σ_{pt}. The composite marketing service is itself a CES aggregate of all trade and transportation services needed to get the good from the producer to the purchaser. The constant elasticity of substitution σ_{pm} governs the degree of substitutability between individual marketing services as relative prices vary.

In addition to applying domestic margins on the purchases of all agents in the model, domestic margins are also applied on all commodities that are exported. These margins represent domestic trade and transport services utilized to get the commodity from the producer to the port of departure. Similar to Figure , a two-level nested CES structure is utilized. At the bot-

[45] The composite imported commodity is a CES aggregate of imports from various source regions. This nest is not shown in Figure 4.

tom level, domestic trade and transport services are combined to create a composite marketing service. At the top level, this composite marketing service is combined with exports to create the f.o.b. export composite commodity.

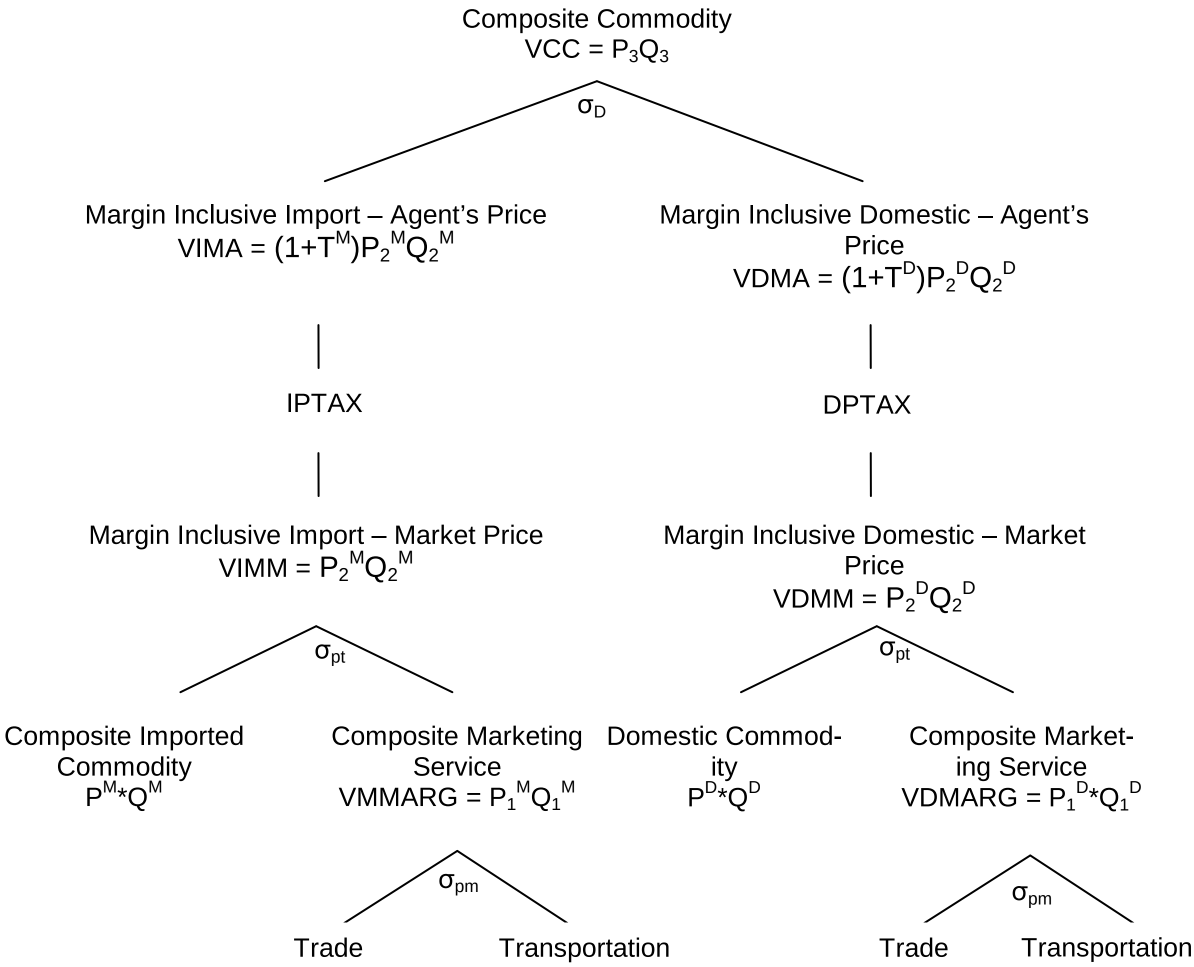

Figure A-4: Structure of Domestic Marketing Margins

A.1.8 Data and Model Aggregation

The data used to implement the model is based on domestic margin-inclusive version of the GTAP version 7 data base that contains information on trade and transportation margins for all intermediate input purchases, purchases by households, and purchases by governments of domestically produced and imported commodities (Peterson, 2006). It also includes all domestic trade and transport margins required to get exports to the port of departure. The level of initial CO_2 emissions for each region by energy commodities are based on the GTAP version 7 energy data base. The base year of the data used in this analysis is 2004.[46]

For comparability the model is calibrated to reproduce the baseline developed in the ADAM project (http://www.adamproject.eu/) with regards to GDP growth, population growth, CO_2 emissions growth and output growth for selected industry sectors (e.g. steel).

The table below shows the regional disaggregation used for the analysis in this report. In total, 24 countries and regions are modeled, 11 Annex I and 13 Non-Annex I countries. The European Union is disaggregated into two regions because of differences in CO_2 emissions, product carbon content, and reduction targets between the EU15 and rest of the member states, but results are presented for the EU 27 aggregate. Apart from major Non-Annex I countries that are modeled separately, Non-Annex I countries are further divided into Non-Annex I developed countries, advanced developing countries, other developing countries and least developed countries eleven region and seventeen commodity aggregation is used in this paper.

