Exploring comparable post-2012 reduction efforts for Annex I countries

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M.G.J. den Elzen*
N. Höhne**
J. van Vliet*
C. Ellermann**

* Netherlands Environmental Assessment Agency (PBL), The Netherlands
** Ecofys, Germany

Corresponding author:
Michel den Elzen, Netherlands Environmental Assessment Agency (PBL),
michel.denelzen@pbl.nl

This research was performed with the support of the Dutch Ministry of Housing, Spatial Planning and the Environment as part of the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change (WAB).

This publication can be downloaded from the website www.pbl.nl/en.
A hard copy may be ordered from: reports@pbl.nl, citing the PB publication number.

Netherlands Environmental Assessment Agency
PO Box 303
3720 AH Bilthoven
T: +31 30 274 2745
F: +31 30 274 4479
E: info@pbl.nl
www.pbl.nl

Acknowledgements

This report is part of a research project entitled ‘Exploring comparable post-2012 efforts for Annex I countries and Advanced Developing Countries’. The project was conducted by the Netherlands Environmental Assessment Agency (PBL) and Ecofys–Germany.

The project has been financed by the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM), as part of its National Research Programme on Climate Change (NRP–CC), particularly its sub-programme dealing with ‘Scientific assessments and policy analyses’.

The results from an earlier version of this report were first presented and discussed during teleconference calls with members of a CCAP (Center for Clean Air Policy) working group on Annex I targets. Preliminary results were presented and discussed by Jack Schmidt (representing CCAP) at the Future Actions Dialogue workshop in Tokyo, Japan, held in February 2008, and by Chris Ellerman (representing Ecofys) at the subsequent Future Actions Dialogue workshop, held in July 2008 in San Francisco, USA, which was attended by senior climate negotiators from more than 30 countries. The results were also discussed at the International Workshop on Sectoral Emission Reduction Potential in Paris, France (presented by Michel den Elzen) in June 2008, which was attended by senior climate negotiators and policy advisors from about 20 countries.

Our special thanks are given to Jack Schmidt and Ned Helme (CCAP) for organising the telephone conferences, invitations for the CCAP meeting and comments on earlier drafts. The authors also gratefully acknowledge the comments and input from the participants of the telephone conference calls and the CCAP meeting in Tokyo.

This report has benefited from the comments of a Steering Committee consisting of Marcel Berk (Ministry of VROM), Tom van Ierland and Martin Weiss (European Commission DG Environment), Guido Knoche (UBA, Germany) and Stephen Cornelius (DEFRA, United Kingdom).

Special thanks are also due to Patrick Criqui (CNRS-Université de Grenoble, France) and Alban Kitous (Enerdata, France) for providing the marginal abatement costs and baseline emissions of the POLES energy system model. The authors are also grateful to Alice Barrs, Alon Carmel and Federico Gallo of the UK Office of Climate change (OCC) for their assistance with the POLES data.

Finally, the authors would like to thank Leo Meyer, Paul Lucas and Detlef van Vuuren (PBL) for their comments on and contributions to this report. Filip de Blois and Kees Klein Goldewijk (PBL) are thanked for their support in graphics design and production. Finally, we thank Annemieke Righart (PBL) and Ann Jenks for language-editing assistance.

Rapport in het kort

Verkennen van vergelijkbaarheid van post-2012 reductie-inspanningen voor Annex I en rijkere ontwikkelingslanden

In 2007 kwamen de EU landen overeen dat de broeikasgasemissies in 2020 met 30% moeten zijn teruggedrongen als bijdrage aan een algemene en alomvattende klimaatovereenkomst voor de periode na 2012. Voorwaarde is dat andere geïndustrialiseerde (Annex I) landen zich verplichten tot "vergelijkbare" reductie-inspanningen. Dit rapport beschrijft verschillende conceptuele benaderingen van "vergelijkbare inspanningen", en analyseert hun voor- en nadelen. Het rapport analyseert vervolgens de gevolgen van zes geselecteerde benaderingen van "vergelijkbare inspanningen", bijvoorbeeld gelijke kosten in procenten van het BBP of gelijke marginale reductiekosten, voor de reductiedoelstellingen en reductiekosten voor de verschillende Annex I landen. Dit is gedaan voor drie scenario's voor de totale Annex I reductiedoelstelling, namelijk een vermindering van 20%, 30% en 40% van de broeikasgasemissies van alle Annex-I landen onder het niveau van 1990 in 2020. Uit de analyse blijkt dat er voor alle Annex I landen aanzienlijke reducties noodzakelijk zijn. De grootste reducties ten opzichte van de 1990 emissieniveaus behalen Rusland en Oekraïne; hun uitstoot daalde tussen 1990 en vandaag. Daarna volgt de EU. De EU wordt gevolgd door Canada en in mindere mate Japan en de Verenigde Staten. In dit laatste land is de uitstoot sterk is toegenomen sinds 1990 en wordt een sterkere groei van de emissies in het basisscenario voorzien. Ten slotte blijkt het alleen mogelijk om de 2 graden doelstelling te halen als de EU een reductie van tenminste 30% realiseert, de andere Annex I landen een vergelijkbare inspanning plegen, en voldoende steun aan de ontwikkelingslanden wordt verleend om hun emissies met 15-30 % ten opzichte van hun emissies in het basisscenario te verlagen.

Trefwoorden: Post-2012 regimes, sectorale doelstellingen, UNFCCC, toekomstige verplichtingen, technologie, emissies, klimaatveranderingen, broeikasgassen

Contents

Samenvatting

Naarmate de internationale onderhandelingen over een nieuwe klimaatovereenkomst vorderen wordt het onderwerp 'vergelijkbare reductie-inspanningen' tussen de landen steeds belangrijker. In maart 2007 hebben de EU landen besloten tot een eenzijdige of unilaterale reductiedoelstelling van de broeikasgasemissies met 20% in 2020 ten opzichte van de niveaus van 1990. Voorts kwamen de EU landen overeen dat de broeikasgasemissies in 2020 met 30% moeten zijn teruggedrongen als bijdrage aan een algemene en alomvattende klimaatovereenkomst voor de periode na 2012. Twee voorwaarden worden aan dit besluit verbonden: ten eerste dat andere geïndustrialiseerde landen (de landen in Annex I in Kyoto Protocol) zich verplichten tot vergelijkbare emissiereducties, en ten tweede dat economisch meer ontwikkelde ontwikkelingslanden ook aanzienlijk bijdragen in overeenstemming met hun verantwoordelijkheden en mogelijkheden. Het doel van dit rapport is inzicht te verschaffen in de verschillende manieren waarop het concept 'vergelijkbare emissiereducties' kan worden uitgewerkt voor ontwikkelde landen in een raamwerk voor een internationale klimaatovereenkomst na 2012. De Conferentie van de Partijen bij het Raamverdrag van de Verenigde Naties betreffende klimaatverandering heeft in Bali in december 2007 (COP13) in het Bali Actie Plan alle ontwikkelde landen opgeroepen reductieverplichtingen op zich te nemen, zodanig dat de onderlinge vergelijkbaarheid van de inspanningen verzekerd is.

Dit rapport beschrijft verschillende conceptuele benaderingen van "vergelijkbare inspanningen" van Annex-I landen en analyseert hun voor- en nadelen. De benaderingen kunnen worden gebruikt voor de beoordeling van reductie-inspanningen van alle Annex I landen. Op basis van de criteria van de weergave van deze inspanningen en technische haalbaarheid zijn zes benaderingen geselecteerd:

1. Gelijke reductie van het basis- of referentiescenario
2. Gelijk marginale reductiekosten
3. Gelijke reductiekosten als percentage van het BBP (exclusief benutting van internationale emissiehandel en CDM)
4. Gelijke reductiekosten als percentage van het BBP (met benutting van internationale emissiehandel en CDM)
5. Convergentie in de emissie-uitstoot per hoofd van de bevolking (dat wil zeggen gelijke emissies per hoofd van de bevolking in een eindpunt, hier in het jaar 2050)
6. Triptiek aanpak (d.w.z. de toewijzing van de toekomstige emissiereducties tussen de landen gebaseerd op convergerende technologische normen of doelstellingen op sectorniveau, maar rekening houdend met structurele verschillen tussen landen.)

De eerste vier benaderingen zijn gericht op gelijke toekomstige lasten, zoals gelijke kosten, en zijn afhankelijk van het toekomstige referentiescenario en (voor de kostenbenaderingen) ook afhankelijk van de reductiekosten veronderstellingen. Deze benaderingen houden geen rekening met reductie-inspanningen die in het verleden zijn gedaan. De laatste twee benaderingen richten zich op een gelijk eindpunt, zoals de convergentie van de uitstoot per hoofd van de bevolking of de energie-efficiëntie, en zijn dus minder afhankelijk van een referentiescenario. Deze benaderingen houden wel rekening met reductie inspanningen die in het verleden zijn gedaan.
Dit rapport analyseert vervolgens de gevolgen van ieder van de zes benaderingen voor de emissiereducties en de bijbehorende reductiekosten die door de verschillende Annex I landen in 2020 moeten worden gemaakt om de complete Annex-I doelstellingen te halen. Dit is uitgewerkt voor drie '*Annex I vergelijkbare*' scenario's, die gericht zijn op vermindering van broeikasgassen (de zes Kyoto Protocol broeikasgassen) door Annex I van respectievelijk -20%, -30% en -40%

onder het niveau van 1990 in 2020. Daarbij wordt aangenomen dat ook de niet-Annex I landen (ontwikkelingslanden) als groep hun emissiegroei moeten beperken: hun emissies moeten worden gereduceerd onder het referentiescenario met respectievelijk 10 %, 16% en 22% in 2020 om te komen tot lange termijn stabilisatie van de broeikasgasconcentraties op het niveau van 550, 450 en 400 ppm CO_2-eq. Tot slot bevat het rapport een analyse van de robuustheid van de resultaten op basis van alternatieve marginale emissie reductiekosten. De belangrijkste bevindingen van deze studie zijn (andere belangrijke uitkomsten zijn te vinden in hoofdstuk 7):

- *De keuze van de complete reductiedoelstelling van Annex I is voor de meeste landen van groot belang*, aangezien de reductieverschillen in reducties tussen de 20%, 30% en 40% van Annex I reductie scenario meestal groter zijn dan de reductieverschillen tussen de verschillende benaderingen die gericht zijn op dezelfde Annex I reductiedoelstelling.
- Significante reducties voor alle landen onder alle zes benaderingen zijn noodzakelijk voor het bereiken van de Annex I reductie doelstelling.
- *Reductie ten opzichte van 1990 emissieniveau is geen goede maat voor vergelijkbare inspanning.* Voor de gekozen benaderingen zijn doorgaans in 2020 de grootste reducties ten opzichte van 1990 emissieniveaus voor de Oekraïne en Rusland, aangezien hun emissies zijn afgenomen sinds 1990, en omdat we voor de berekeningen veronderstellen dat hun initiële (2010) emissies begint bij hun referentie emissies, die ver onder hun Kyoto doelstellingen liggen. De eerstvolgende grootste reducties worden gevonden door de EU, waarvan de emissies sinds 1990 zijn afgevlakt en in het referentiescenario weinig groeien . De EU wordt gevolgd door Canada en in mindere mate Japan en de Verenigde Staten, waarvan de emissies al aanzienlijk zijn gestegen sinds 1990 en een sterkere groei van de emissies in het referentiescenario wordt voorzien. In het 20%, en zelfs in het 30% Annex I reductiescenario, is voor Australië en Nieuw-Zeeland in veel benaderingen nog altijd ruimte voor een verhoging de emissies ten opzichte van het niveau van 1990. Dit zou anders kunnen liggen indien emissies uit landgebruik volledig in de analyse zouden worden meegenomen. De *Triptiek* en de *Convergentie in de emissie-uitstoot per hoofd-* benadering geven relatief strenge reducties voor de Verenigde Staten, Canada en Australië en Nieuw-Zeeland (alleen voor convergentie) en relatief minder strenge reducties voor de EU en Japan (alleen Triptiek), omdat deze benaderingen rekening houden met reducties in hert verleden. De uitkomsten voor de *Convergentie in de emissie-uitstoot per hoofd-* bendering hangen sterk afhankelijk van het veronderstelde convergentiejaar (hier 2050). Een vroeger convergentiejaar zou zelfs leiden tot meer reducties voor de VS en minder voor de EU. Benaderingen op basis gelijke marginale reductiekosten wijzen sterke emissiereducties toe aan emissie-intensieve (maar minder rijke regio's) als de Oekraïne en Rusland, en minder strenge reducties aan Japan en de EU.
- *De reductiekosten (als percentage van het BBP) geven een brede spreiding uit uitkomsten voor alle Annex I landen.* De reductiekosten (als percentage van het BBP) voor de Annex I landen liggen tussen 0,1% en 0,3% van het BBP voor het 20% Annex I reductiescenario, 0,3% en 0,6% van het BBP voor de 30% scenario en 0,5% en 1,5% van het BBP voor het 40% scenario. De totale reductiekosten per BBP zijn vrij hoog voor alle benaderingen voor Canada, de VS, Australië en Nieuw Zeeland (regio's met de hoogste uitstoot per hoofd), en iets lager voor de EU en Japan (regio's met een gemiddelde uitstoot per hoofd). De kosten vertonen een grote verscheidenheid tussen de benaderingen, vooral voor de gelijke marginale kosten en Triptiek methode. Vooral de kosten (en reductiedoelstellingen) voor de Russische Federatie en de Oekraïne zijn gevoelig voor de gekozen aanpak. Hierbij moet worden opgemerkt dat deze reductiekosten alleen de directe kosten van de desbetreffende reductieactie en geen rekening houden met de macro-economische effecten (als gevolg van de sectorale veranderingen en (brandstof)handelimpacts).

- *De* VS *heeft relatief lage reductiedoelstellingen ten opzichte van 1990.* De reductie-inspanningen voor de VS zijn voor de verschillende benaderingen gelijk aan 0%, 10-15% en 25-30% ten opzichte van de 1990 niveaus voor het 20%, 30% en 40% Annex I reductie scenario. De gematigde reductiedoelstellingen van de Verenigde Staten ten opzichte van die van de andere Annex I landen zijn een direct gevolg van de veronderstelling dat de Verenigde Staten begint in 2010 vanuit hun nationale emissieintensiteit doelstelling. Deze doelstelling leidt tot hogere baseline emissies dan de historische emissie trend (2001-2006), echter de hier genoemde conclusie dat de Verenigde Staten een relatief lagere doelstelling heeft dan andere landen is robuust. Zowel de nationale doelstelling als de historische emissies liggen ruim boven de voorgestelde Kyoto-doelstelling.
- *Een reductie van de* EU *van minstens 30% gecombineerd met vergelijkbare inspanningen van andere Annex I landen en voldoende emissiereducties in de ontwikkelingslanden (15-30%) ten opzichte van het referentiescenario is nodig voor het halen van de klimaatdoelstelling van 2°C.* De emissiereductiedoelstellingen voor de EU voor de onderzochte benaderingen variëren van ongeveer 20-30%, 30-40% en 40-50% reductie ten opzichte van 1990 niveaus voor respectievelijk de 20%, 30% en 40% Annex I reductiescenario's. Voor sommige van de benaderingen is de emissiereductie voor de EU meer dan de Annex I reductie. Een reductie van de EU van minstens 30% onder het 1990-niveau in 2020, gecombineerd met vergelijkbare inspanningen voor de andere Annex I landen met emissiereducties zoals berekend volgens deze studie, zou de uiteindelijke Annex I emissies verminderen met tussen de 20 en 30% onder het 1990-niveau in 2020 . Dit is aan de ondergrens van de 25%-40% reductie voor de Annex I die in overweging is bij de Ad-hoc Werkgroep betreffende verdere verplichtingen voor de Annex I landen onder het Kyoto Protocol (AWG-KP), maar kan nog steeds in overeenstemming zijn met de lange termijn klimaatdoelstelling van de EU om de mondiale temperatuurstijging te beperken tot 2°C boven het pre-industriële niveau. Dit alles onder de voorwaarde dat ook de emissies in de ontwikkelingslanden met voldoende (15-30%) worden gereduceerd ten opzichte van hun emissies in het referentiescenario. De reductiemarges hier gepresenteerd zijn afhankelijk van de gekozen benaderingen, het model en de veronderstellingen ten aanzien van de reductiekosten.
- *De reducties en kosten van de verschillende benaderingen zijn afhankelijk van een aantal veronderstellingen over parameterinstellingen, het referentiescenario en de emissiereductiekostencurves.* De benadering van *gelijke reductie ten opzichte van het referentiescenario* en *gelijke reductiekosten* zijn afhankelijk van het veronderstelde referentiescenario en de marginale reductiekosten. De benadering *convergentie in de emissie-uitstoot per hoofd van de bevolking* is sterk afhankelijk van het veronderstelde convergentiejaar en de Triptiekmethode hangt af van de veronderstelde parameterinstellingen en de toekomstige activiteitenniveaus in de industrie- en elektriciteitssector in het referentiescenario. De gevoeligheidsanalyse van de kostenallocatie benaderingen onder alternatieve marginale emissiereductiekostencurven (en referentiescenario's) van het POLES model geeft aan dat berekende regionale reducties redelijk robuust zijn, maar verschillende aannames over de emissiereductiekostencurves kunnen een aanzienlijke invloed hebben op de regionale doelstellingen, en vergen daarom nader onderzoek. De POLES model kostenveronderstellingen leiden tot hogere reductiedoelstellingen voor Australië en Nieuw-Zeeland en de Verenigde Staten, aangezien POLES lagere reductiekosten heeft voor deze regio's ten opzichte van onze standaard (IMAGE / TIMER MAC) kosten. POLES geeft ook lagere reducties voor de EU en Japan. Bijvoorbeeld, in het kader van het 30% Annex I reductie wordt de EU reductie 25-38% ten opzichte van 1990 niveaus in plaats van 30-40% voor onze standaard (IMAGE / TIMER MAC) berekeningen. Voor de VS geldt onder dezelfde 30 % Annex I reductie een reductie van 15-20 % ten opzichte van 1990 in plaats van 10-15 %. De resultaten tonen een grote onzekerheid op de totale kosten voor de

Annex I onder het 20% en een 30% Annex I reductiescenario in 2020, en nog meer op het niveau van landen, zoals voor Canada. Deze onzekerheden hangen ook af van verschillen in de referentiescenario's.
- *De resultaten hangen ook af van de gekozen aanpak en andere factoren, zoals landgebruiks-verandering gerelateerde emissies*. Afgezien van de onzekerheden met betrekking tot het referentiescenario en de marginale reductiekostencurves, zijn de berekende reducties ook gerelateerd aan de keuze die we gemaakt hebben ten aanzien van de benaderingen, en de gemaakte veronderstellingen hiervoor. Bovendien houden we onvoldoende rekening met een (gedetailleerde) uitwerking van de landgebruikverandering gerelateerde emissies. Verschillende regels voor het wel meenemen hiervan kan van invloed zijn op de resultaten, vooral voor de Annex I landen met een aanzienlijk aandeel van deze "emissies", zoals Australië, Canada en Rusland.

Dit onderzoek is een eerste poging om vergelijkbare inspanningen voor Annex I landen te definiëren en analyseren. Verdere analyses met meerdere en verschillende modellen, met inbegrip van macro-economische modellen, zijn wenselijk om te komen tot meer robuuste resultaten en gedeelde inzichten.

Tot slot blijkt uit deze analyse dat alleen een compromisvoorstel aantrekkelijk kan zijn voor alle landen. Deze studie onderzocht verschillende benaderingen, variërend van zeer eenvoudig (gelijke procentuele vermindering) tot zeer complex (gelijke kosten benadering). Elke benadering is voor landen respectievelijk meer of minder aantrekkelijk. Een eenvoudige benadering kan alleen maar dienen als een algemene oplossingsrichting. Een uiteindelijk akkoord over een internationaal klimaatregime, en ook de benadering van de lastenverdeling binnen Annex-I landen, zal waarschijnlijk gebaseerd worden op een samengestelde formule die rekening houdt met de verschillende nationale bezwaren, en zal uiteindelijk moeten leiden tot een onderhandelingscompromis.