Countries/ Regions	GTAP Regions
Annex I	
Australia	aus
Canada	can
EU-15	aut, bel, dnk, fin, fra, deu, grc, irl, ita, lux, nld, prt, esp, swe. gbr
EU-12	cyp, cze, est, hun, lva ltu, mlt, pol, svk, svn, bgr, rou
Japan	jpn
Norway	nor
Russian Federation	rus
Switzerland	che
Ukraine	ukr
USA	usa
Other Annex I	nzl, xef, blr, hrv, kaz
Non Annex I	
Argentina	arg
Brazil	bra

[46] Because the base year is 2004, the GTAP version 7.0 data base contains trade barriers between some of the new EU member states, such as Poland, and other EU member states. These barriers are removed in an initial simulation that creates an updated data base with no trade barriers between EU member states. We use this updated data as the base for all simulations conducted in this paper.

China	chn
Egypt	egy
India	ind
Indonesia	idn
Mexico	mex
Turkey	tur
Rest of Non-Annex I Developed Countries	twn, sgp, xse, xna, chl, xer, xws
Rest of Advanced Developing Countries	hkg, mys, tha, col, per, ury, ven, xsm, cri, pan, irn, tun, xnf, mus
Other Developing Countries	xoc, xea, lao, phl, vnm, lka, bol, ecu, pry, gtm, nic, xca, xcb, alb, xee, kgz, xsu, arm, aze, geo, mar, bwa, zaf, xsc
Least Developed Countries	khm, mmr, bgd, pak, xsa, nga, sen, xwf, xcf, xac, eth, mdg, mwi, moz, tza, uga, zmb, zwe, xec

Table A-1: Regional/ country aggregation in DYE-CLIP

Table 2 provides a description of the sectoral/commodity aggregation used in the model. Paper, petroleum and coal products, other mineral products, ferrous metals, and electricity are the GTAP sectors that most closely correspond to those covered by the EU ETS. Coal, oil, and gas represent the extraction of the fossil based energy commodities. Trade and transport are identified separately because of their use in providing domestic margin services and the use of petroleum products by the transport sector.

Sector	Description	Sectors in GTAP notation
ely	Electricity	ely
crp	Chemicals, rubber, plastic products	crp
nmm	Other mineral products	nmm
i_s	Ferrous metals	i_s
nfm	Other metal products	nfm
ppp	Paper products	ppp
p_c	Petroleum, coal products	p_c
oman	Other manufacturing	tex, wap, lea, lum, fmp, mvh, otn, ele, ome, omf
coal	Coal	coa
oil	Oil	oil
gas	Gas	gas, gdt
trans	Transport	otp, wtp, atp
trd	Trade	trd
agr	Agriculture	pdr, wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap, rmk, wol
onres	Other natural resources	frs, fsh, omn
food	Food	cmt, omt, vol, mil, pcr, sgr, ofd, b_t
serv	Services	wtr, cns cmn, ofi, isr, obs, ros, osg, dwe

Table A-2: Sector aggregation

The production and trade elasticities of substitution used in the model are listed in Table 3. The elasticities of substitution between non-energy intermediate inputs and value-added (σ_T) are set equal to zero. We also assume fixed domestic margins and set the values of σ_{pm} and σ_{pt} equal to zero.[47] The elasticities of substitution between components of valued added are set equal to their values in the GTAP version 7.0 database. Based on the results of van der Werft (2008), we set the elasticity of substitution between capital and the energy composite (σ_{KE}) equal to 1.0. Given that the model is solved in five-year increments, a unitary elasticity of substitution implies only modest annual substitution possibilities. The values of σ_{ELY}, σ_{COAL}, and σ_{FU} are set to 0.25, reflecting an assumption of limited substitution possibilities among alternative fuel sources. Following Burniaux and Truong (2002), we do not allow for substitution among energy commodities or between energy and capital in the mining and refining of fossil fuels and set σ_{KE}, σ_{ELY}, σ_{COAL}, and σ_{FU} equal to zero for coal, oil, gas, and

[47] While a carbon tax may raise the cost of transportation relative to trade services, it is unlikely that there are large substitution possibilities between transportation and trade services that comprise domestic margins.

petroleum and coal products. We also do not allow substitution between electricity and non-electricity in the electricity sector. Finally, the elasticities of substitution between domestic and the composite imported commodity (σ_D) and between imported commodities (σ_M) equal the values in the GTAP v7 data base for most commodities. For oil, the trade elasticities are set equal to 30, reflecting the belief that crude oil is a more homogeneous commodity. Similarly, σ_M is set equal to 30 for coal while σ_D is increased from 3.0 to 10.0. Finally, to prevent large changes in gas production, the values of both σ_D and σ_M are reduced compared to the GTAP database.

Additional Literature:

Van der Werft, 2008. Production functions for climate policy modelling: An empirical analysis. Energy Economics 30 (2008) 2964–2979.

Dellink, R., G. Briner and C. Clapp (2010), “Costs, Revenues, and Effectiveness of the Copenhagen Accord Emission Pledges for 2020”, OECD Environment Working Papers, No. 22, OECD Publishing;

Burniaux, J-M. and J. Chateau, 2008, An overview of the OECD ENV-Linkages Model. *OECD Economics Department Working Papers* No 653.

	Production					Trade	
Sectors	σ_{VA}	σ_{KE}	σ_{ELY}	σ_{COAL}	σ_{FU}	σ_{D}	σ_{M}
agr	a	1.0	0.25	0.25	0.25	2.45	4.90
food	1.12	1.0	0.25	0.25	0.25	2.41	4.94
coal	0.20	0.0	0.0	0.0	0.0	10.00	30.00
oil	0.20	0.0	0.0	0.0	0.0	30.00	30.00
gas	0.30	0.0	0.0	0.0	0.0	5.00	10.00
onres	0.25	1.0	0.25	0.25	0.25	1.38	2.20
ppp	1.26	1.0	0.25	0.25	0.25	2.95	5.90
p_c	1.26	0.0	0.0	0.0	0.0	2.10	4.20
crp	1.26	1.0	0.25	0.25	0.25	3.30	6.60
nmm	1.26	1.0	0.25	0.25	0.25	2.90	5.80
i_s	1.26	1.0	0.25	0.25	0.25	2.95	5.90
nfm	1.26	1.0	0.25	0.25	0.25	4.20	8.40
oman	1.26	1.0	0.25	0.25	0.25	3.79	7.66
ely	1.26	0.0	0.0	0.25	0.25	2.80	5.60
trd	1.68	1.0	0.25	0.25	0.25	1.90	3.80
trans	1.68	1.0	0.25	0.25	0.25	1.90	3.80
serv	1.28	1.0	0.25	0.25	0.25	1.91	3.80

Table A-3: Production, Margin and Trade Elasticities of Substitution

a The parameter values of σ_{VA} for agriculture varies by region. For aus, chn, usa, arg, bra, EU12, che, nor, rus, ukr, xa1, xna1d, xd, xod, and xldc, it's value equals 0.226. The values for other regions are: jpn 0.18, kor 0.99, idn 1.21, ind 0.82, mex 0.37, EU15 0.10, and tur 0.12.