Summary

As the international negotiations on a new climate agreement advance, the issue of comparable efforts between countries becomes increasingly important. In March 2007, the EU decided to adopt the unilateral target of reducing its greenhouse gas (GHG) emissions by 20% in 2020, compared to 1990 levels. It also declared a willingness to reduce its emissions by 30% as a contribution to a global and comprehensive agreement for the period beyond 2012 – with two provisos. Firstly, other developed countries must commit themselves to *comparable emission reductions.* Secondly, economically more advanced developing countries must also contribute proportionally in accordance to their responsibilities and respective capabilities. The aim of this report is to provide insights in options for elaborating the concept of *comparable emission reductions* for developed countries within the framework of a future international climate agreement, beyond 2012. The thirteenth Conference of the Parties (COP 13) to the United Nations Framework Convention on Climate Change (UNFCCC), in Bali in December 2007, called for mitigation commitments or actions by all developed countries, while ensuring the *comparability of efforts* among them.

This report first describes possible conceptual approaches to assess the comparability of Annex I countries [1] GHG mitigation efforts, assessing both the pros and cons of each approach. Six approaches were selected for quantification based on the criteria of representation of efforts and technical feasibility. The selected approaches are:
1. equal percentage reduction below a baseline scenario
2. equal marginal abatement costs (MAC)
3. equal abatement costs as a percentage of the gross national product [GDP; excluding international emissions trading and clean development mechanism (CDM)]
4. equal abatement costs as a percentage of the GDP (including international emissions trading and CDM)
5. converging per capita emissions (i.e. equal per capita emissions by a certain year; here taken to be the year 2050)
6. Triptych approach (i.e. allocating future reductions among countries based on converging technological standards or targets at the sectoral level, accounting for structural differences.)

The first four approaches focus on an 'equal future burden', such as equal costs, and depend on the future reference scenario and (for the costs approaches) on assumptions on abatement costs; they do not take past efforts into consideration. The last two approaches focus on 'an equal endpoint', such as converging per capita emissions or energy efficiencies and are, therefore, less dependent on a reference scenario. These approaches do acknowledge past abatement actions. The report analyses the implications of each of these six approaches in terms of the future reductions and abatement costs that must be made by different Annex I countries in order to meet the overall Annex I reduction targets. This analysis has been elaborated for three '*Annex I comparable*' scenarios that have a reduction target for 2020 of an aggregate GHG emission reduction by Annex I countries of –20%, –30% and –40%, respectively, below their 1990 levels (Kyoto basket of six GHGs). We assumed that the emissions of non-Annex I countries as a

1 Annex I Parties include the industrialized or developed countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition, including the Russian Federation, the Baltic States, and several Central and Eastern European States.
See: http://unfccc.int/parties_and_observers/parties/annex_i/items/2774.php

group would have to be below the baseline by 10%, 16% and 22%, by 2020, to achieve atmospheric concentration stabilisation at 550, 450 and 400 parts per million carbon dioxide equivalent (ppm CO_2eq), respectively. In a final analysis, we assessed the robustness of the results for alternative marginal abatement costs (MACs). The most important findings of this study are:

- *The choice of the aggregate Annex I reduction level is of major importance.* The choice of the overall Annex I reduction target is, for most countries, of major importance, as the difference in reduction between the 20%, 30% and 40% Annex I reduction scenarios, usually, is larger than the difference between the various approaches aiming for the same Annex I reduction target.
- For all Annex I countries under all six approaches, significant reductions from baseline levels are necessary for meeting the aggregate Annex I reduction targets.
- *Looking at reductions below 1990 levels only, is not a method for measuring comparable effort.* The Ukraine and the Russian Federation will achieve the largest reduction, compared to 1990 levels, as their emissions have declined rather than increased, since 1990. In our calculations, their emission levels by the year 2010 have been taken as the reference or baseline emission levels, which are well below their Kyoto target. The next highest reductions are found for the EU, for which emissions have levelled off, since 1990, and are not expected to grow much in the baseline scenario. The EU is followed by Canada and, to a lesser extent, by Japan and the USA, the latter of which has had a significant increase in emissions, since 1990, which are expected to continue to grow. In the '20%' and even the '30% Annex I comparable' scenarios, Australia and New Zealand are, in most cases, still allowed an increase from 1990 levels, but this could be different if land-use emissions were to be fully included in the analysis. The *Triptych* and *converging per capita emissions* approaches show relatively stringent reductions for the USA, Canada and Oceania (i.e. Australia and New Zealand) (only in the *convergence* approach) and relatively less stringent reductions for the EU and Japan (only in the *Triptych* approach), as these approaches both acknowledge past actions. The outcomes for the *converging per capita emissions* approach are highly dependent on the assumed convergence year (here 2050). An earlier convergence year would assign even more stringent reductions to the USA and less stringent ones to the EU. Approaches based on mitigation potentials (equal marginal costs) assign stringent reductions to the emission-intensive (but less rich) regions, such as the Ukraine and Russian Federation, while assigning less stringent reductions to Japan and the EU.
- *The abatement costs (as a percentage of GDP) also show a wide range for all Annex I countries.* The abatement costs (as a percentage of GDP) for the Annex I countries generally range between 0.1% and 0.3% of GDP in the '20% Annex I comparable' scenario, between 0.3% and 0.6% of GDP in the '30% Annex I comparable' scenario and between 0.5% and 1.5% of GDP in the '40% Annex I comparable' scenario. Total abatement costs per GDP mostly tend to be relatively high in all the approaches for Canada, USA and Oceania (regions with the highest per capita emissions) and somewhat lower for the EU and Japan (regions with medium per capita emissions). There is a wide range of costs between the approaches explored, particularly for the equal marginal costs and *Triptych* cases. The abatement costs (and reduction targets) for the Russian Federation and the Ukraine are particularly sensitive to the allocation approach chosen. It should be noted that these costs only capture the direct costs of the abatement action and do not take into account macroeconomic impacts [due to sectoral changes and (fuel) trade impacts].
- The USA has relatively low reduction targets for 2020, compared to 1990 levels, when starting from their national target, in 2010, and not from their Kyoto target. Emission reduction efforts by the USA would consist of a range of reduction targets of near 0%, 10 to 15% and 25 to 30% below 1990 levels, in the '20%', '30%' and '40% Annex I comparable' scenarios,

respectively. The relatively modest USA reduction targets – in comparison to those for other developed countries – are a direct result of the assumption that, in 2010, the USA will start from their national target. The national target leads to higher baseline emissions compared to the historical emission trend (2001-2006). However, the conclusion above that the USA has relatively low target compared to other countries is robust. Both the national target and historical emissions are well above their proposed Kyoto-targets.

- Reductions by the EU of at least 30%, combined with comparable efforts by other Annex I countries and with support for developing countries to keep emissions substantially below baseline (about 15 to 30%) would be sufficient to secure the climate goal of 2°C. The emission reduction targets for the EU, for the cases explored, range from about 20 to 30% to 30 to 40% and 40 to 50% below 1990 levels, in the '20%', '30%' and '40% Annex I comparable' scenarios, respectively. For some of the approaches, the EU would have to reduce its emissions more than to the average Annex I level. This implies that if the EU were to reduce its emissions by 30% below the 1990 level, by 2020, and if other Annex I countries would undertake a 'comparable effort' according to the approaches analysed here, the overall reduction for Annex I countries would be between 20% and 30% below the 1990 level. This target would be at the lower end of the 25% to 40% reduction range considered by the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP). However, it would still be consistent with the EU long-term climate goal of limiting the global temperature increase to 2°C above pre-industrial levels, as this range corresponds with the stabilisation of GHG concentrations at 450 ppm CO_2eq, provided that emissions in developing countries also deviate substantially from the baseline scenario (about 15 to 30%). The ranges found are also dependent on the cases explored and the model and cost assumptions made.
- The reductions in and costs of the various approaches as presented above are dependent on many assumptions on the parameter settings, the baseline and on the MAC curves used. As such, the approaches equal percentage reduction from a baseline and equal abatement costs depend on the assumed baseline and marginal abatement costs. The converging per capita emissions approach depends on the assumed convergence year and the Triptych approach depends on the assumed parameter settings and baseline activity levels. When using one set of alternative MAC curves (and baselines projections) from the energy system model POLES, our assessment has shown that – while the pattern of reductions found seems to be rather robust – different assumptions on MAC can have a considerable influence on regional targets and, therefore, require further study. The assumptions in the POLES model result in a higher reduction range for Oceania and the USA, and in a lower range for the EU and Japan. For example, for the 30% Annex I reduction scenario, the EU reduction range becomes 25 to 38% below 1990 levels, instead of the 30 to 40% determined by using our default (IMAGE/TIMER MAC) calculations. For the USA, under the same 30% Annex I reduction scenario, the range becomes 15 to 20% below 1990 levels, instead of 10 to 15%. The results show a considerable uncertainty in the overall costs for Annex I countries, in terms of achieving an overall reduction of 20% and 30%, by 2020, and at country level (e.g. for Canada) these uncertainties are even greater; the uncertainties are also related to differences in baseline projections.
- *The outcomes also depend on the selected approaches and other factors, such as land-use emissions.* Apart from uncertainties related to the baseline assumptions and the MAC curves used, the ranges need to be used cautiously, as they are contingent on the approaches included in the analyses and the modelling assumptions. Moreover, (detailed) inclusion of emissions from land use and land-use changes and forestry (LULUCF) – possibly according to different rules – could affect the outcomes, particularly for Annex I countries with a significant share in these emissions, such as Australia, Canada and the Russian Federation.

Other main findings can be found in Chapter 7.

This study was a first attempt at exploring how comparable efforts could be defined. Further analyses involving more and different models, including macroeconomic models, would be needed for obtaining more robust results and common insights.

Based on the results of our analysis, we conclude that a compromise is probably the most attractive approach, for all countries. This study has tested several approaches, varying from the very simple (equal percentage reduction) to the very complex (equal costs approach). Each approach has different characteristics that make it more – or less – attractive to any one (or more) of the Annex I countries. It would appear that any simple approach can, therefore, only serve as a general indicator of direction. The final agreement on an international climate change regime and also on the concept of burden-sharing within the Annex I countries, is likely to be based on an approach with a complex formula that accounts for various national concerns and, ultimately, will be a negotiated compromise.

1 Introduction

The objective of this report is to provide insights into the various options/approaches that can be used to characterise the concept of comparable efforts for developed countries in a future international climate agreement, to be in place by 2012. Negotiations on this topic have already been initiated, with the aim of being finalised by the end of 2009. This report provides Parties (countries) with accurate information on the implications of the approaches that could be used for comparing mitigation efforts between developed countries.

Two processes, both under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC), have been initiated with the objective of negotiating a future international climate agreement, post-2012. Working within the framework of the Kyoto Protocol, the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP) has started to explore possible new commitments for developed countries, to take on, beyond 2012. This forum excludes the USA, which is not a party to the Kyoto Protocol. Within the framework of the UNFCCC, the Parties, together with the USA [1)], reached an agreement on the Bali Action Plan in Bali (2007), to start negotiations on five building blocks – shared vision, mitigation, adaptation, technology and financing – within the Ad Hoc Working Group on long-term cooperative action (AWG-LCA). Both working groups intend to finalise their work by the end of 2009. The subjects under discussion relate to emission reduction efforts required from developed countries and a proportional distribution of reduction commitments between the various Parties. The Bali Action Plan aims for ‘comparable efforts’ by all developed countries.

In March 2007, the European Union (EU) decided to adopt a unilateral target of reducing its greenhouse gas (GHG) emissions by 20%, by 2020, compared to 1990 levels, and declared its willingness to reduce emissions by 30%, as the EU’s contribution to a global and comprehensive agreement for the period beyond 2012, provided that other developed countries commit themselves *to comparable emission reductions* and that economically more advanced developing countries also contribute, proportionally, according to their responsibilities and respective capabilities. By adopting a 20% unilateral target and proposing a 30% target as part of a broader post-2012 agreement, thus indicating the level of commitments they are willing to adopt, the EU has moved ahead of the AWG-KP process and put pressure on other developed countries to follow suite. However, the EU has also agreed to allow its Member States to deviate from the adopted 30% reduction target. Consequently, although in principle the EU also demands a 30% reduction from other Annex I Parties, it will also have to consider both the concept of differentiation of reduction efforts amongst other Annex I countries, as well as level of deviation it finds acceptable.

In August 2007, the Parties to the AWG-KP agreed that a reduction in GHG emissions by Annex I countries in a range of 25 to 40% below 1990 levels, by 2020, would provide a practical basis for further consideration. The reduction range of –25% to –40% refers to Box 13.7 in the Working Group III report of the Fourth Assessment report of the Intergovernmental Panel on Climate Change (IPCC AR4; Gupta et al., 2007). This range is understood to be the overall group reduction, as reductions by individual countries have not yet been specified. In line with

1 The USA is an UNFCCC Party, but the USA is not a Kyoto Protocol Party as it has not ratified the Kyoto Protocol.

its working programme, the AWG-KP is discussing the means for reaching emissions reduction targets, before turning to the topic of the differentiation between reduction target levels, in 2009.

At the thirteenth Conference of the Parties (COP 13) in Bali, in December 2007, the issue of the reduction range for Annex I countries was discussed again, this time with all countries, including the USA. Initial drafts by the EU called for the same wording as already agreed on under the Kyoto Protocol. However, ultimately, there was a lack of consensus on the reduction percentages in the negotiations under the Convention and, instead, the Bali Action Plan recognised that 'deep cuts' in GHG emission levels would be needed and a reference to the IPCC AR4 was included in a footnote. The action plan also called for enhanced action on the mitigation of climate change, by both developed and developing countries, and for '*Measurable, reportable and verifiable nationally appropriate mitigation commitments or actions'*, including quantified emission limitation and reduction targets, by all developed country Parties. Meanwhile ensuring that '*efforts would be comparable, for developed and developing countries, taking into account the differences in their national circumstances*'.

Thus, the issue of comparability of effort is an important component of EU policy and in UNFCCC discussions. It, therefore, has been the focus of substantial attention.

The issue of comparable emission reduction efforts is particularly relevant among the Annex I countries, as these have reached a relatively comparable level of development (even though a large difference in development between a few Annex I Parties still remains). Defining comparable efforts for countries at very different levels of development is much more difficult and, in fact, would relate to equitable levels of commitment that also account for differences in responsibility and development needs. Some Annex I Parties may also want to extend the concept of comparability to developing countries, as these Parties view some degree of effort by developing countries as a (pre-)condition for their own participation and commitment. A number of the more advanced developing countries (e.g. South Korea and Mexico) have, in fact, reached levels of economic development, comparable to some of the poorer Annex I countries. However, including developing countries in this discussion on emissions reduction efforts, is beyond the scope of this report. Instead, we have made simple assumptions, where necessary, on mitigation actions by developing countries, in accordance with common but varying responsibilities and respective capabilities for the few cases where this would have an impact on efforts by developed countries, due to international trading of emission allowances.

Table 1.1 provides an overview of some basic indicators for Annex I countries. It shows the diversity in countries, in terms of trend since 1990, emissions per gross domestic product (GDP) and per capita.

In the discussion on future differentiation between Annex I countries, the USA plays a particularly important role. It abandoned its 7% reduction target for the first commitment period of the Kyoto Protocol and has had a major increase in its GHG emissions since 1990 (+16% in 2006). The US Senate has proposed a number of measures pertaining to countrywide emission reduction targets for GHG, but none of these are as ambitious as the EU targets. At most, the proposed US measures are aimed at a return to 1990 emission levels, by 2020 (for an overview of those proposals and its implications, see Paltsev et al., 2007). In informal policy discussions, some Parties have indicated that the USA should not be rewarded for refusing to take on a target for the first commitment period of the Kyoto Protocol, while others have pointed at the differences in baseline developments (e.g. population growth) between the EU and the USA, which make it

Table 1.1 Basic indicators for Annex I countries

Party	GHG emissions in 2006 ($MtCO_2eq$)[a]	Change in GHG emissions from base year to 2006 (%)[b]	GHG emissions/ GDP PPP in 2006 (tCO_2eq/USD 1,000)	GHG emissions/ capita in 2006(tCO_2eq)
Australia	536	29%	0.75	25.9
Belarus	81	-36.4%	0.88	8.3
Canada	721	22%	0.62	22.1
Croatia	31	-5.2%	0.50	6.9
Iceland	4	24%	0.39	14.0
Japan	1,340	5%	0.34	10.5
New Zealand	78	26%	0.75	18.6
Norway	54	8%	0.24	11.5
Russia	2,120	-36.0%	1.62	14.7
Switzerland	53	0.8%	0.20	7.1
Turkey	332	95%	0.56	4.5
Ukraine	443	-51.9%	1.57	9.5
USA	7,017	14%	0.55	23.4
EU 27	5,139	-16.2%	0.38	10.5
Annex I	17,483	–5.5	0.50	14.1

[a] Excludes land use and land-use change and forestry (LULUCF) CO_2 emissions and excludes international transport.
[b] Base year is 1990, except for Bulgaria (1988), Hungary (average of the years 1985–1987), Poland (1988), Romania (1989) and Slovenia (1986). Some countries chose 1995 as the base year for fluorinated gases.
Sources: Inventory submissions to the UNFCCC, World Bank Development Indicators

inconceivable for the USA to make up for not meeting its 7% reduction target under the Kyoto Protocol.

In the USA, the discussion around climate change policy is very much domestically oriented, focusing on what the USA can do at home and generally irrespective of international agreements. Moreover, the process of having an international climate change agreement ratified in the USA is very difficult, and it may well be impossible for the USA to become a Party to any new international regime, within a short time frame. It is, therefore, quite conceivable that the EU will be confronted with a situation in which the USA is willing and able to act at home, but not internationally. Such a scenario may not necessarily hamper a new international agreement, provided that the domestic effort of the USA is considered to be significant and comparable to the efforts of other Parties under the post-2012 agreement. The conditions pertaining to such a significant and comparable effort by the USA, are as yet unclear.

Given this background, this report provides the following:

a. Indicators for comparing commitments among Annex I Parties (Chapter 2). It lists the various indicators that could be used to define the comparable GHG mitigation efforts by Annex I countries. We have assessed whether these indicators adequately reflect comparable efforts and whether their implementation is technically feasible. Based on this evaluation, we have selected a number of indicators for further consideration in the following chapters.
b. Comparable absolute emission reduction targets, based on the indicators selected (Chapter 4). We have provided three Annex I reduction scenarios of varying overall stringency, for the aggregate reduction of 20%, 30% and 40%, respectively, below the 1990 level, by 2020.

2 Defining ‘comparable efforts’

Two issues need further exploration in defining comparable efforts: (a) comparability of different types of commitments and (b) differentiation between efforts by countries with different national circumstances. These are discussed below.

Different types of commitment may complicate a comparison of Parties’ efforts, because some Parties may prefer to make commitments that are not directly related to absolute emission reduction targets. After all, the Bali Action Plan speaks of ‘mitigation commitments or actions’ that may include other types of commitment.

In the past, the US administration has shown a preference for relative and non-binding emission targets and for technology-oriented agreements, although the current position of the USA is unclear. The types of commitment to adopt after Kyoto is also the subject of much debate in Japan (IGES, 2005; Sawa and Fukushima, 2007). Japan currently supports the Asian Pacific Partnership initiative, which is based on technology cooperation, and for some time has appeared to be expressing doubt on the appropriateness of absolute binding emission targets. For example, at the UNFCCC meeting in Bangkok, in April 2008, Japan proposed using the sectoral analysis of efficiencies as the basis for future commitments, although it did not specify whether the commitment would be targeted at reaching a certain level of efficiency or at the resulting emission reductions. The EU, New Zealand, China and Canada all stressed that sectoral approaches should support, not replace, national targets. Many observers interpreted Japan’s reaction at the Bangkok meeting as another indication of acceptance of absolute binding emission targets.