A.2 Appendix 2: Tables and Figures

	Acronym	country	Emis-sions [Mt]	Baseline			
				Average growth rate of emissions		Average growth rate of GDP	
			2005	2005-2020	2020-2030	2005-2020	2020-2030
Australia***	aus	AI	373	0.02%	0.83%	1.88%	1.11%
Japan***	jpn	AI	1130	0.19%	0.19%	1.01%	1.10%
Canada***	can	AI	542	0.16%	1.13%	1.82%	1.64%
USA***	usa	AI	6011	-0.12%	0.49%	1.66%	2.03%
EU27***	EU27	AI	4161	-0.59%	0.09%	1.60%	1.41%
Switzerland***	che	AI	45	0.43%	0.43%	1.55%	1.54%
Norway***	nor	AI	37	0.32%	0.43%	1.96%	1.60%
Russia***	rus	AI	1379	-0.43%	-0.12%	3.31%	2.09%
Ukraine*	ukr	AI	284	0.01%	-0.40%	3.38%	1.96%
China**	chn	ADC	5259	4.31%	2.15%	6.85%	3.83%
Korea**	kor	NAID	447	2.15%	0.80%	2.99%	1.51%
India**	ind	ODC	1108	6.38%	3.52%	7.06%	5.18%
Mexico**	mex	ADC	413	1.04%	1.13%	2.55%	2.77%
Brazil**	bra	ADC	382	2.96%	1.72%	3.77%	2.31%
Indonesia*	idn	ODC	412	2.16%	1.53%	3.85%	3.17%
Argentina*	arg	NAID	152	3.03%	0.77%	3.82%	2.06%
Turkey*	tur	NAID	246	3.65%	2.08%	3.94%	3.51%
Egypt*	egy	ODC	166	4.53%	0.86%	5.77%	3.16%
Rest AI*	xa1	AI	257	0.88%	0.77%	3.98%	2.78%
Rest Non AI developing*[48]	xna1d	ADC	1350	2.63%	1.65%	4.30%	3.35%
Rest of ADC (incl. RSA)**[49]	xad	ADC	1267	2.61%	1.35%	4.09%	2.90%
Rest of ODC	xod	ODC	1055	4.12%	2.08%	4.06%	3.08%
LDC*	xldc	LDC	493	4.41%	2.45%	4.35%	3.40%
World	world		26967	2.03%	1.47%	2.41%	2.19%

* Business as usual (BAU) target for 2020; ** Reduction target of 15% in 2020; *** Individual reduction target in 2020

Table A-4: Overview of country groups and baseline CO2 emission and GDP

[48] Includes, for example, Israel, Chile, Singapore, Taiwan, or Serbia and Montenegro.

[49] Includes, for example, Malaysia, Iran, Colombia, or Venezuela.

	Copenhagen Accord			Scenarios			
	Target (in%)	Base year	Reduction below 1990/ BAU (in %)	Weak Pledges	Ambitious Pledges	30%-Annex-I	40%-Annex-I
Annex I countries							
Australia	-5 up to -15 or -25	2000	13/ 1/ -11	13.0	-11.0	-28.0	-41.0
Canada	-17	2005	3	3.0	3.0	-27.0	-39.0
EU27	-20/ -30	1990	-20/ -30	-20.0	-30.0	-28.0	-38.0
Japan	-25	1990	-25	-25.0	-25.0	-25.0	-35.0
Norway	-30/ -40	1990	-30/ -40	-30.0	-40.0	-25.0	-36.0
Russia	-15/-25	1990	-15/ -25	-15.0	-25.0	-47.0	-53.0
Switzerland*	-20/ -30	1990	-20/ -30	BAU	BAU	-22.0	-32.0
Ukraine*	-20	1990		BAU	BAU	-62.0	-66.0
USA	-17	2005	-4	-4.0	-4.0	-28.0	-39.0
Rest AI**				BAU	BAU	BAU	BAU
Non-Annex I countries							
Brazil	It is anticipated that these actions will lead to an expected reduction of 36.1% to 38.9% of the projected emissions of Brazil by 2020.			-36.1	-38.9	-15.0	-15.0
China	Lower CO_2-emissions per unit of GDP by 40-45% by 2020 compared to the 2005, increase the share of non-fossil fuels in primary energy consumption to around 15% by 2020 and increase forest coverage by 40 million ha and forest stock volume by 1.3 billion m^3 by 2020 from the 2005 level.			-1.1	-9.3	-15.0	-15.0
India	Reduce the emissions intensity of its GOP by 20-25% by 2020 in comparison to the 2005 level. The emissions from agriculture sector will not form part of the assessment of emissions intensity.			-4.6	-10.5	-15.0	-15.0
Mexico	Mexico aims at reducing its GHG emissions up to 30% with respect to the business as usual scenario by 2020, provided the provision of adequate financial and technological support from developed countries as part of a global agreement.			-30.0	-30.0	-15.0	-15.0
South Africa	South Africa reiterates that it will take nationally appropriate mitigation action to enable a 34% deviation below the 'Business As Usual' emissions growth trajectory by 2020 and a 42% deviation below the 'Business As Usual' emissions growth trajectory by 2025			-34.0	-34.0	-15.0	-15.0
South Korea	Reduce national greenhouse gas emissions by 30% from the BAU emissions by 2020.			-30.0	-30.0	-15.0	-15.0

* *As of 11March 2010 emission reduction targets for Switzerland and Ukraine (and also Belarus) were not yet published at the UNFCCC homepage and hence could not be considered in the analyses.*

Table A-5: Overview of Copenhagen Accord and policy scenarios

Region	Weak Pledges	Ambitious Pledges	30% Annex-I	40% Annex-I
		($millions, 2004)		
Australia	-2,573.2	-4,580.6	-6,769.5	-8,542.7
Japan	1,481.4	2,726.7	5,075.2	3,238.1
Canada	-1,752.0	-2,371.4	-6,295.6	-8,892.7
USA	412.2	7,576.8	-12,517.8	-26,551.5
EU27	16,383.8	21,389.5	40,934.4	41,862.9
Switzerland	-492.3	-810.4	-857.2	-1,174.5
Norway	-2,413.2	-3,869.5	-5,691.9	-7,109.0
Russia	-1,760.6	-5,139.9	-18,001.0	-24,580.8
Ukraine	344.9	592.1	2,859.6	3,199.9
China	25,337.8	48,538.8	95,600.6	152,146.1
South Korea	1,617.4	2,877.8	7,982.5	10,900.8
India	12,406.6	23,154.0	40,453.4	58,036.4
Mexico	-3,587.0	-4,999.4	-3,549.4	-3,242.6
Argentina	-229.2	-458.3	-485.7	331.7
Brazil	-2,373.3	-3,896.5	-3,163.6	-3,601.2
Indonesia	-1,721.2	-2,408.8	-748.5	-911.3
Turkey	58.6	253.7	398.9	622.3
Egypt	-355.6	-473	-638.5	-722.4
Rest Annex-I	-1,145.0	-1,688.5	-2,336.7	-2,682.9
Rest Non-Annex-I, Developing	-19,811.9	-30,366.3	-44,230.6	-53,737.1
Rest of Advanced Developing	-8,235.4	-12,852.3	-18,972.5	-23,011.0
Rest of Other Developing	488.9	4,676.4	19,123.0	29,742.4
Rest of Least Developed	-3,184.4	-5,121.3	-7,666.7	-9,397.4
Global	8,897.3	32,749.6	80,502.4	125,923.5
Annex-I with targets	9,778.40	15,731.60	-3,266.2	-30,575.7
Non-Annex-I with targets	33,890.40	70,351.10	159,124.4	247,914.8
No targets	-34,771.50	-53,333.10	-75,355.8	-91,415.6

Table A-6: Equivalent Variation in 2020 (in millions 2004$)

Region	Weak Pledges	Ambitious Pledges	30% Annex-I	40% Annex-I
		($millions, 2004)		
Australia	-12,774.3	-15,406.2	-26,563.7	-33,228.0
Japan	8,153.6	-2,208.4	7,265.7	-6,811.6
Canada	-16,496.1	-15,235.1	-32,297.8	-41,190.5
USA	43,599.5	52,379.3	-43,954.2	-109,061.7
EU27	134,415.1	63,393.5	155,205.5	126,723.3
Switzerland	-3,353.9	-3,147.8	-6,040.1	-7,286.9
Norway	-21,929.8	-19,929.0	-27,626.3	-30,235.7
Russia	-20,452.7	-20,560.1	-85,289.1	-107,787.7
Ukraine	12,424.4	14,495.7	11,679.6	10,596.8
China	368,928.0	383,719.9	360,757.4	374,124.6
South Korea	11,768.7	12,033.6	22,026.2	22,596.7
India	126,334.6	132,930.1	128,586.7	131,983.6
Mexico	-16,893.3	-16,353.3	-23,033.7	-29,892.3
Argentina	-23,743.8	-23,685.6	-18,513.6	-20,402.2
Brazil	4,899.6	9,377.9	9,984.2	11,632.4
Indonesia	4,353.4	6,972.9	5,495.5	5,684.6
Turkey	25,656.0	29,027.0	31,405.3	32,735.8
Egypt	10,750.1	13,368.6	14,984.3	16,299.4
Rest Annex-I	2,677.5	4,695.7	5,733.6	6,910.3
Rest Non-Annex-I, Developing	-119,581.5	-97,343.1	-137,867.0	-146,889.7
Rest of Advanced Developing	-22,266.3	-7,127.3	-17,807.4	-17,381.3
Rest of Other Developing	41,943.7	55,745.7	69,026.9	73,366.7
Rest of Least Developed	-27,394.1	-33,044.1	-30,002.3	-30,678.1
Global	511,018.4	524,100.0	373,155.9	231,808.5
Annex-I	126,263.3	58,477.6	-41,886.7	-191,371.7
Non-Annex-I with targets	412,149.2	498,666.5	445,044.9	453,858.3
LDCs	-27,394.1	-33,044.1	-30,002.3	-30,678.1