In some proposals for post-2012 regimes, Annex I countries are offered the choice of different commitment types (Kameyama, 2004). In the Sao Paulo proposal (see http://www.basic-project.net/), Annex I countries would even be able to choose for a combination of absolute and/or relative emission targets and a financial payment into international technology and adaptation funds. This proposal provides a methodology for determining the level of financing that can compensate for a less ambitious emission reduction target. Other proposals have stated that commitments can be binding or non-binding. *Such proposals raise the question of how these diverse commitments could be compared, in terms of the different levels of effort they would represent.*

It is possible to make these different commitments comparable by applying, for example, a common metric, as most of them can be transformed into absolute emissions. However, this still leaves the question of when reductions would occur: for emission targets, this is well defined; for technology research and development (R&D), however, it would be at some time into the future. The non-binding or binding character of a commitment would also have to be translated into the likelihood of achieving emission reductions, which could be accomplished by attaching a greater uncertainty to the likelihood of emission reductions in non-binding commitments.

In this report, we have made no further attempt to compare the level of effort required for the different commitments, since apart from by the EU there are no other commitments on the table, at the present time. Rather, we have adopted a top-down approach, looking at indicators that describe comparable efforts and calculating emission targets according to these indicators, using the FAIR model (Den Elzen and Lucas, 2005) (Chapter 3). These emission levels could then be compared to countries’ (future) commitments.

Differentiating between efforts by countries in different national circumstances is another issue. 'Comparable' does not necessarily mean 'equal'. The concept of comparability of efforts can incorporate the notion of *equal treatment of Parties in similar circumstances*. Countries at a similar level of socio-economic development should make similar contributions to climate change mitigation. However, there are significant differences between the national circumstances in developed countries, which need to be taken into account, including whether a country has made any efforts in the past. The concept of comparing efforts between developed countries, thus, implies efforts in equal proportion rather than equal in size. Comparability should give countries a feeling of fairness that would provide a background for solidarity and political consensus on the actions to be taken by them. This feeling of fairness would also provide politicians with a basis for convincing their constituents of the success of the negotiations. However, in practice, the outcome will also be determined by Parties' relative willingness to act. This differentiation between efforts is the focus of this report.

For the purpose of this report we have distinguished between two conceptual approaches for assessing comparable efforts: equal burden and equal endpoint:
- **Equal future burden:** The first and more common approach is to define the problem as a burden that needs to be shared fairly by all countries. The efforts to be compared relate to the needed *change in the current state* or the *change in a likely reference development*. This perspective focuses on future efforts and, usually, neglects differences in starting points due to (in)actions that have taken place in the past.
- **Equal endpoint:** The second approach is to assess the efforts needed for reaching *the same state in the future*, such as those defined in terms of efficiencies. This perspective accounts for differences in starting points. Countries that already have undertaken efforts in the past are, usually, closer to the endpoint and will not have to undertake as much effort in the future.

These two concepts are described in more detail in the following sections.

2.1 Equal future burden

The first approach defines the problem as being a future burden that needs to be distributed fairly between countries. When this approach would be adopted, the first step would be to define the burden, such as in terms of emissions avoided or additional costs. In any metric, the burden always consists of the difference between a reference case and a desired development. The second step is to distribute this burden fairly between countries, taking into account the different national circumstances.

The **major advantage** of this approach is that its aim is to quantify each country's effort. Each country carries the same burden. This concept can be considered to be fair, as each country is making a contribution to solving the common problem.

The **major disadvantages** of this approach include:
- The development in the reference case is always hypothetical. It is intended not to take place, so the accuracy of the scenario cannot be proven, ex post.
- The reference case is based on assumptions on production patterns and lifestyles. These may converge, but some differences will remain between the reference scenarios for the different countries. For example, a country in which people drive larger cars will have a reference

scenario that also reflects this, and, therefore, it would have to make a greater effort to reduce the emissions from these cars.
- Efforts of the past are not acknowledged. This means that a country which has already reduced its emissions, still will have to make a future 'effort' that is comparable to that made by a country that has reduced no emissions in the past.

There are a number of possible options for determining the 'comparable efforts' associated with the concept of equal future burden:
- equal percentage reduction in emissions, below base year
- proportional, according to simple criteria for differentiating between reductions
- equal percentage reduction in emissions, below a reference or baseline scenario
- equal marginal abatement costs
- equal total abatement costs per GHG reduced (€/tCO_2eq)
- equal total abatement costs per (current) GDP
- equal total abatement costs per capita
- equal macroeconomic burden

The various advantages and disadvantages of these options are described in more detail in the following subsections. We have also assessed whether any of these options could be used for detailed modelling (Chapter 3). The two criteria used for determining the suitability of the options for modelling are:
1. **Representation of efforts:** All approaches intend to represent comparable efforts, but some may be too simplistic or be misleading and, therefore, fail to give the right direction.
2. **Technical feasibility:** Are data and tools available for calculating the efforts under this approach?

We have summarised the evaluations inTable 2.1 and Table 2.2.

2.1.1 Equal percentage reduction in emissions below base year

This approach requires all countries to achieve a certain equal percentage reduction in their emissions, by a target year, compared to a base year.

A similar (not equal) percentage reduction below a base year was used for setting the emission reduction targets for Annex I countries in the first commitment period of the Kyoto Protocol. When the targets were negotiated, one requirement was that Annex I countries as a group reduce emissions by 5% below the 1990 level. The percentages of individual countries were adjusted upwards and downwards during the negotiations, taking into account national circumstances. For a detailed discussion, see Depledge (2000).

An approach involving the application of equal percentage reductions below a base year, can be easily implemented, since accurate figures on base year emissions are readily available. It is too simplistic, however, as it does not take into account national differences in future emission developments, base year emissions or past efforts, among others.

Using the EU and USA as examples, Figure 2.1 illustrates the implications of this option. Emissions in the USA have increased, up to 2005; consequently, to reach a level that lies 25% below that of 1990, requires the USA to achieve larger reductions than is required of the EU, for which the emissions have decreased since 1990. The figure also shows that the choice of base year is

Table 2.1 Sharing approaches and their strengths and weaknesses – Equal future burden

Equal burden	Strengths	Weaknesses	Representation of efforts	Technical feasibility	Further consideration?
Equal % reduction in emissions, below base year	Simple	Does not take into account past efforts, current starting points and different possible future emissions	Low	High	No
Equal % reduction below a reference scenario	Relatively simple	Requires agreement on a reference scenario Does not take into account past efforts Leads to less stringent reductions for countries that report high baseline emissions.	Medium	Medium	Yes
Proportionality, according to simple criteria for differentiating between reductions below base year	Can consider ability to pay, energy efficiency, equity	Ignores limiting factors (renewable resources, etc.) Leads to high reductions for the high income countries Outcome highly depends on assumptions on weighting factor and scaling factors	Medium	Low	No
Equal marginal abatement costs	Widely used concept	Requires agreement on marginal abatement costs per country Ignores possible changes in lifestyle and behaviour Indicator for the effort of the last reduced tonne, but not for total reductions	Medium	Low	Yes*
Equal total abatement costs per GHG reduced (€/tCO_2 eq)		Requires agreement on reference scenario and marginal abatement costs per country Ignores possible changes in lifestyle and behaviour Indicator for the average effort per tonne but not for the country	Medium	Low	No
Equal total abatement costs per GDP	Richer nations bear more costs	Requires agreement on reference scenario and marginal abatement costs per country Ignores possible changes in lifestyle and behaviour	Medium	Low	Yes
Equal total abatement costs per capita	Most closely mirrors 'future effort'	Requires agreement on reference scenario and marginal abatement costs per country Ignores possible changes in lifestyle and behaviour Less equitable given substantial differences in GDP per capita	High	Low	No**
Equal macroeconomic burden	Theoretically comprehensive	High uncertainty Data and calculation intensive	High	Low	No***

v: The approach is selected, but this case is not analysed in detail. Only the reductions below 1990 levels are presented, see Chapter 4.
*: The approach is selected for further analysis, because it is commonly used, although it does not score well when using the criteria.
**: This approach is not considered further, as it is less equitable given substantial differences in GDP per capita, although it does mirror future effort well.
***: This approach is not considered further, due to the lack of a consistent modelling framework.

important. Choosing 1990 as the base year would factor in past developments and efforts. Using 2005 as the base year would neglect efforts made before that year.

This approach seems to be rather simplistic and does not represent a good measure of comparable effort. Therefore, it will not be considered for further study here, although it does illustrate the need for differentiation between countries, to arrive at comparable efforts.

Table 2.2 Sharing approaches and their strengths and weaknesses – Equal endpoint

Equal endpoint	Strengths	Weaknesses	Representation of efforts	Technical feasibility	Further consideration?
Equal per capita emissions at an endpoint	No reference scenarios needed Simple	Not taking into account national circumstances	Medium	High	Yes
Achieving equal efficiency levels per sector	No reference scenarios needed for production Sectoral consideration allows detailed consideration of mitigation potential Internationally competing industries are treated the same in all countries	Data intensive Efficiency indicators may not be defined for all sectors Efficiency endpoints need to be defined May not allow emission trading Environmental effectiveness uncertain	High	Low	No
Triptych approach	National circumstances are explicitly accommodated Explicitly allows for economic growth at improving efficiency in all countries Aims to put internationally competitive industries on same level	Complexity of the approach requires many decisions and sectoral data, making global application a challenge, and it may be perceived as not being transparent Agreement on required projections of production growth rates for heavy industry and electricity may be difficult	High	Medium	Yes

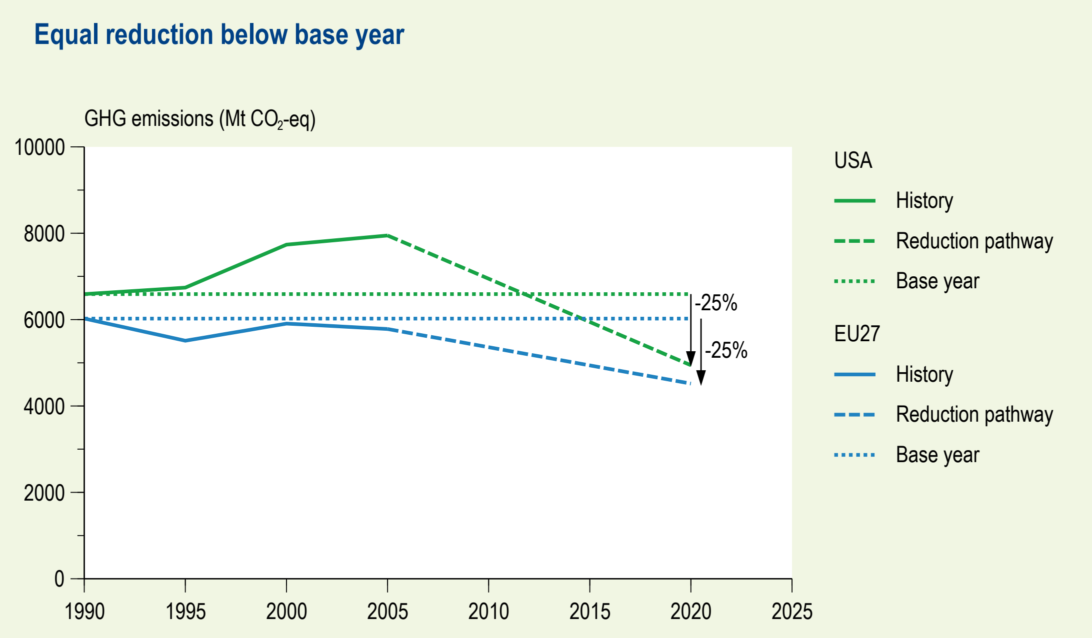


Figure 2.1 Illustrative example of equal reduction below base year (example here: – 25% from 1990 to 2020)

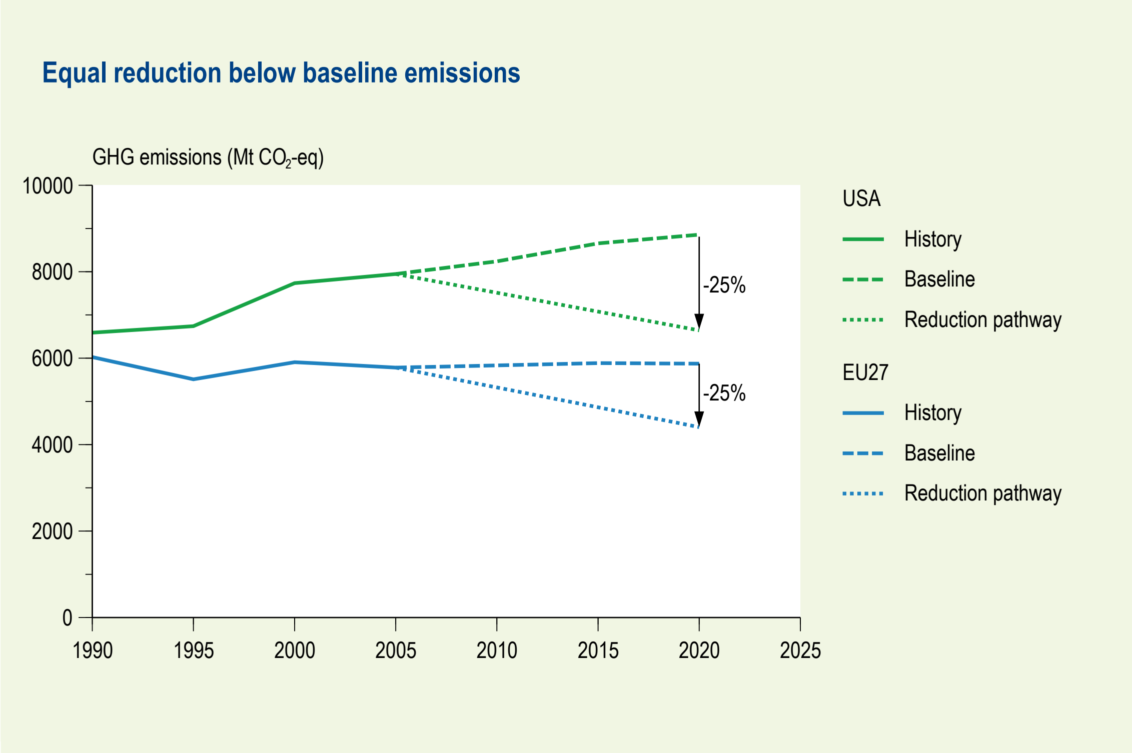


Figure 2.2 Illustrative example of equal reduction, relative to a reference scenario (example here: –25 % from BAU in 2020)

2.1.2 Equal percentage reduction below a reference scenario

An equal percentage reduction below a reference or Business-As-Usual (BAU) scenario is a simple approach for implementing simple relative reductions. Emissions have to be a certain equal percentage below the emission level in a scenario.

The results are highly dependent on the assumed reference scenario, and countries need to agree on the reference scenario chosen. Countries with a higher emission level in their reference scenario, may have to make less of an effort to achieve the reductions (see Figure 2.2). Thus, this provides an incentive for Parties to inflate their reference projections. Such reference scenarios, usually, are the result of often unclear model calculations that depend on the inclusion of various assumptions. Moreover, a reference scenario always will be hypothetical, as it cannot be validated ex post. Reaching agreement on these scenarios, therefore, may be difficult.

In this approach, possible changes in future emissions are estimated within the constraints of the reference scenario, but past efforts are disregarded.

As this approach does account for the impact of trends, such as population, it can be considered to be a relevant representation of effort. In addition, it is relatively simple to implement. Therefore, we will study it in more detail in the following chapters.

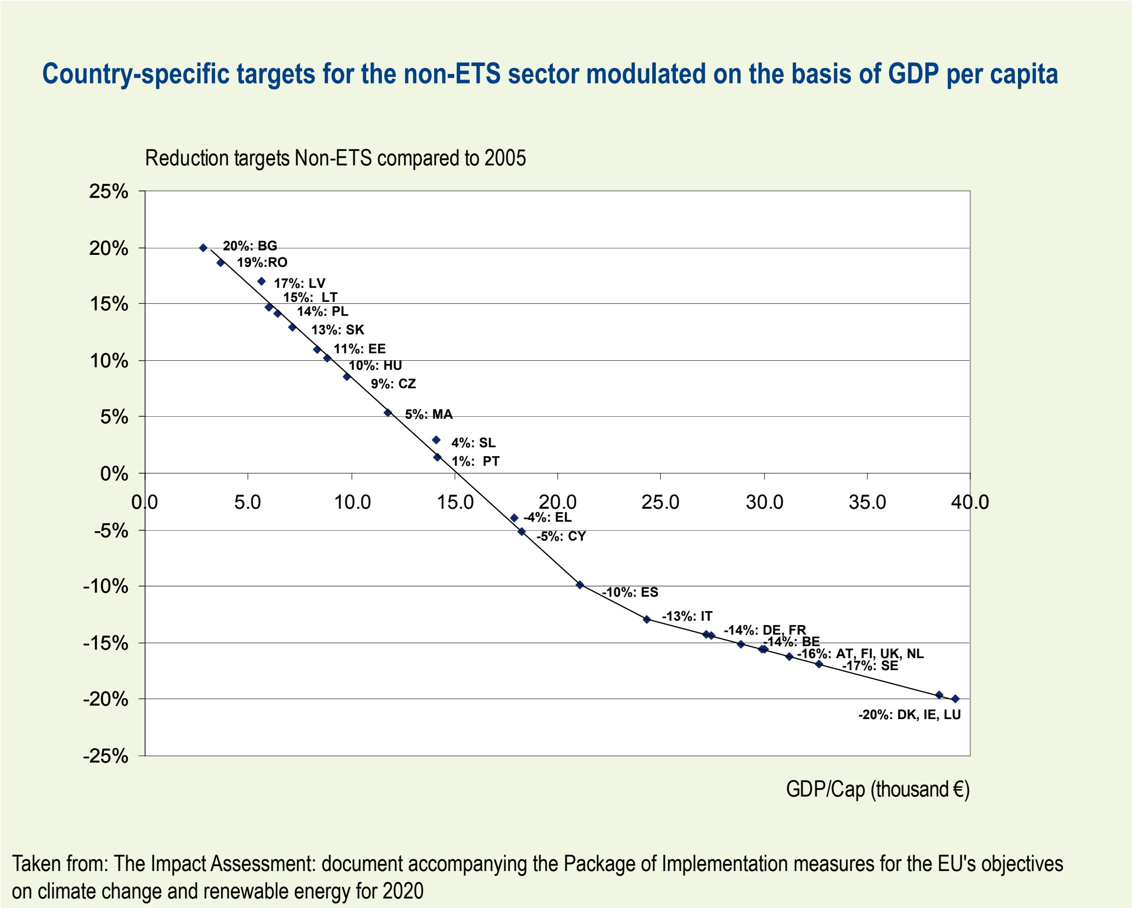


Figure 2.3 Relationship between assigned reductions/allowed increases and GDP per capita in the EU Member States. Source: EC (2008)

2.1.3 Proportional, according to simple criteria for differentiating between reductions

Several options have been proposed for differentiating between percentage reductions below a base year, proportionally per country, using certain simple indicators or criteria. We will discuss two illustrative options here.

The European Commission has proposed that emission reductions within the EU be shared for those sectors not included in the Emissions Trading Scheme, and that this sharing be almost proportional to GDP per capita (EC, 2008). Figure 2.3 shows the required reductions/allowed increases as a function of GDP per capita. This proposal is based on the assumption that the higher the GDP per capita, the more stringent the required reduction percentage. The underlying philosophy is that the 'effort' by the wealthiest country of reducing its emissions by 20%, is comparable to the effort by the least wealthy country of limiting its emission growth to +20%.

Another simple option is a multi-criteria approach, as proposed during the Kyoto Protocol negotiations (see Torvanger and Godal, 2004). It comprises a differentiation between emission reductions, based on a multi-criteria rule containing indicators for energy efficiency (emissions per unit of GDP), equity (emissions per capita) and the ability to pay (GDP per capita). The approach is similar to the one recently taken by the European Commission, but is not only based on GDP per capita, but also on three indicators. Deviation from the assumed overall reduction target for

Annex I countries (such as –25% compared to 1990 levels) depends on the deviation by that country from the group average, for one or more of the indicators.

The formula for the specific country's reduction burden, measured as the relative change in emissions compared to 1990 levels (or 2005 levels) ($R_{country}$), is given as:

$$R_{country} = A.\langle x \frac{\frac{EM_{country}}{GDP_{country}}}{\left(\frac{EM^{base}_{Annex+}}{GDP_{Annex+}}\right)} + y \frac{\frac{EM_{country}}{POP_{country}}}{\left(\frac{EM^{base}_{Annex+}}{POP_{Annex+}}\right)} + z \frac{\frac{GDP_{country}}{POP_{country}}}{\frac{GDP_{Annex+}}{POP_{Annex+}}} \rangle \quad (1)$$

where A is an appropriate scalar, which is typically negative to secure the aggregate total reduction level. POP, GDP and EM represent population, GDP and emissions, respectively. The factors x, y and z are weights that add up to one. These weights can be subject to negotiation, but in our calculations they were equalised to one third. The approach can also be translated into a burden-sharing approach, solely based on per capita income (almost the approach described above), where weights x and y are set to 0 and z becomes 1.

This approach can account for differences in ability to pay, energy efficiency and per capita emissions (equity), but it still ignores a number of limiting factors, such as access to renewable energy resources, climatic differences and historically grown sectoral spreads, among others. However, this approach has been part of the Kyoto negotiations.

In the model analysis, in the next chapter, we have implemented a simple approach that is based on the approach presented above using GDP per capita. First, each country is to reduce emissions below its 2005 level by the same percentage (here 20% below 1990 level, which is 21.6% below 2005 level). Second, each country also has to reduce or increase the percentage that its GDP/capita is above or below that of the Annex I average, times a proportionality factor (here chosen to be 0.3 for illustrative purposes). The resulting reductions below the 2005 level, are shown in Figure 2.4. This model leads to high reductions, compared to the 2005 emission levels, for the high-income countries of the USA and Canada. Conversely, these countries benefit from the choice of 2005, for the reference year, since their emissions have shown an increase in the period from 1990 to 2005.

2.1.4 Equal marginal abatement costs

The first approach that uses costs would require countries to reduce emissions up to a level at which an equal MAC for the reduction of a unit of emissions (i.e. tCO_2eq) is reached. For example, all countries would implement all mitigation options up to €50/tCO_2-eq. If MAC curves for all countries were to be available, an abatement cost level could be chosen that would correspond to a certain targeted total amount of emissions. Figure 2.6 shows how the emissions reductions (points A and B) for individual countries can be derived, at the intersection of a country MAC curve and the line representing equal MACs. [1]

1 Some models would implement this option by setting an equal carbon tax.

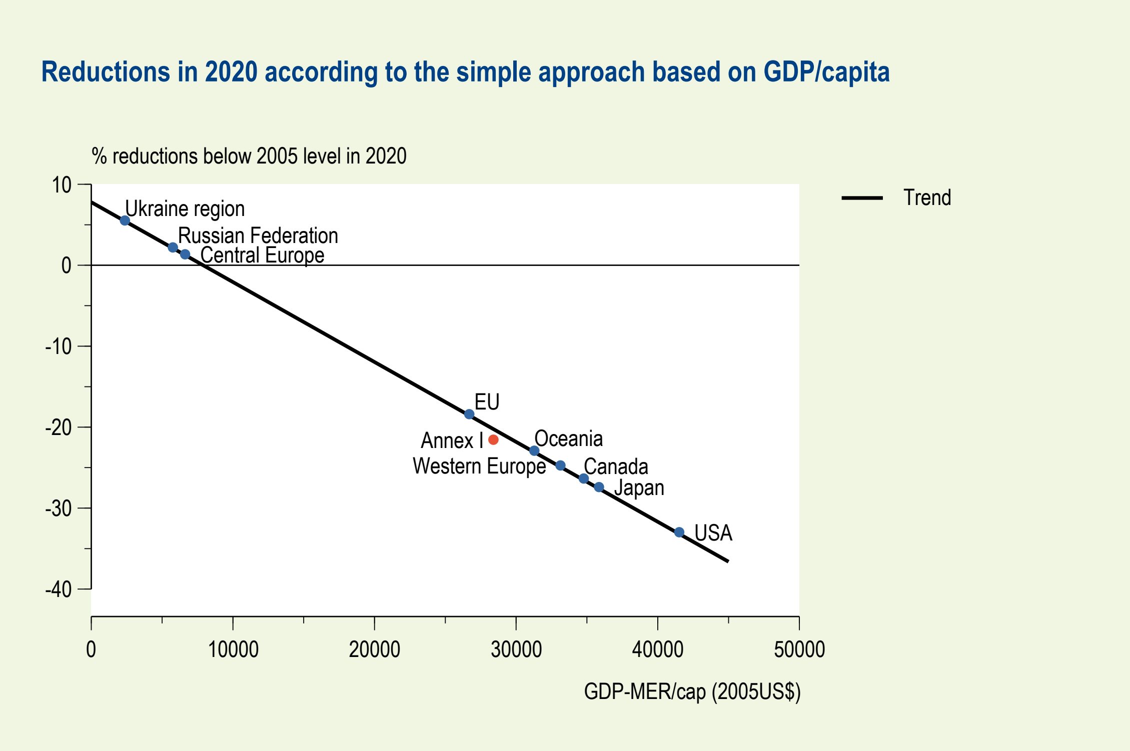


Figure 2.4 Reductions according to the simple approach based on GDP/capita, with Annex I as a group reducing 20% below 1990, 21.6% below 2005.

As shown in Figure 2.6, equal MACs indicate an equal effort, only for the last saved tonne of GHGs, but they do not account for the total cost of reductions including possible gains from initial reductions. In our example in Figure 2.6, country B could exploit its reduction potential at a negative cost and for some measures at a moderate cost. The total (the area under the curve) would result in a gain, not a cost. Conversely, country A would have significant total costs, following this approach. If the shape of the curves were to be relatively similar for all countries, to assume equal marginal costs would be a fair representation of total costs. The approach requires a good knowledge of – and agreement on – the MAC curves for each country, which are used both to determine the equal MACs based on the targeted amount of emissions, and to calculate the contribution by each individual country. However, any agreement on these costs can be difficult.

Calculating these costs means having to consider many different aspects, such as population growth, renewable energy endowments and the geographical conditions of the countries, many of which are not within the control of the government of these countries. It can be assumed that most countries agree that these factors should be taken into consideration when efforts are being compared.

Cost calculations may also take historical efforts into account, as some countries may have less inexpensive mitigation potential than others. However, cost calculations are also dependent on assumptions on the future lifestyle and behaviour in a reference scenario, which can raise (marginal) mitigation costs and, to a certain extent, *can* be controlled by the countries themselves.

Box 1: Abatement costs

Several approaches consider estimations of the costs of achieving emissions reductions. For these approaches, we only consider abatement costs and disregard all other costs. In this context, abatement costs only represent the direct cost effects, based on marginal abatement costs (MAC) curves, but not on the various rebound effects via the economy or impacts of carbon leakage. Research and development costs are not taken into account, because of the uncertainties surrounding the causality of the resulting emission reductions. Adaptation funding is a separate issue, which should not be mixed with abatement, and the calculation of adaptation costs is also more difficult than of abatement costs. Finally, abatement benefits, such as reduced climate damage due to reducing GHG emissions, are not included.

It is important to note that there are different methods for calculating the costs of climate policy. On the one hand, (top-down) general equilibrium models are used to assess the macroeconomic changes resulting from climate policy (reported as consumption or welfare losses); on the other hand, system engineering partial (bottom-up) equilibrium models are used to estimate the increase in energy system costs or abatement costs, as we do here. Both methods have their strengths and weaknesses. The strength of the abatement-costs approach is that it is relatively simple and flexible, and it focuses on the direct cost factor – additional costs for energy and abatement technology – which is also a good proxy for the total direct costs of climate policy. Macroeconomic costs are more comprehensive (as they also capture indirect effects within the economy) but, usually, much less detailed in their technical representation, while the economic feedbacks of direct mitigation costs are much more uncertain. In fact, many of the factors not included in abatement-costs approaches (such as the impact of various investment patterns and recycling of tax revenues) are examples of such uncertainties and, in various macroeconomic models, they can lead to both higher and lower overall costs, depending on the model assumptions. In conclusion, macroeconomic costs are more comprehensive – but also more uncertain – and abatement costs still form a good proxy for the total direct costs of climate policy.

Marginal abatement cost curves are a way of graphically representing costs that occur when emissions are being reduced. Two illustrative examples are given in Figure 2.9. Moving from left to right, measures are added that reduce emissions, ordered by increasing price per tonne of CO_2 reduced. The first measures taken are those which are the most cost effective, that is, those with even, negative costs. For these measures, the initial investments are usually overcompensated by reduced energy costs during the operation. A movement to the right implies the addition of more and more mitigation measures and, consequently, the increasing reduction in emissions.

The cost curves applied for reductions in a particular year – for example in 2020 – may be different for other years, as the reference point changes, and different assumptions on mitigation options are made.

The shape of the curve differs, depending on the economic structure of the country being assessed. One country may have large energy efficiency potential at negative costs, for example, based on an old building stock and high heating requirements. Another

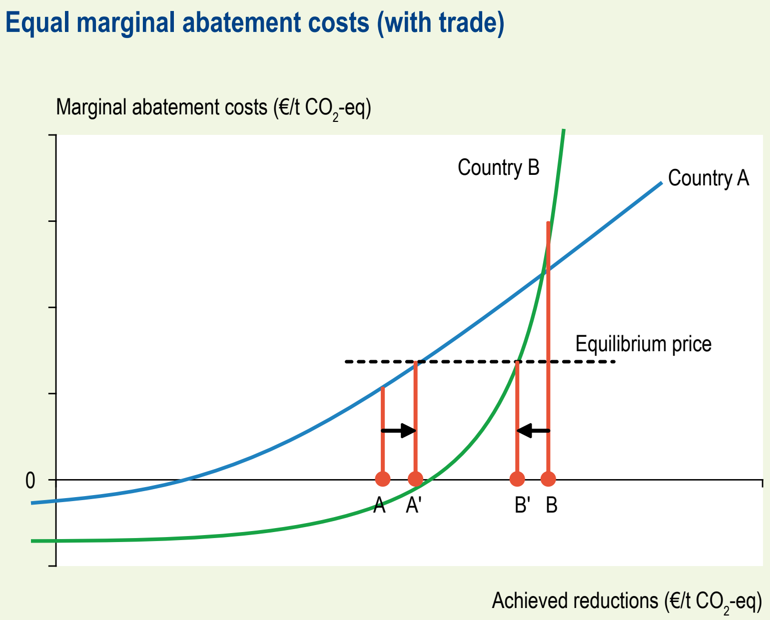


Figure 2.5 Illustrative marginal abatement costs (MACs) for two countries. Reduction requirements (A, B) and emission outcomes after trading (A', B')

country may have less of this efficiency potential, because its climate does not require extensive heating or because it is already more efficient.

The calculation of MAC curves can result in differently shaped curves, depending on the way they are calculated (see also Hoogwijk et al., 2008). Many assumptions are necessary to calculate a MAC curve, such as an emission reference scenario from which to reduce emissions, assumptions on energy prices and discount rates, assumptions on the costs of technologies and the current application rates of these technologies. As with reference scenarios, it may be difficult to agree on one curve per country.

If international emission trading is allowed, total costs result from two elements: (1) emission reduction costs up to a certain (market equilibrium) price and (2) the costs of or revenues from purchasing or selling allowances. In the illustrative case in Figure 2.9, countries A and B have reduction obligation A and B. Without trading, country B would have to use mitigation options that are associated with a relatively high price tag. With trading and assuming perfect market conditions, country A would reduce a bit more up to point A' and then sell the allowances to country B, which, in turn, would reduce a bit less up to point B'. Country A would sell all its additional allowances at the equilibrium price, although its costs for reducing are lower. It would therefore make a profit from trading. In some cases, these profits from trading can outweigh the costs of reducing emissions domestically.

For the quantification of costs, we usually assume costs to be defined as the abatement costs, that is, abatement costs plus emission credit sales revenues, minus emission credit purchase costs, which are calculated with costs models [for example, as with the FAIR model in this report (Den Elzen and Lucas, 2005)].

A sharing of efforts on the basis of equal marginal costs would contribute towards implementing reductions where they are most cost effective – that is, where they would be economically ideal. It also would provide a level playing field for industrial sectors across countries. However, a cost-effective distribution of mitigation efforts can also result in unfair burden sharing between countries, such as when the largest mitigation potential occurs in less affluent countries. A cost-effective allocation of mitigation measures can also be reached by making use of emission trading (with equal marginal costs as an *output* of the carbon market, rather than as an *input* method to sharing efforts). In an ideal market the marginal costs would be equalised through trading, irrespective of the initial targets (see Figure 2.5).

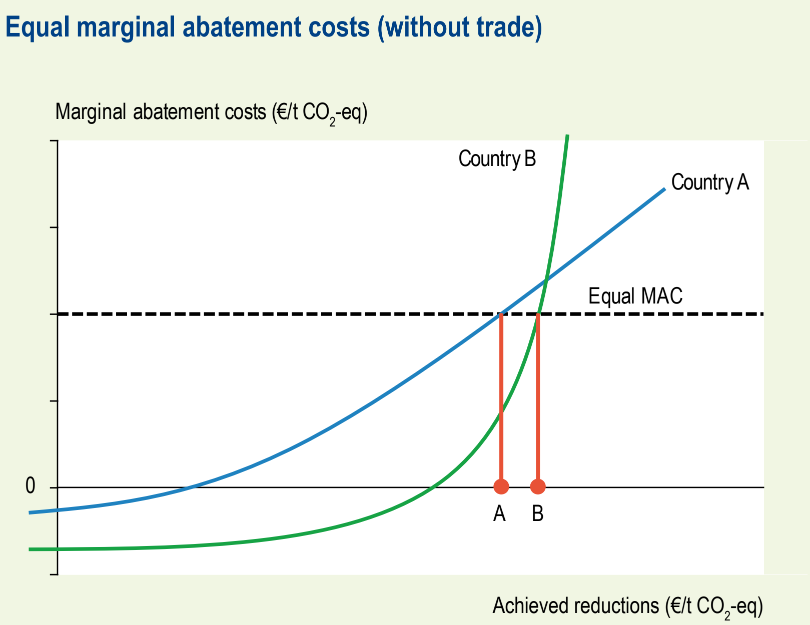


Figure 2.6 Equal marginal abatement costs (MACs)

Nevertheless, the concepts of equal marginal costs is still a widely proposed concept, and for this reason it will be examined in more detail in our analysis, even though it does not score well on our indicators.

2.1.5 Equal total abatement costs per unit of GHG reduced

Yet another approach would be to ensure that the total costs per tonne of GHG emissions reduced, are the same for all countries. Figure 2.7 shows how total (cumulative) abatement costs, in general, represent a superior measure of 'effort' because possible gains and differences in the cost structure are taken into account. In our example, country B would have to reduce its GHG emissions by much more, until the average abatement costs per tCO_2eq would be equal. A country with many low-cost options would have to do more. If the shapes of the curves were relatively similar for all countries, the use of equal average costs could be a fair representation of total costs.

Similar to the equal MACs approach discussed above, a knowledge of and agreement on the MAC curves for individual countries is required. Integration of the MAC curves (blue and green areas in Figure 2.7) leads to the total abatement cost. A certain equal total abatement costs per unit GHG reduced (€/tCO_2eq) can be set, from which the reduction levels for individual countries can be derived by optimisation (points A and B).

In this approach, all other advantages and disadvantages are the same as those in the equal MACs approach.

The approach of equal total abatement costs per unit of GHG reduced requires an equal average effort per tonne of GHG reduced, but it disregards the specific situation in each country, such as the size of its population or economy. For these reasons, we do not consider it for further discussion in this report.

2.1.6 Equal total abatement costs per GDP

To bring a country's costs into perspective, the total abatement costs (blue and green areas in Figure 2.7) can be applied in relation to the size of that country's economy (GDP). One can aim for the same abatement costs for all countries as a percentage of GDP (Rose et al., 1998; Babiker and Eckaus, 2002). Countries can be required to spend a certain equal percentage of the GDP, of a given year, on the abatement of GHG emissions [similar to the Official Development Assistance (ODA) standard of 0.7%].This leads to higher absolute costs for richer nations.

It would be possible to extend this approach to a consideration of the net present values of total abatement costs and GDP over the time period from a base year (for example 2005) to a target year. Nevertheless, this will not be considered here, any further, because of the difficulties surrounding how to discount future costs

The GDP can be measured in market exchange rates (MER) or in purchase power parities (PPP). Here, we use regional GDP in MER, as we are considering the costs for a country, relative to its GDP, including international trade of emission credits, which will be paid in local currencies, but based on market exchange rates.

Equal total abatement costs (without trade)

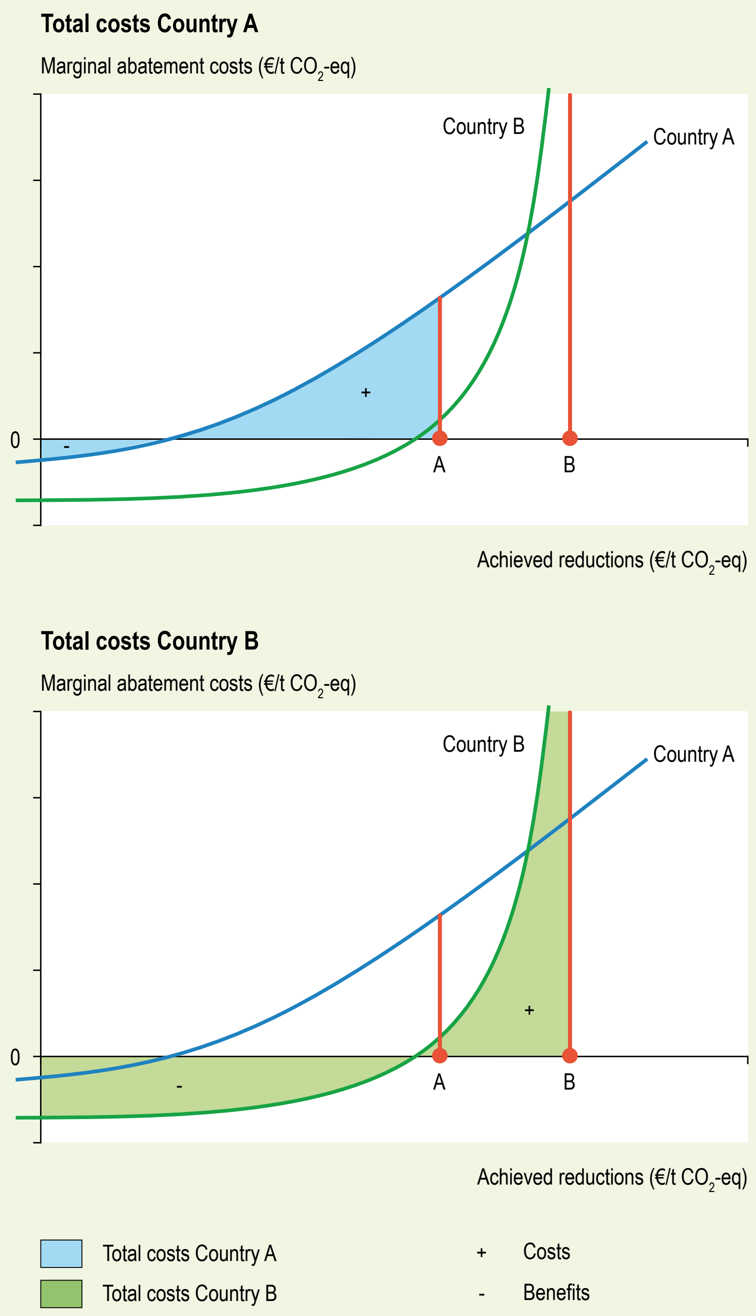


Figure 2.7 Equal total abatement costs per GHG reduced (before trading)

If – in a future emission trading regime – trading and project-based mechanisms would be allowed, a country's mitigation costs could include the costs of purchasing allowances, if these are less high than domestic reduction costs or than the revenues of selling allowances. Therefore, we have included trading in the analysis of costs presented in all the following chapters. For illustrative purposes, we also provide a case in which we assume that trading is not allowed, to show the differences between the countries more clearly.