Table A-7: Equivalent Variation in 2030 (in millions 2004$)

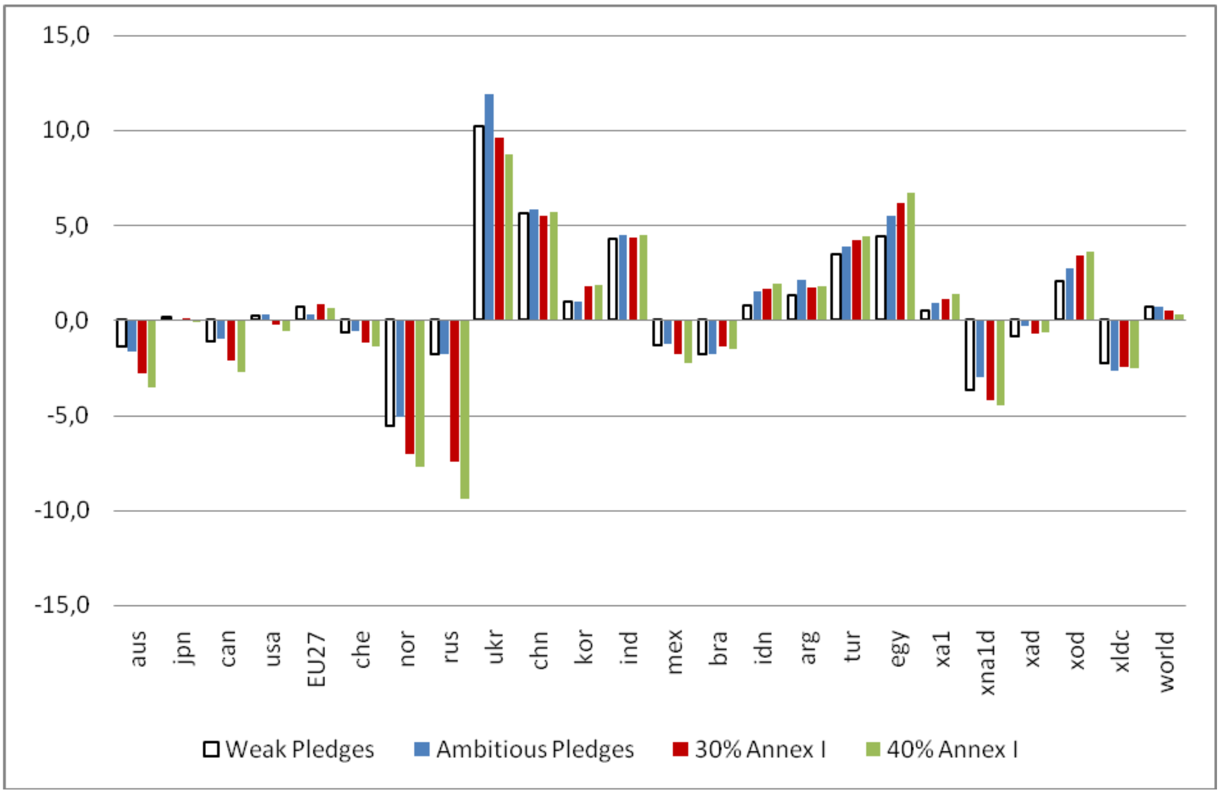

Figure A-5: Change in welfare in 2030 (in % of baseline GDP)