Analogous to the approaches outlined above, the MAC curves used are derived from costs based on current lifestyle, behaviour, etc. Consequently, possible future changes in these aspects are ignored, as is the level of future economic development. As this is a widely used concept, we will assess it further in our analysis.

2.1.7 Equal total abatement costs per capita

In this approach, the total abatement costs (blue and green areas in Figure 2.7) are applied in relation to the size of the population of countries. An equal effort (in terms of costs) per person is required, leading to proportional, absolute GHG reduction goals for each country.

As in the approaches outlined above, an agreement on the shapes of the MAC curves will have to be reached.

This approach represents the concept of 'comparable effort' most closely, since an equal monetary contribution is expected from all inhabitants, of each country. However, this definition of effort does not consider differences in wealth between countries – that is, the ease with which a population could contribute to the equal monetary effort. Therefore, we have not considered it in the following analysis.

2.1.8 Equal macroeconomic burden

Top-down general equilibrium models can be used to extend the above approaches in such a way that the total macroeconomic changes can be considered, resulting from emission reductions, not just the total abatement costs. Approaches based on macroeconomic costs are more comprehensive (as they also capture indirect effects within the economy), but they are also much more uncertain. In fact, the macroeconomic effects of a country's emission reductions may be vastly different, depending on which kind of policies are chosen to achieve them.

Macroeconomic approaches will not be considered further, in this report, due to the lack of a macroeconomic modelling framework consistent with the modelling of abatement costs. However, studies have shown that pure abatement costs form a relatively good proxy for the total macroeconomic impacts on developed countries.

2.2 Equal endpoint

This section describes alternative approaches that look at the efforts needed for each country to reach the *same state, at a certain time in the future*. In contrast to the options associated with the conceptual approach of an equal burden, those associated with an equal endpoint do not assume equal future effort.

The equal end point approaches assume that all countries undertake their own individual efforts to reach a similar level of, for example, per capita emissions or efficiencies in the future. This implies that inefficient countries have to reduce more since they pollute more, compared to efficient countries that may have undertaken efforts in the past. These approaches could also deal with the differences in lifestyles.

The major advantages include:
- The calculation of a reference scenario is not required. The reference development is irrelevant in this approach. The approach focuses on the current situation and procedure used to reach the endpoint. Critical elements of the approach are reaching an agreement on the current situation and on a common future endpoint, both of which are easier to agree on, than defining a hypothetical future development,
- Actions in the past are acknowledged. Countries that have made efforts in the past to improve their efficiency now have to undertake relatively less effort.

The disadvantages include:
- It may not be possible to adequately deal with any different national circumstances. Emission intensities may not (only) be related to efficiencies or lifestyles, but also to different national circumstances, such as the access to renewable energy resources. One country might be able to make use of hydropower, while another might not. The efficiency indicators have to take this into account.
- Defining current efficiency levels can be difficult and data intensive. It may be difficult to find an appropriate indicator for some sectors, such as for emissions from land use and land-use changes and forestry (LULUCF). The process involved in calculating efficiencies may be technically difficult due to different national practices and different boundaries of the statistics, among others.

In the following sections, we describe three approaches that are based on the concept of an equal endpoint.
- Equal per capita emissions
- Achieving equal efficiency levels per sector
- Triptych approach

2.2.1 Equal per capita emissions at a future endpoint

This convergence approach requires countries to reach equal levels of per capita emissions, by a predefined target year. It assumes that, in the long term, living standards and technology availability will be the same for all countries and that, therefore, the need for equal per capita emissions increases in time.

To reduce overall emissions, the average per capita emissions need to be reduced, requiring strong cuts by above-average emitters (see Figure 2.8). Consequently, countries that have already taken action in the past or have followed a relatively sustainable development path, are rewarded in this approach.

An advantage of the approach is that it does not require reference scenarios or MAC curves (apart from population projections, if the approach is to be translated into fixed emission targets). It is also simple and easy to communicate. However, it does ignore limiting factors, such as the availability of renewable energy resources, climatic differences and historically grown sectoral spreads, among others.

2.2.2 Achieving equal efficiency levels per sector

A different approach would be to require countries to reach equal future sectoral efficiency levels (being lower than the current average), instead of equal per capita emission levels. Coun-

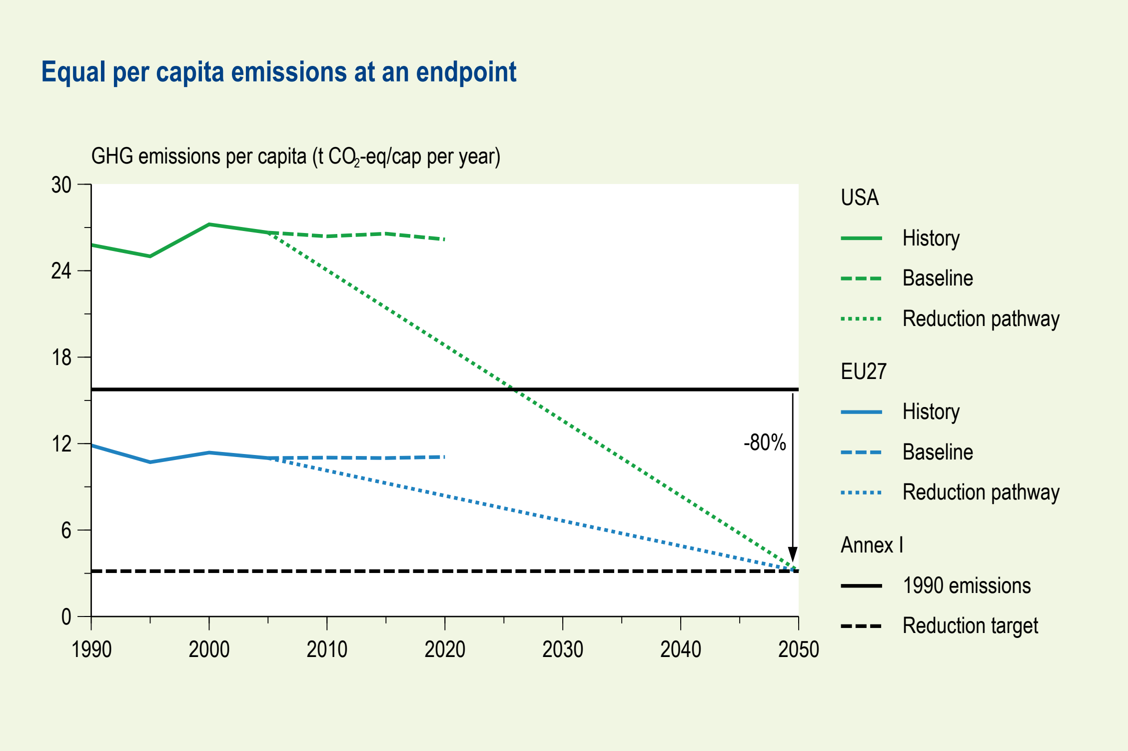


Figure 2.8 Illustrative example of equal per capita emissions by a set target year (example here: Annex I countries reduce 80% of per capita emissions, between 1990 and 2050)

tries would be required to reach the level of efficiency and not an absolute emission level. Targets, such as *xt*CO_2 *per tonne of cement,* are set for different sectors.

Sectoral rules could include the following:

- Emissions per kilowatt hour of electricity are reduced by a percentage (adjustments are made to credit the use of combined heat and power)
- Emission intensity converges in the sectors for cement, iron and steel, pulp and paper, and chemicals.
- Passenger-car emissions per kilometre driven converge
- Emissions per square metre of floor space converge

Advantages include:

- *No reference* production level is needed, as countries need to reach the efficiency level regardless of actual production.
- *Detailed mitigation potential* of a country is considered on a sectoral level.
- Countries are *rewarded for early action*, while countries with relatively low sectoral efficiency need to make an extra effort to reach the equal level of the target year.
- *Structural differences* between countries are acknowledged and do not lead to an extra burden.
- *International competitive sectors* are treated equally in all countries.
- *There is more transparency* than in the approach using cost calculations.

Disadvantages of the approach include
- *Data requirements* are comparatively extensive for this approach. Efficiency indicators and benchmarks have to be defined for all subsectors. The approach requires detailed definitions of the boundaries between subsectors, which could be difficult for some sectors. It also requires a detailed analysis of efficiencies in and emissions from a large number of subsectors, in all countries (see also Baron et al., 2007). These data are currently not available, but first efforts have been made (UNFCCC, 2007). A mechanism would be required which ensures that the detailed data are collected in a comparable manner, across all countries. Furthermore, sectoral efficiency endpoints need to be agreed on, so that emission reductions add up to the overall reduction level envisaged. Given these disadvantages, the approach is still more transparent than that of the costs estimates.
- *Cost effectiveness* may be lower: the effectiveness could differ per sector, as the sectoral targets are set unequally, requiring high costs in some sectors and low costs in others. However, emission trading would eliminate this concern. Efficiency loss can be minimised by using cost-effectiveness criteria to guide the level of emission reductions, established for the targeted sector(s).
- *Limiting the approach to a few selected sectors* will ignore emissions from sectors that may contribute significantly to national emissions. Omitting specific energy-intensive or high-growth sectors may make it more difficult to achieve global GHG stabilisation levels and will also increase overall costs.

2.2.3 Triptych approach

The Triptych approach[2)] is a method for allocating future GHG emission reductions to countries, based on (1) converging criteria for meeting certain technological standards or targets at the sector level, and on (2) accounting for structural differences. As such, it presents a combination of the two previous approaches. The Triptych methodology calculates emission allowances for the various sectors, which are summed up to obtain a national target. Consequently, only the national targets are binding, not the individual sectoral targets. This approach provides countries with a certain degree of flexibility in their choice of cost-effective emission reduction strategy.

The emissions from six sectors are treated differently. For 'electricity production', a growth in the physical production is assumed together with a convergence of emissions per kilowatt hour and per fuel, and a decrease is assumed in coal and oil percentages in the fuel mix, as well as an electricity consumption efficiency improvement (demand). For the 'industrial production' sector, a growth in production is assumed, combined with a calculated improvement in energy efficiency, based on a convergence in the Energy Efficiency Index (EEI). For example, Figure 2.9 shows a scenario of a converging EEI, where '1' is the current, best available technology, and countries converge to a lower EEI. For the 'domestic' sectors (transport and building), convergence of per capita emissions is assumed, which takes into account the converging living standard within the countries. For the remaining sectors 'fossil fuel production', 'agriculture' and 'waste', similar rules for reduction and convergence are applied.

The Triptych approach builds on the philosophy that countries reach an equal state by an agreed target year, but it defines this equal state not simply in terms of per capita emissions, but also in

2 This approach was originally developed at the University of Utrecht (Blok et al., 1997) and it has been updated and revised subsequently (Den Elzen et al., 2008a; Höhne et al., 2005).

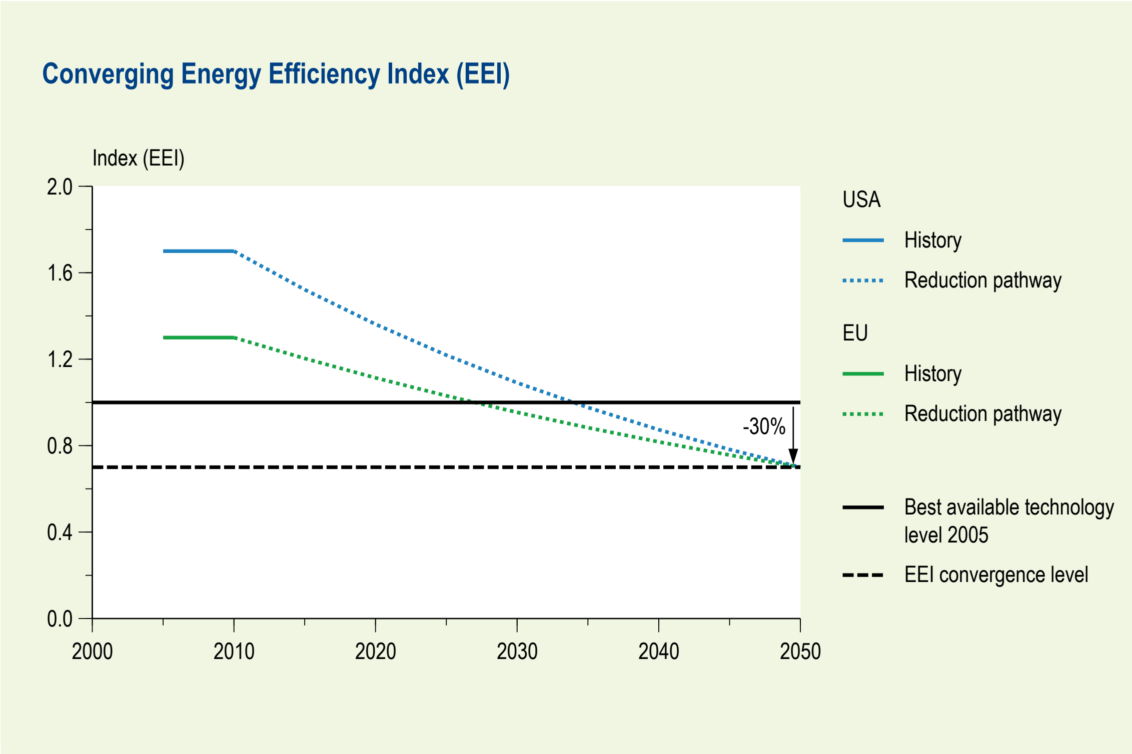


Figure 2.9 Illustrative example of a converging Energy Efficiency Index (EEI) in the Triptych approach. Source: adapted from Den Elzen et al. (2008a)

terms of emissions per kilowatt hour in the electricity sector, in energy efficiency in the industry sector and in per capita emissions in transport and building sectors. As such, it is better suited for taking the economic structure of a country into account. For example, countries largely dependant on the energy-intensive exporting industry need to make this industry efficient, but they are not penalised for the sheer size of the industry, whereas under the approach of converging per capita emissions, this would definitely be the case.

The major disadvantage of the approach is that it is complex and the data requirements are comparatively high. Countries have to agree on the Triptych parameters that are applicable to all countries, such as the convergence level of the domestic sectors and changes in the fuel mix for electricity generation. Furthermore, the approach requires a set of scenarios, including the expected growth rates of production in the various sectors, which can be provided by the countries themselves. There is, however, an incentive to provide high-growth scenarios.

The Triptych approach been successfully applied (on the EU15 level) as a basis for negotiating the Kyoto targets at an EU Member State level.

3 Methodology

3.1 The FAIR model

We used the FAIR 2.2 model for our more detailed analyses of the different approaches used to determine 'comparable efforts'. The FAIR model is designed for the quantitative exploration of the cost and emission reduction for a range of alternative climate regimes. It is intended for differentiating between future commitments compatible with meeting long-term climate targets, such as concentration stabilisation targets (Den Elzen and Lucas, 2005; Den Elzen and Van Vuuren, 2007; Den Elzen et al., 2008b). The emission reductions, expressed in emission allowances (before emission trading), are calculated as CO_2-equivalent emissions. These include the anthropogenic emissions of six Kyoto GHGs [fossil carbon dioxide (CO_2), methane (CH_4), nitrogen dioxide (N_2O), hydrofluorocarbons (HFCs), perfluorocompounds (PFCs), sulphur hexafluoride (SF_6); using the 100-year global warming potentials (GWPs) of IPCC, 2001)], but excluding CO_2 emissions from land use, land-use change and forestry (LULUCF).

3.1.1 Abatement costs

Costs are calculated on the basis of MAC curves, which indicate the costs of reducing an additional emission unit. These curves only capture the direct costs of abatement actions and do not take into account the costs related to a change in fuel trade or macroeconomic impacts (including sectoral changes or trade impacts). In other words, there is no direct link with macroeconomic indicators, such as GDP loss or other measures of income or utility loss. The regional abatement costs are calculated by making full use of the flexible Kyoto mechanisms, such as emission trading and the distribution of reductions over the different gases and sources (Den Elzen et al., 2005). The model uses aggregated permit demand-and-supply curves derived from (aggregated) MAC curves for the different regions, gases and sources (see below).

The permit demand-and-supply curves are used to determine the equilibrium permit price (hereafter: 'permit price') on the international trading market, its buyers and sellers and the resulting domestic and external abatements for each region. The costs are in US dollars (2005).

We assume that emissions can be traded freely between all of the regions that have accepted emission reduction targets (although we do include transaction costs). The transaction costs associated with the use of the Kyoto mechanisms are assumed to consist of a constant US$0.55 per tonne CO_2eq emissions plus 2% of the total costs (Michaelowa et al., 2003; Michaelowa and Jotzo, 2005). Only a limited amount of the abatement potential is assumed to be operationally available on the market, because of the project basis of the Clean Development Mechanism (CDM) (trading between participating and non-participating regions) and implementation barriers, such as properly functioning institutions and project size (small projects are economically less viable due to the relatively high transaction costs). Consistent with earlier studies (Criqui, 2002; Den Elzen and De Moor, 2002; Jotzo and Michaelowa, 2002), availability here is set at 10% of the theoretical maximum by 2010, and it is assumed that this will increase, linearly, to 30% by 2030, remaining constant thereafter (Den Elzen et al., 2008b). The model calculations allow no banking and/or borrowing in future commitment periods. Further, it is assumed that all banked excess emission allowances during the first commitment period (2008 to 2012) are fully used in the second commitment period (2013 to 2018) and, therefore, do not play a role in the carbon market, by 2020. Future excess emission allowances are avoided by stringent reduction, by 2020, for all Annex I and participating non-Annex I countries.

3.1.2 Baseline emissions and MAC curves

The model uses the baseline emission scenarios from the integrated climate assessment model IMAGE 2.3 (Bouwman et al., 2006) [1], including the energy model TIMER 2.0 (Van Vuuren et al., 2006). [2] Furthermore, the IMAGE model provides the MAC curves for energy-related CO_2 emissions, determined with the TIMER 2.0 (Van Vuuren et al., 2007) energy model, by imposing a carbon tax and recording the induced reduction in CO_2 emissions, taking into account technological developments, learning effects and system inertia. The carbon tax leads to the use of biofuels, renewable energy or less carbon-intensive fuels and technologies and efficiency. As a result, CO_2 emissions will be decreased. [3] For a detailed overview of the MAC curves, we refer to the following studies (Den Elzen and Van Vuuren, 2007; Den Elzen et al., 2007b; Den Elzen et al., 2008b). The IMAGE model also provides the MAC curves for carbon plantations (Strengers et al., 2008). MAC curves from the Energy Modelling Forum (EMF)-21 project (Weyant et al., 2006) were used for non-CO_2 GHG emissions. These EMF curves have been made consistent with the baselines used here and made time-dependent, to account for technology change and removal of implementation barriers (Lucas et al., 2007). In addition to these carbon credits from carbon plantations, the model also includes carbon credits from forest management, based on a conservative, low estimate from our earlier study about 160 MtC (Den Elzen and De Moor, 2002; Van Vuuren et al., 2003), which remains constant in the future. The model does not include MAC curves for reduction potential and costs of avoiding deforestation.

3.1.3 Updates of our calculations

For the analysis of this report we used version 2.2 of the FAIR model. This version differs from version 2.1, which is extensively described in Den Elzen et al. (2007b , 2008b), with respect to the following three aspects:

1. *Extension towards 26 regions* - All models (IMAGE, FAIR and TIMER) operate on the scale of 26 regions (see Figure 3.1), with the inclusion of a larger number of individual countries (instead of 17 regions) [4]. This expansion of the model is a major step forward, as this allows burden-sharing and cost calculations to be performed for individual countries, using consistent and accurate data of baseline emission scenarios and marginal abatement costs at the level of major countries, such as Turkey, Russian Federation, South Africa and China (excluding Korea).

1 The IMAGE 2.3 integrated assessment model consists of a set of linked models that together describe the long-term dynamics of global environmental change, such as agriculture and energy use, atmospheric emissions of GHGs and air pollutants, climate change, land-use change (including the impacts of bio-energy and carbon plantations) and environmental impacts (Bouwman et al., 2006).

2 The global energy model TIMER, as part of IMAGE, describes the primary and secondary demand and production of energy, and the related emissions of GHGs, on a regional scale (26 world regions) (Van Vuuren et al., 2006). The model describes the investments in, and the use of, different types of energy options influenced by technology development (learning-by-doing) and resource depletion. It calculates regional energy consumption, energy-efficiency improvements, fuel substitution and the supply and trade of fossil fuels and the application of renewable energy technologies as well as of carbon capture and storage.

3 To capture some of the important dynamics here, two different tax profiles were used to explore the level of emission reduction in TIMER (in the 'response year') (see Den Elzen et al., 2007b): one assumes a linear increase in the carbon tax value of 2010 in the response year (linear tax), and one reaches the maximum value 30 years earlier (block tax). The two sets of time- and path-dependent response curves for various carbon tax levels are used in the FAIR model as MAC curves. A combination of the linear-tax and block-tax MAC curves is made, depending on the trajectory of the calculated actual carbon tax (international permit price).

4 More specifically, eight Annex I regions: Canada, USA, Western Europe, Central Europe, Ukraine region, Russian Federation, Japan and Oceania (Australia and New-Zealand); Eighteen Non-Annex I regions: Mexico, remainder of (Rest) Central America, Brazil, remainder of (Rest) South America, northern Africa, western Africa, Eastern Africa, South Africa, Kazakhstan, Middle East, Turkey, India, Korea region, China region, Mekong region, Indonesia region, remainder of (Rest) Southern Asia and remainder of (Rest) southern Africa.

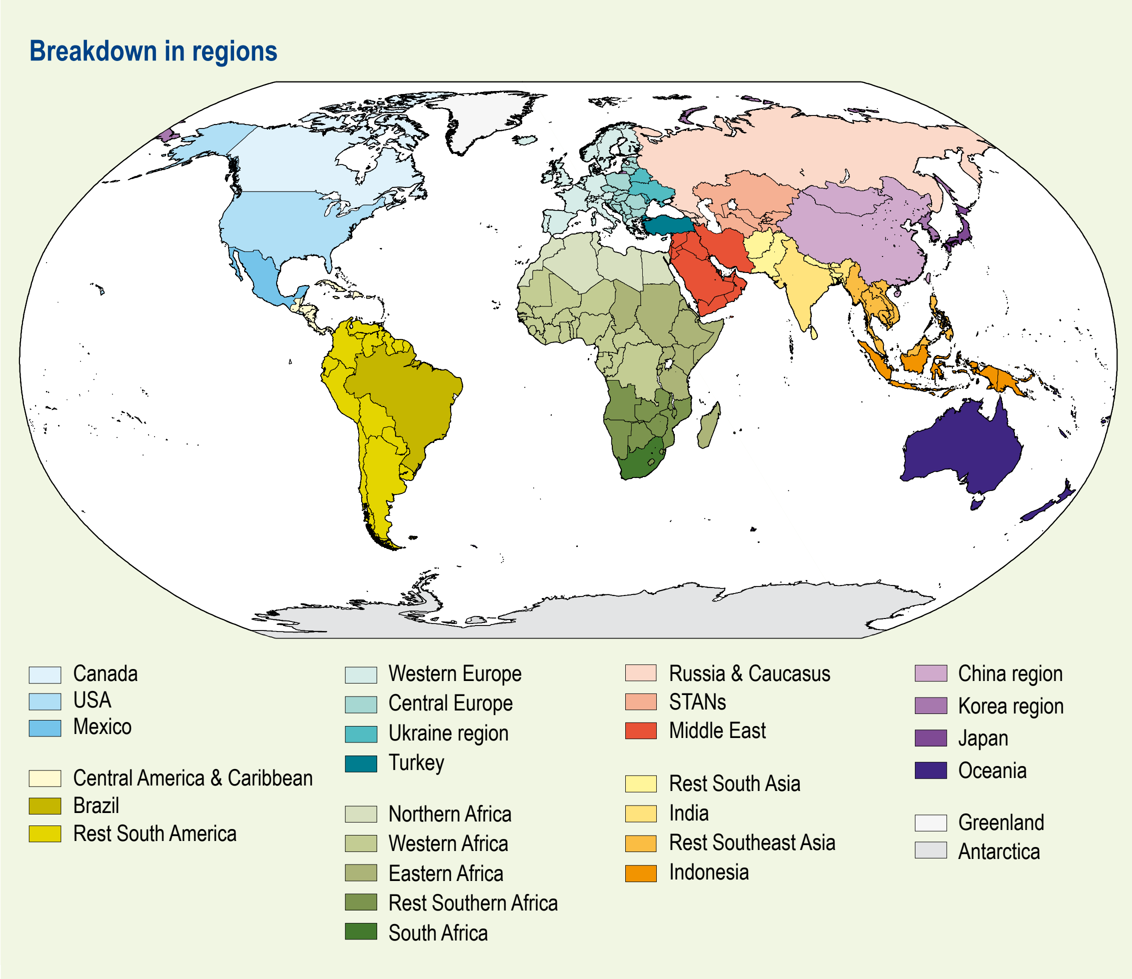


Figure 3.1 Map of regions used in the FAIR 2.2 model

For this study, we focused on the Annex I countries or regions: Canada, USA, EU (Central Europe and Western Europe, including the non-EU countries Croatia, Norway, Switzerland), Russian Federation, Japan, Oceania (Australia and New Zealand) and Ukraine region (Ukraine and Belarus). In the calculations, we assume that Turkey is not part of the Annex I regions and, therefore, does not participate in the allocation of the overall Annex I reduction target.

2. *Updated reference scenario* – We used the recently developed reference scenario, developed within the ADAM project (Van Vuuren et al., 2008, in preparation), which is an elaboration of the reference scenario World Energy Technology Outlook (WETO) (Lapillonne et al., 2007) (as described below).
3. POLES MAC *curves* – For alternative cost calculations, we also included the MAC curves and baseline emission scenarios derived from the energy model POLES[5] (Criqui et al., 1999). This baseline emission scenario is consistent with the one used for our default calculations from IMAGE/TIMER, as this is the common POLES-IMAGE baseline developed for the ADAM project (Van Vuuren et al., 2008, in preparation), constructed by combining and harmonising the reference scenarios of the POLES and IMAGE model.

5 The POLES model is a world simulation model for the energy sector. It works in a year-by-year recursive simulation and partial equilibrium framework, with endogenous international energy prices and lagged adjustments of supply and demand by world region. It has been used for policy analyses by EU-DGs Research, Environment and TREN and by the French Ministry of Environment.

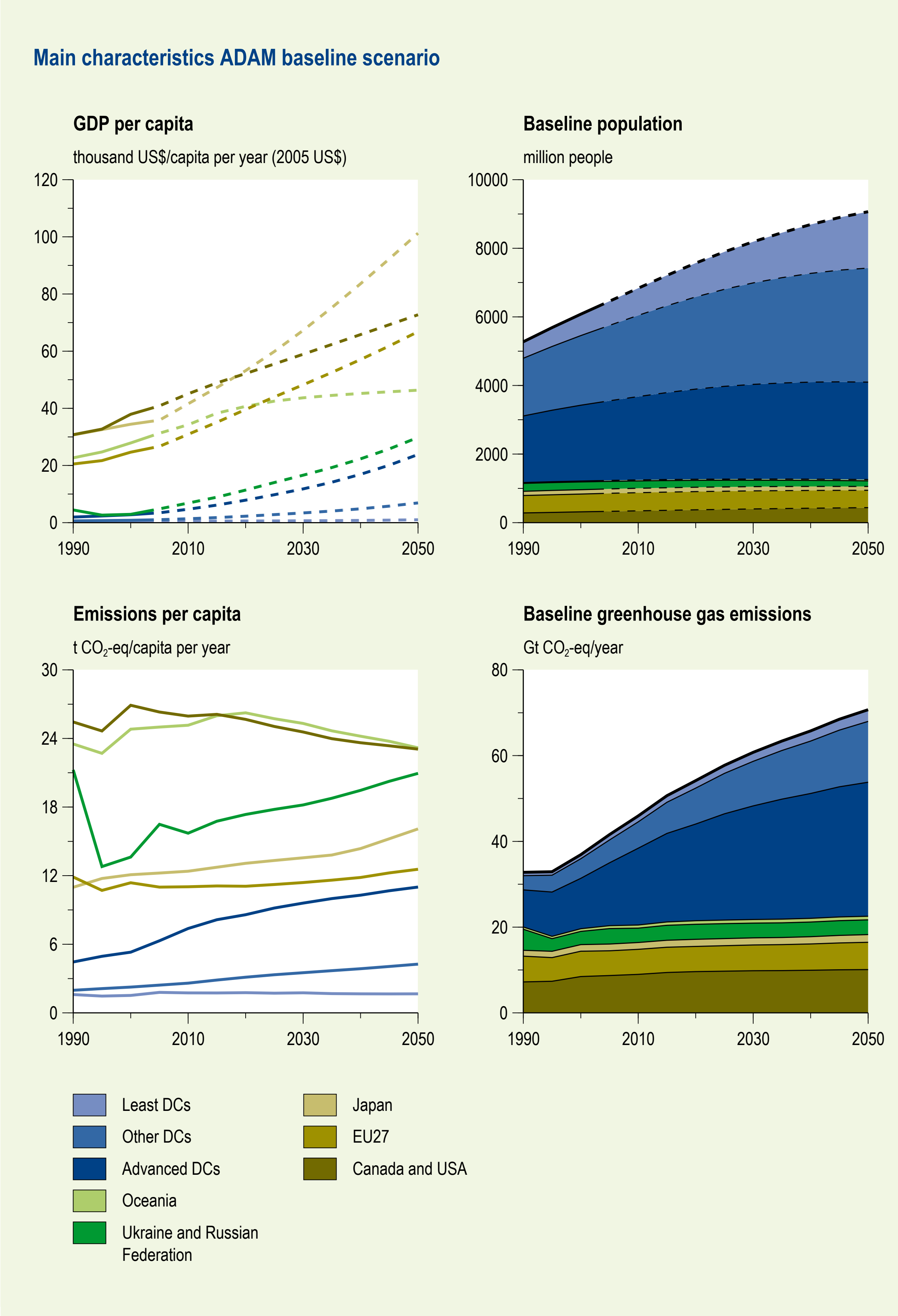


Figure 3.2 Reference baseline projections for GDP per capita (in market exchange rates, MER), population, GHG emissions per capita and GHG emissions for the different regions (for TIMER data). The energy-related CO_2 emissions are TIMER results that are calibrated with the 1990–2003 emissions data of IEA (2005). The other non-CO_2 GHG emissions are IMAGE results that are calibrated with the 2000 emission data from various sources (see Bouwman et al., 2006).

3.2 Baseline

As a reference for possible developments in the absence of climate policy, we used a scenario that, overall, should be considered as a 'median' baseline projection with a time horizon up to 2100. The socio-economic and the energy sector projections represent the reference scenario developed for the ADAM project (Van Vuuren et al., 2008, in preparation). The main characteristics of the scenario are given in Figure 3.2 and inTable 3.1.

The ADAM baseline is a high economic growth scenario, based primarily on optimistic growth assumptions for China and India. Outside these regions, growth assumptions are considered to be comparable to other more medium economic growth projections. The economic projections also show that in per capita terms, the current Annex I regions remain the wealthier regions in the world. At the same time, however, in terms of total economic activity, some regions clearly start to become increasingly more important, including China, India, Latin America and the rest of Asia. The population projection used is the UN medium scenario.

The outcomes, in terms of energy, are broadly similar to those of the WETO reference scenario (Lapillonne et al., 2007). Oil production is not expected to decrease until 2060, where a decreasing production of oil from conventional sources is offset by an increased production from unconventional sources. The oil price shows a more or less constant price level at 2005 levels (about 55 US$(2005)/barrel of oil) over the period 2005 to 2050. Non-fossil energy sources provide a more or less constant contribution to the total demand (about one-fifth). Coal continues to supply to the largest part of energy demand, supplying a third of the demand by 2050, and thereafter rapidly increasing to one half of the world supply, by 2100.

Energy intensity will halve by 2050, compared to 2001 levels, and halve again, by 2100. Because of a continued growth in per capita income and population, the decreasing energy intensity will be offset, and per capita emissions will continue to grow for most regions, except Oceania, Canada and the USA.

The resulting total GHG emissions are expected to increase from 36.9 GtCO_2eq in 2000 to 70.7 GtCO_2eq, by 2050, with energy-related emissions remaining dominant. These emissions lie within the range of most long-term projections and between those predicted in the A1 and B2 scenarios from the IPCC-Special Report on Emissions Scenarios (SRES). The projected emissions, as provided by the International Energy Agency (IEA, 2006) in their World Energy Outlook 2006, fall between the ADAM and B2 projections.

Table 3.1 Global population, GDP per capita and anthropogenic GHG emissions for 1990, 2000 and 2020 for the ADAM baseline (Van Vuuren et al., 2008, in preparation)

	Population (in million inhabitants)			GDP (1000 US$(2005) per capita)			GHG emissions ($GtCO_2eq$ per year)		
	1990	2000	2020	1990	2000	2020	1990	2000	2020
Annex I regions									
Canada	28	31	36	26.6	31.7	43.0	0.62	0.73	0.77
USA	256	284	338	31.2	38.6	53.2	6.59	7.74	8.86
Western Europe	376	391	407	26.1	31.1	47.6	4.48	4.62	4.57
Central Europe	131	129	123	4.5	5.0	13.3	1.54	1.29	1.31
EU27*	507	519	530	19.4	23.4	36.5	6.02	5.91	5.87
Ukraine region	67	63	53	2.4	1.2	6.0	1.08	0.56	0.57
Russian Federation	165	163	150	5.3	3.6	13.3	3.84	2.52	2.94
Japan	124	127	127	30.7	34.4	53.2	1.36	1.53	1.66
Oceania	23	26	31	22.7	27.9	40.7	0.53	0.64	0.82
Non-Annex I regions									
Mexico	84	100	125	6.0	7.1	8.9	0.47	0.58	0.76
Rest Central America	62	73	96	3.1	3.5	6.1	0.22	0.22	0.41
Brazil	149	174	219	3.7	4.2	5.9	0.67	0.88	1.32
Rest South America	148	176	227	2.9	3.6	4.8	0.81	1.03	1.40
Northern Africa	118	142	194	1.4	1.5	2.4	0.35	0.44	0.72
Western Africa	241	316	504	0.6	0.6	0.6	0.35	0.43	0.87
Eastern Africa	156	201	330	0.4	0.4	0.4	0.25	0.31	0.50
South Africa	37	46	48	4.6	4.6	5.5	0.37	0.44	0.63
Rest Southern Africa	84	108	152	0.6	0.6	0.7	0.17	0.22	0.37
Turkey	57	68	87	3.7	4.4	10.1	0.23	0.30	0.58
Kazakhstan region	50	55	68	1.6	1.1	3.5	0.69	0.48	0.64
Middle East	136	174	259	4.4	4.9	7.2	0.93	1.43	2.41
India	849	1021	1332	0.4	0.6	2.1	1.53	2.07	3.95
Korea region	63	69	73	5.6	9.1	23.1	0.49	0.72	1.25
China region	1158	1276	1427	0.6	1.4	8.2	3.78	5.67	13.15
Mekong region	258	310	397	1.1	1.6	4.0	0.67	1.01	1.79
Indonesia region	186	214	263	0.8	1.1	3.0	0.41	0.56	0.97
Southern Asia	269	342	503	0.4	0.5	1.0	0.36	0.49	0.94
World	**5273**	**6078**	**7569**	**5.6**	**6.4**	**10.3**	**32.77**	**36.89**	**54.16**

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

4 Model analysis

4.1 Introduction

4.1.1 Three 'comparable effort' scenarios for the Annex I countries

In this chapter, we analyse the reduction targets and abatement costs for the Annex I countries and regions for the six allocation approaches (cases) selected in Chapter 2:
1. equal percentage reduction below a baseline scenario
2. equal MAC
3. equal abatement costs as a percentage of GDP, by 2020 [excluding international emissions trading (IET) and CDM]
4. equal abatement costs as a percentage of GDP, by 2020 (including IET and CDM)
5. converging per capita emissions (i.e. equal per capita emissions by a fixed year)
6. Triptych approach

In the analysis, we focus on three scenarios for our assumptions on the aggregate Annex I emission reduction, that is, 20%, 30% and 40%, by 2020, compared to 1990 levels (hereafter referred to as '20% Annex I comparable', '30% Annex I comparable' and '40% Annex I comparable'). These reduction values have been chosen as corresponding both with the values around the 25 to 40% Annex I reduction range under consideration by the AWG-KP and with the Annex I reduction range for meeting the 450 ppm CO_2eq stabilisation target (lowest category) of the IPCC Fourth Assessment Report (in Box 13.7, Chapter 13, WGIII) (Gupta et al., 2007).

In our calculations, we have not included possible comparable emission reduction efforts from the more advanced developing countries. However, for the cases that explicitly consider trading, we have had to make assumptions on the actions of these countries, as well (see Section 4.1.2).

Annex I reduction targets for 2010 – The first step of the model is to calculate the emission levels for 2010 (the central year of the Kyoto period). We assume that all Annex I countries (excluding the USA, but including Australia) have agreed to a reduction of their emission levels to the minimum of their Kyoto target or their reference (BAU) scenario, by 2010. We also assume that Canada meets its Kyoto target, even though this is unlikely. For the USA, the 2010 level is based on the national target of an improvement in emissions per GDP by 18% from 2002 to 2012. This would result in emissions far above the Kyoto target (+26%, compared to –7%). However the currently reported emissions by the USA are lower than the national target. In our calculations we therefore overestimate the 2010 emission, which also influences the 2020 reduction targets, which are underestimated in the order of 3-4 percentage points (as analysed in more detail in Section 5.3). For the Russian Federation and the Ukraine region in Annex I, we choose the reference emissions for 2010 as a starting point, which is well below their Kyoto targets (–28% and –40%, compared to 0 to –8%; see Table 4.4). The impact of these assumptions is assessed in Chapter 5. After the calculations for 2010 have been completed, the model determines the emission allowances of the individual Annex I countries for 2020, according to the rules laid down for each of the various approaches (see Chapter 2). It should be noted that it is assumed that all banked excess emission allowances during the first commitment period (2008 to 2012) are fully used in a second commitment period (with 2015 as the central year); consequently, these do not enter into our 2020 calculations.

4.1.2 Assumed reduction targets for the non-Annex I countries

For the cases that explicitly allow for trading (equal costs per GDP inclusive of trading), assumptions on the non-Annex I emission reductions do affect the Annex I reduction targets. In all cases, the abatement *costs* for Annex I countries (not the emission reduction targets) are influenced by the reduction commitments adopted by the non-Annex I countries and the related availability of carbon credits from flexible Kyoto mechanisms (i.e. CDM and emission trading). In this section, we first set down a number of assumptions on the reductions for the non-Annex I countries as a group, and then we focus on the reductions for individual non-Annex I regions.

1. Reductions for non-Annex I countries as a group – Figure 4.1 shows the trade-off between the Annex I reduction, compared to 1990 levels, and the non-Annex I deviations from their baseline scenario emissions – i.e. below the most current business-as-usual GHG emission projections, by 2020, for a range of CO_2-equivalent stabilisation levels, based on the work of Den Elzen and Höhne (2008). Note that the reductions resulting from these trade-offs are assumed to occur independently in Annex I and non-Annex I countries. If Annex I countries decide to achieve some of these reductions outside of the group (through CDM or any other future mechanism), additional reductions have to be achieved in developing countries.

Figure 4.1 shows that the emission reductions for Annex I countries as a group, by 2020, will be 25% relative to 1990 (top range of the grey-shaded area) and that the emissions for non-Annex I countries as a group will be below the baseline (around 7%, 22% and 30%), which is consistent with 550, 450 and 400 ppm CO_2eq, respectively. We now assume that the '20% Annex I comparable', '30% Annex I comparable' and '40% Annex I comparable' scenarios correspond with a global emission scenario that meets long-term GHG concentration stabilisation levels of 550, 450 and 400 ppm CO_2eq, respectively. This implies that the emission reductions in the non-Annex I countries, compared to the baseline, become approximately 10%, 16% and 22%, as indicated in Figure 4.1.

Presently CDM is the only international climate policy tool, which leads to measured, verified and quantified emission reductions in non-Annex I countries. As CDM "offsetting" credits are used for Annex-I country compliance and are currently planned to be eligible in the EU for reaching its 20% reduction target, they cannot be counted towards the reductions in non-Annex I countries as given above. According to the Bali Action Plan agreed by the UNFCCC Parties in December 2007, developed countries shall support developing countries through additional technology, financing and capacity building in achieving their reduction actions. The distribution of effort given in Figure 4.1 does not cover this additional support. Therefore, the Annex I countries could support the non-Annex I countries to meet this reduction, through a mixture of finance, carbon trade or other mechanisms.

The more demanding reductions for the non-Annex I countries (i.e. 16% or 22%) are assumed to be acceptable, because part of this reduction can be achieved by (1) the support from the Annex I countries through a mixture of finance, carbon trade or other mechanisms, and (2) the additional Annex I reduction effort. It can also be argued that the increased Annex I reduction effort increases the demand for CDM and IET, which is beneficial to developing countries.

2. Reductions for individual non-Annex I countries – Next, we allocate the non-Annex I countries' group reduction to the individual countries. There are vast differences between developing countries in terms of their contribution to climate change and their ability to cope with

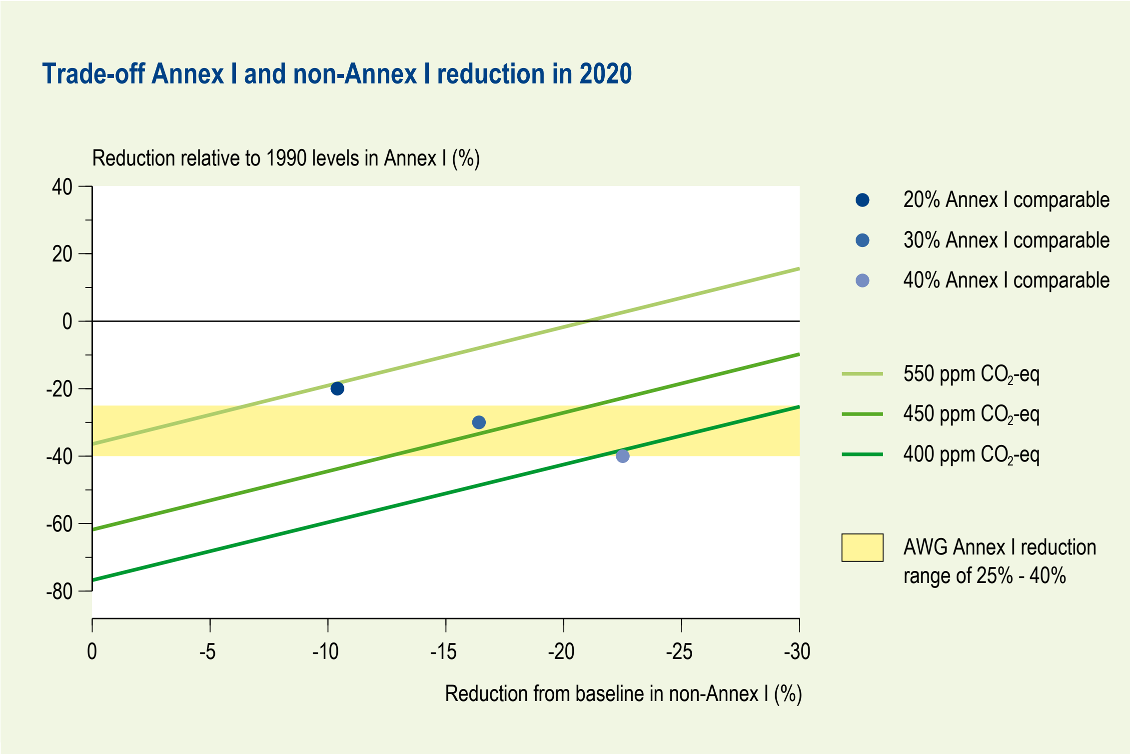


Figure 4.1 The position of the '20% Annex I comparable', '30% comparable' and '40% comparable' scenarios, compared to the trade-off in emission reductions (excluding LULUCF CO_2 emissions) by 2020, for both groups of Annex I and non-Annex I countries, for meeting three concentration stabilisation targets. This figure also depicts the AWG-KP Annex I countries' reduction range of 25 to 40%. Selecting alternative baselines can shift the lines several percentage points.
Source: adapted from Den Elzen and Höhne (2008).

it. Article 3.1 of the UNFCCC states that such a differentiation should be in accordance with Parties' 'common but differentiated responsibilities and respective capabilities….' (UNFCCC, 1992). Here, to determine the differentiation between non-Annex I countries, we follow the South–North Dialogue Proposal (Ott et al., 2004) (http://www.south-north-dialogue.net), which recommends that the differentiation should be based on the criteria of responsibility, capability and potential to mitigate. This Proposal defines four groups of non-Annex I countries, each group consisting of countries with similar national circumstances. This categorisation is based on an index that is defined by an equal weighting of cumulative fossil CO_2 emissions per capita, the Human Development Index and an indicator of mitigation potential (derived from CO_2 emissions/GDP and GHG emissions/capita). The first two groups are comprised of the newly industrialised countries and the rapidly industrialising developing countries, which we have combined into one group – the advanced developing countries (ADCs). This group of countries is considered to be particularly important, as they provide the momentum for moving the next round of climate negotiations forward. The two other groups consist of the least-developed countries (LDCs) and 'other developing countries' (ODCs), with the latter group comprising of countries not belonging to any of the other three groups. The LDCs are excluded from taking on quantitative commitments. Table 4.1 presents how the three groups are distributed over the IMAGE 2.3 non-Annex I regions, and shows their assumed reductions. It also shows increasing reductions for the ADCs and ODCs in the more ambitious Annex I reduction scenarios. Note that these reductions are compared to the baseline emission levels, thereby still implying a growth in their emissions, compared to 1990 levels.

Table 4.1 Assumed reduction levels below the baseline, by 2020, for the non-Annex I countries, grouped into *Advanced Developing Countries, Other Developing Countries* and *Least-Developed Countries* for all three scenarios of this study.

Region	Configuration	20% comparable Annex I	30% comparable Annex I	40% comparable Annex I
Non-Annex I as a group		–10%	–16%	–22%
Advanced Developing Countries (ADCs)	Mexico, rest Central America, Brazil, rest South America, South Africa, Kazakhstan region, Turkey, Middle-East, Korea region and China: Reduce below baseline emission levels and can participate in IET	–15%	–20%	–25%
Other developing countries (ODCs)	North African region, Middle East, India, rest southern Asia, Indonesia region, rest south-eastern Asia: Reduce below baseline emission levels and can participate in CDM	0%	–10%	–20%
Least developed countries (LDCs)	Western Africa, eastern Africa and rest of south African region: Follow baseline emission levels and can participate in CDM	0%	0%	0%

We further assume that those ADCs that have committed themselves to absolute reductions (in terms of reductions compared their baseline emission levels), can all participate in IET and joint implementation (JI), by 2020. There is also the availability of CDM beyond 2012, as an emission reduction option for countries with no or low restrictions on emissions, being the ODCs and LDCs. These countries may benefit from the financial revenues from CDM, but this effect is limited compared to the possible damage from climate impacts, which will be larger for these particularly vulnerable countries.

4.1.3 Parameter settings of the cases

For those cases based on equal burden, no specific assumptions on parameters are needed, as these only depend on the assumptions on the baseline and MAC curves (see Chapter 3). For the *converging per capita emissions* approach, we assume the contraction and convergence approach, with a convergence year of 2050, under a global emission pathway for stabilisation at 550, 450 and 400 ppm CO_2-eq concentrations, leading to an overall Annex I reduction target of 20%, 30% and 40% [1]. The *Triptych* parameter settings of the '20% Annex I comparable' scenario correspond with the medium technology scenario by Den Elzen et al. (2008a), with the exception of a few parameters (indicated in bold in Table 4.2). For the scenarios '30% Annex I comparable' and '40% Annex I comparable', the settings of the strong technology scenario of Den Elzen et al. (2008a) is used and further modified, to meet the total Annex I reduction target. For the non-Annex I countries, we adopt the reduction targets as described in the previous section and not those according to the *Triptych* or *converging per capita emissions* approach.

4.1.4 Global emission trading market and CDM

Table 4.3 presents the emission reductions, financial flows and costs in the three global scenarios for the groups of Annex I and non-Annex I countries. The figures are presented both globally and as the percentage of emission reduction acquired through domestic abatement, within and

1 The pathways are slightly modified for 2020, to match them to an overall Annex I reduction of 20%, 30% and 40%.

Table 4.2 Choice of model parameter for the three scenarios. Values in bold, indicate changes compared to the original settings of Den Elzen et al. (2008a) (see text).

Sector	Quantity	20% Annex I comparable	30% Annex I comparable	40% Annex I comparable
General	Convergence year for Annex I countries	2050	2030	**2025**
Industry	Level of the Energy Efficiency Indicator (see Section 2.2.3)	0.7	1.0	**0.7**
Domestic	Domestic convergence level – per capita emissions in tCO_2 per capita per year	1.5	1.25	1.25
Power	Convergence level of GHG emissions (gCO_2/kWh)			
	Coal	**550**	600	600
	Oil	**450**	450	450
	Gas	**250**	300	300
	Reduction in the share of coal and oil compared to 2004 levels	90%	60%	65%
	Yearly decrease in electricity consumption (demand) by the industry and domestic sector	**1.7%**	2%	2%
Domestic	Domestic convergence level – per capita emissions in tCO_2/capita/year	1.5	**1.7**	**1.25**
Fossil fuel production	Percentage-reduction of baseline emission levels in convergence year	90%	90%	90%
Agriculture	Reduction below baseline emission levels in convergence year	40%	40%	40%
Waste	Reduction below base-year, per capita emissions from waste in convergence year	90%	90%	90%

outside of the Annex I groups and the international market equilibrium permit price for the world permit trading market.

Figure 4.2 and Table 4.3 clearly show that most of the reduction occurs domestically, amounting to approximately 75 to 80% of the target reduction. Increasing the reduction objective to 30% for Annex I countries, slightly increases the domestic abatement fraction, as seen in the '20% Annex I comparable' scenario. It further increases the permit price, from about 50 US$(2005)/ tCO_2 eq to 95 US$(2005)/$tCO_2$eq for the 30% reduction case, and to 235 US$(2005)/$tCO_2$eq for the 40% reduction case, as a result of the higher demand for permits from a large coalition of Annex I countries and ADCs, with a comparable reduction effort. Figure 4.2 shows that Annex I countries do more domestically, to achieve the higher Annex I aggregate target and that non-Annex I countries take on higher reduction targets.

Overall, the Annex I countries as a group act as buyers on the market, while the ADCs (via IET) and other developing countries (via CDM) are net sellers (Figure 4.3). The largest supplier is China, with about 50% of the total traded amount from the Non-Annex I countries (about 80 to 90% of the total traded amount by IET from the ADCs).

The remainder of this chapter focuses on burden-sharing within the Annex I regions.

Table 4.3 Main indicators for 2020 in the three scenarios. Although the results presented are those for the case of 'equal reduction below baseline', the other cases give very similar results, as we focus here only on the groups of Annex I and non-Annex I countries.

TARGETS	20% Annex I comparable	30% Annex I comparable	40% Annex I comparable
Annex I			
Baseline emissions ($MtCO_2eq$)	22064	22064	22064
Reduction compared to 1990 level (%)	–20%*	–30%	–40%
Reduction compared to baseline (%)	–27%	–37%	–44%
Non-Annex I			
Baseline emissions ($MtCO_2eq$)	32093	32093	32093
Reduction compared to 1990 level (%)	130%*	114%	99%
Reduction compared to baseline (%)	–10%	–16%	–22%
Global			
Baseline emissions ($MtCO_2eq$)	54157	54157	54157
Reduction compared to 1990 level (%)	38%	26%	14%
Reduction compared to baseline (%)	–16%	–24%	–31%
ABATEMENT			
Annex I			
Reduction target ($MtCO_2eq$)	5544	7582	9609
Domestic abatement ($MtCO_2eq$)	4315	6087	7701
Domestic abatement (%)	78%	80%	80%
Trade ($MtCO_2eq$)	709	975	1388
Sinks ($MtCO_2eq$)	520	520	520
Non-Annex I			
Reduction target ($MtCO_2eq$)	3363	5233	7169
Domestic abatement ($MtCO_2eq$)	4035	6164	8509
Domestic abatement (%)	120%	118%	119%
Trade (IET) ($MtCO_2eq$)	–738	–997	–1405
IET (ADCs)	–375	–640	–1069
CDM (ODCs and LDCs)	–364	–357	–336
Sinks ($MtCO_2eq$)	66	66	66
Global			
Reduction target ($MtCO_2eq$)	8907	12815	16778
Domestic abatement ($MtCO_2eq$)	8350	12251	16210
Domestic abatement (%)	94%	96%	97%
Sinks ($MtCO_2eq$)	586	586	586
TRADING PRICE			
Permit price (in US$(2005)/$tCO_2$)	49	88	235
COSTS			
Annex I			
Domestic costs (in Million US$(2005))	75625	190818	427355
Financial flows (in Million US$(2005))	35693	88431	333691
Total costs (in Million US$(2005))	111318	279249	761046
Costs as % GDP	–0.22	–0.54	–1.47
Non-Annex I			
Domestic costs (in Million US$(2005))	58744	156346	414786
Financial flows (in Million US$(2005))	–35866	–87911	–330207
Total costs (in Million US$(2005))	22879	68436	84579
Costs as % GDP	–0.09	–0.26	–0.32
Global			
Costs (in Million US$(2005))	134197	347685	845626
Costs as % GDP	–0.17	–0.44	–1.08

* A negative sign means a level below 1990 levels, and a positive sign means a growth compared to 1990 levels

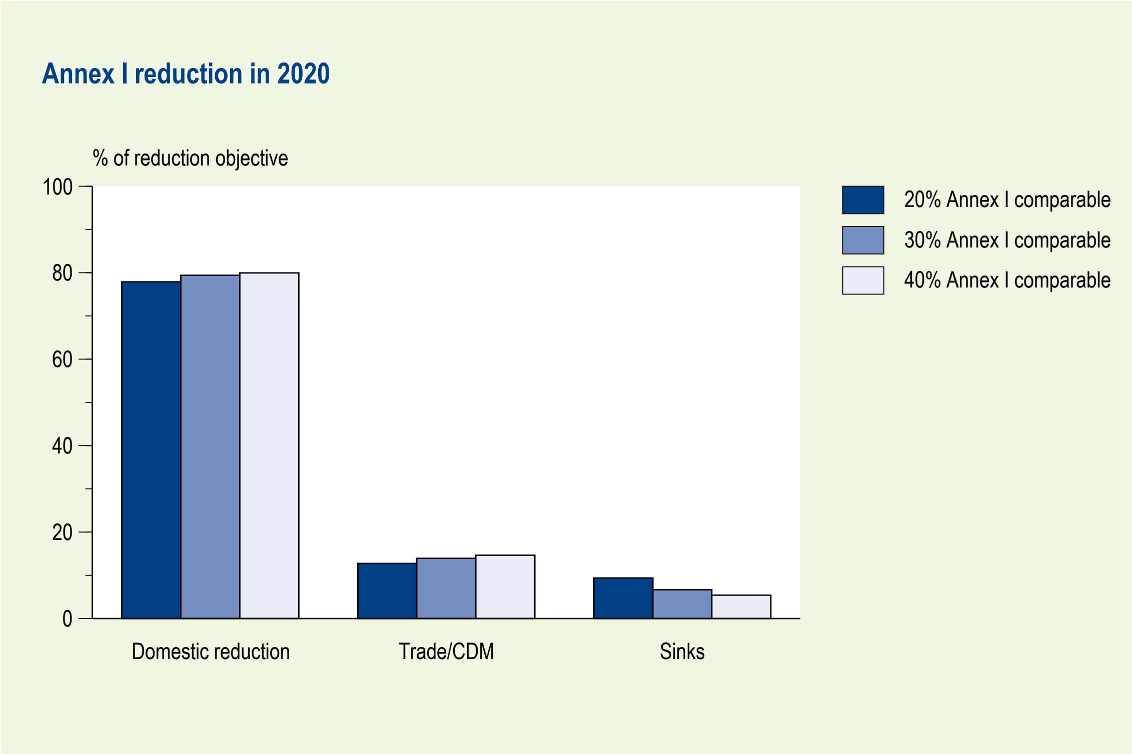


Figure 4.2 Percentage of Annex I emission reductions taken domestically, traded with the non-Annex I regions and via terrestrial sinks for 2020, for the three scenarios.

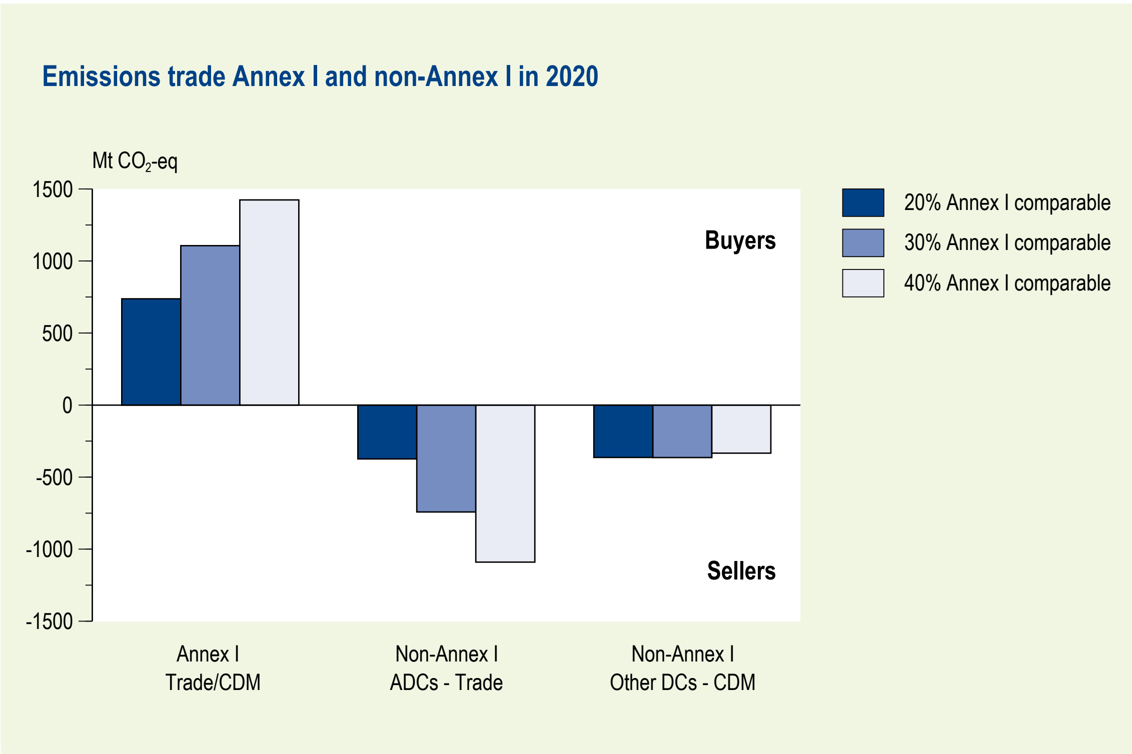


Figure 4.3 The total amount of emissions traded (MtCO2eq) between the different groups and the rest of the world, for 2020, in the three scenarios.

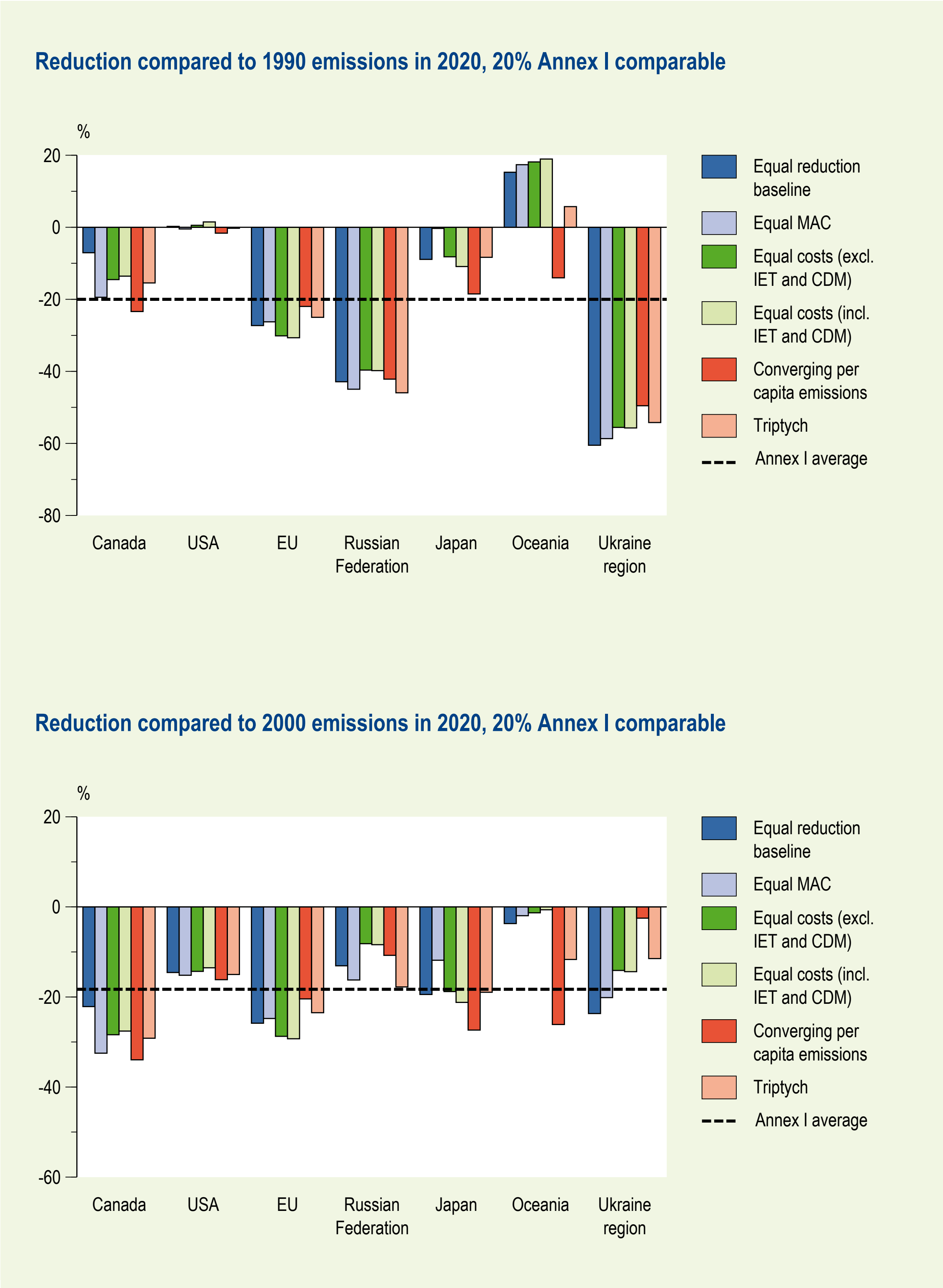


Figure 4.4 Reduction compared to 1990 levels (upper) and 2000 levels (lower) by 2020, under the '20% Annex I comparable' scenario. The dotted line represents the Annex I average.

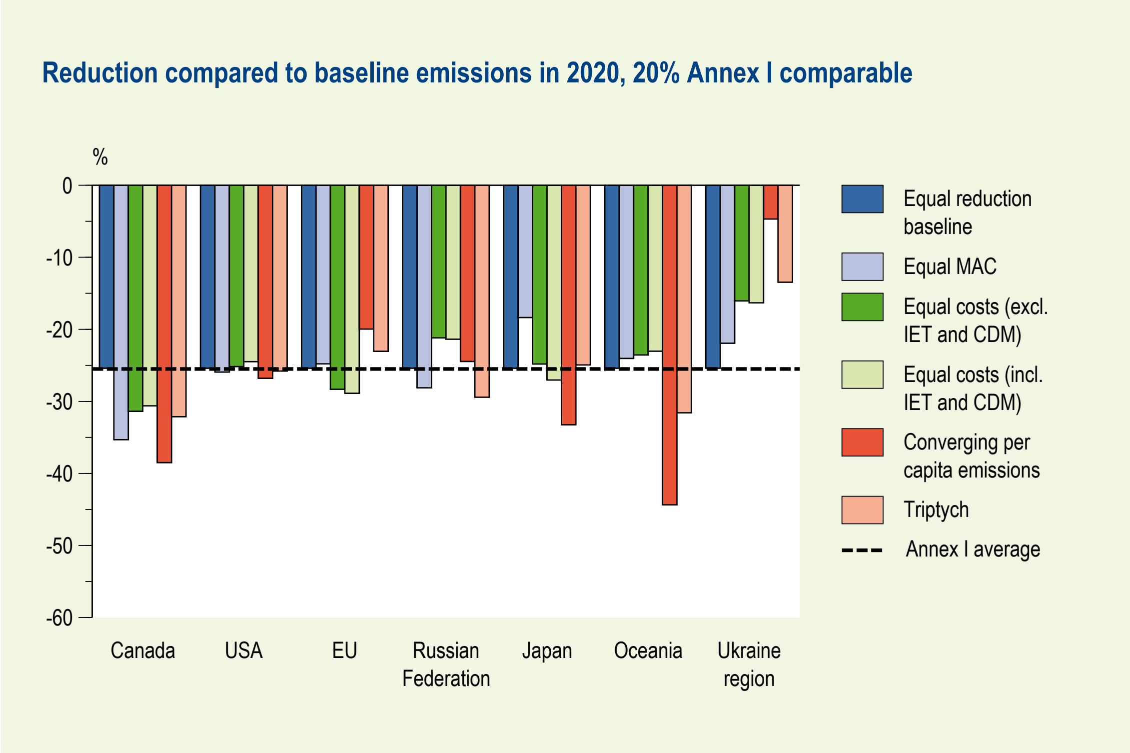


Figure 4.5 Reduction compared to reference or baseline emission levels by 2020, under the '20% Annex I comparable' scenario.

4.2 '20% Annex I comparable' scenario

4.2.1 Annex I countries' reduction targets

Figure 4.4 hows how the different approaches affect the Annex I countries and regions. The effect is dependent on the national circumstances. One important element is the development of emissions between 1990 and the present day. Several countries realise an increase in their emissions (Canada, USA, Japan), while others experience a decrease (EU, Russian Federation, Ukraine). This effect is less visible in the bottom graph, which shows the change from 2000 to 2020.

Equal percentage reduction below a reference scenario – The equal reduction below baseline (about 25%) can be seen as a reference case. Countries with a projected increase in emissions, will have to reduce emissions to a lesser extent below the 1990/2000 level (compare Figure 4.4 with Figure 4.5). This is the case for USA, Canada, Japan and Oceania. Countries, for which lower emissions growth is projected, have to reach a lower level below that of 1990/2000 (EU, Ukraine). For most countries, the reductions under this approach are closer to the middle, compared to the reductions in all cases, except for Canada (representing the lowest reduction targets) and Ukraine (with the highest reductions) (see also Table 4.4).

Equal MAC – In our modelling, the carbon price needs to increase to about 60US$(2005) per tCO_2eq, by 2020, to meet the required Annex I –20% emission reduction level (excluding trade). Note, this price differs from the permit price with emission trading, which is lower (about 50US$(2005) per tCO_2eq) (see Table 4.3). The reduction targets are calculated on the basis of the MAC curves (assuming no emission trading). This approach leads to less stringent reduc-

Table 4.4 Reduction targets (%) compared to 1990 levels, by 2020, for the '20% Annex I comparable' scenario. The red cells indicate the approach using the highest reduction per country and the green cells indicate those countries with the lowest reductions.

Regions	2010 reduction target*	Equal reduction baseline	Equal MAC	Equal costs (excl. IET & CDM)	Equal costs (incl. IET & CDM)	Converging per capita emissions	Triptych
Canada	–6	–7	–19	–15	–14	–23	–15
USA	26	0	0	1	1	–2	0
EU	–8	–27	–26	–30	–31	–22	–25
Russian Federation	–28	–43	–45	–40	–40	–42	–46
Japan	–6	–9	0	–8	–11	–18	–8
Oceania	7	15	17	18	19	–14	6
Ukraine region	–40	–61	–59	–56	–56	–50	–54
Annex I	–1.5	–20	–20	–20	–20	–20	–20

*: For 2010 we assume that all Annex I countries (except the USA) reach the minimum of their Kyoto target or their reference emission levels, by 2010 (see Section 4.1.1).

tion targets for Japan (compared to reduction below baseline), since Japan has fewer low-cost reduction options than the average Annex I country. For other countries, such as the Russian Federation and Canada, this approach leads to more stringent reduction targets in terms of the reduction below the baseline, since these countries are assumed to have more low-cost reduction options than the average Annex I country. The EU has slightly fewer low-cost reduction options and the USA has slightly more, but the effect is very small.

Equal abatement costs as a percentage of the GDP (excluding emission trading) – Moving from *equal* MAC to *equal cost per* GDP, adds two elements to the calculation. First, average costs over all reductions are considered – and not only the marginal costs for the last reduced tonne. The second element is the height of GDP. This is relatively low for the Russian Federation and Ukraine, leading to less stringent reduction requirements than would be required under the *equal MACs* case, and relatively high reduction requirements for Japan and the EU, leading to more stringent reduction targets.

Equal abatement costs as a percentage of GDP *(including emission trading)* – For this case, the abatement costs are determined as being the abatement costs plus emission permit sales revenue, minus permit purchase costs, calculated with the FAIR model. Note: only in this case are the reduction targets for the Annex I countries also dependent on the assumed reduction targets for the non-Annex I countries, as the costs for Annex I countries are equal to the costs of domestic action and emission permit imports (CDM and emission trading with mainly non-Annex I countries). The reduction targets for the developing countries are described in Section 4.1.2. In this particular case, the inclusion of trading does not have much of an effect on a country's total costs, but it does affect whether or not the reductions occur inside or outside of the country. Japan, for example, has fewer low-cost options than other countries. It will, therefore, opt for reductions outside of the country, when trade is included. Countries with many low-cost options abate less abroad, such as Canada. For most countries, with the exception of Japan, the difference between trade being included in reduction targets or not, – is relatively small.

Converging per capita emissions approach – The *converging per capita emissions* approach, which aims at equal per capita emissions for all Annex I countries, by 2050, leads to less stringent reductions – as one might expect – for those countries with currently low per capita emissions, such as the EU, Japan, Russian Federation and, in particular, Ukraine. This approach leads to higher reduction targets for Canada, USA and Oceania, all of which have relatively high per capita emissions. This effect is moderated by the starting year of 2010 and the convergence period of 40 years. An earlier convergence, or taking 1990 as a starting year, would enhance the effect and lead to much higher reduction requirements for the USA and Canada, by 2020.

Triptych approach – The reduction targets under the *Triptych* approach are more stringent for those countries that are inefficient (such as the Ukraine, Russian Federation and Oceania) and less stringent for those that are already efficient (e.g. the EU and Japan).

Looking at all cases, the model results show the following:

- *A wide range of Annex I emission reductions, compared to 1990* – Our study shows a wide range of emission reduction targets, compared to 1990 and 2000, for the various Annex I countries. This is due to the differences in development between these countries, since 1990 and 2000. The reductions show less deviation when emission reduction targets are compared to baseline emission developments. The reduction for the Annex I countries for the 20% scenario ranges between –15% and –40% compared to the baseline emission levels, and from a growth of about 20% to a decrease of 45%, compared to 1990 emission levels.
- *Highest reductions for the Russian Federation and Ukraine, compared to 1990, but lowest in terms of reference emissions* – The Russian Federation and Ukraine show the most stringent reductions, compared to 1990 levels – in the order of 40 to 45% and 50 to 60%, respectively – since their emissions have already decreased, between 1990 and the present day, by 25% and 35%, respectively. However, looking into the future, they have the lowest reductions in both the reference emission levels and 2000 levels.
- *Reductions below 1990 levels are large for* EU *and small for the* USA *and Oceania* – Due to the baseline developments between 1990 and 2020, the EU would need to reduce their emissions well below 1990 levels, by 2020 (20 to 30% below 1990 levels). The USA has to return to1990 levels in most approaches. This result is based on the assumption that also under the *converging per capita emissions* and *Triptych* approaches, only the national target of 2010 is reached, which is 26% above 1990 levels. Canadian reductions are near or below the Annex I average. Here, we have assumed that Canada meets its Kyoto target (even though this is unlikely), which explains the very stringent reduction target for Canada, compared to that for the USA. The reductions to be made by Japan vary significantly from indicator to indicator (0 to 20% below 1990 levels). Oceania can allow their emissions to grow.
- *Differences between approaches are slight for large countries and larger for small countries* – For most countries, the differences in emission allowances between the various approaches is relatively small; this is particularly true for the USA and the EU. They dominate the Annex I average due to their sizes, which is the same in all cases. For a number of smaller countries (Japan, in particular, but also Canada and Oceania), the difference may be larger, because here the specific national circumstances are significantly different from the average.

4.2.2 Abatement costs

For cost measures, we will focus on marginal permit prices and abatement costs. The latter are calculated on the basis of the marginal permit prices and represent the direct additional costs due to climate policy. However, abatement costs do not capture macroeconomic costs (nor the co-benefits of mitigation measures or the costs of avoided damage from climate change). The abatement costs are calculated here by using the FAIR costs model and are presented as the percentage of GDP, in Figure 4.6. The cost projections given here account for emission trading

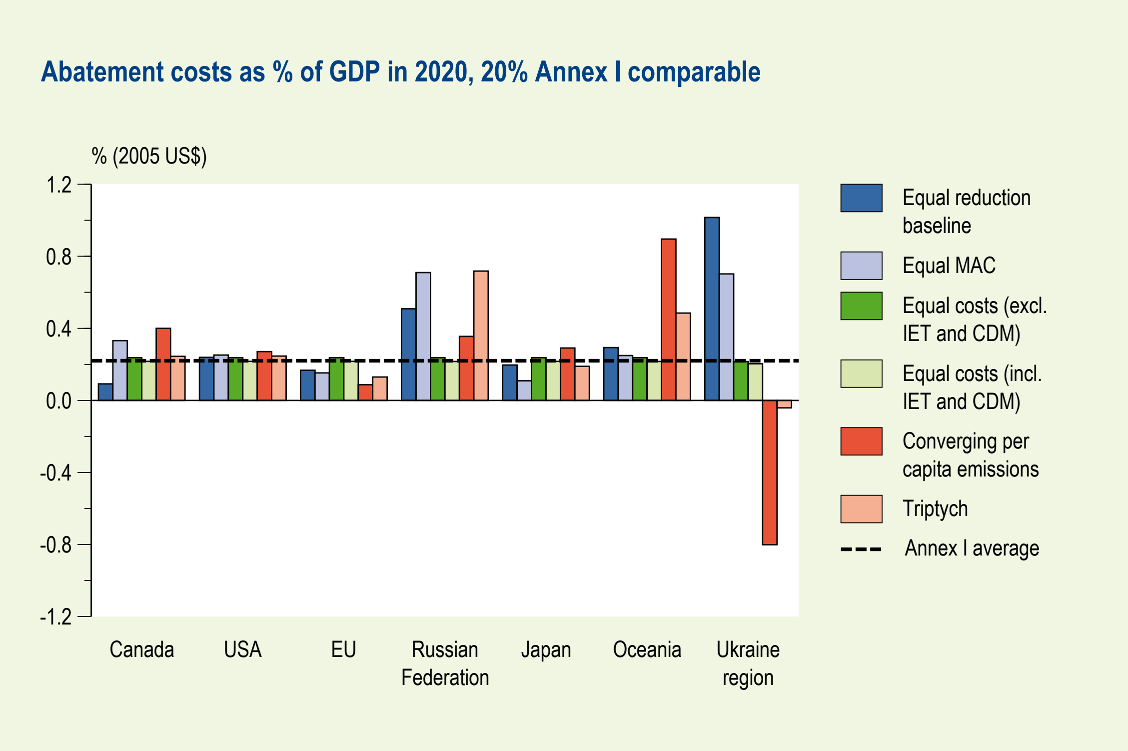


Figure 4.6 Abatement costs as a percentage of GDP, by 2020, under the '20% Annex I comparable' scenario, assuming emission trading with the coalition of Annex I regions and ADCs and CDM with the other developing countries [except for the equal costs case (excl. trade) for which we assume no trade and no CDM].

within the coalition of Annex I countries and ADCs, and for CDM with the other developing countries. The only exception is the case of *equal abatement costs as percentage of* GDP *(excluding emission trading)*, which assumes no emission trading within the coalition and no CDM. Therefore, the abatement costs for this case are higher than those for the other cases.

The Annex I average cost as percentage of GDP is about 0.2%, by 2020, with a permit price of about 50US$(2005) per tCO_2 equivalent. The abatement costs differ considerably according to the cases and regions (Figure 4.6), and these differences between regions can partly be explained by (1) differences in regional reduction targets, compared to the baseline (Figure 4.5), by (2) the diversity in regional volumes traded and associated financial flows (Figure 4.7) and by (3) differences in reduction potentials and GDP. A relatively low GDP combined with high net costs, can result in higher costs as a percentage of GDP, as can be seen for the Russian Federation and Ukraine. In general, total abatement costs tend to be relatively high in all approaches for Canada, USA and Oceania (regions with the highest per capita emissions) and to be somewhat lower for the EU and Japan (regions with medium per capita emissions). Figure 4.6 also confirms our earlier findings, that there are only slight differences between the approaches for large countries, whereas these differences are greater for small countries (compare EU and USA with Canada and Oceania).

In general, most Annex I regions act as permit-importing regions (see Figure 4.7); thus, their total abatement costs also include permit expenses from permit trading. However, Figure 4.7 also shows that some Annex I countries may act as sellers on the market, in particular cases. For

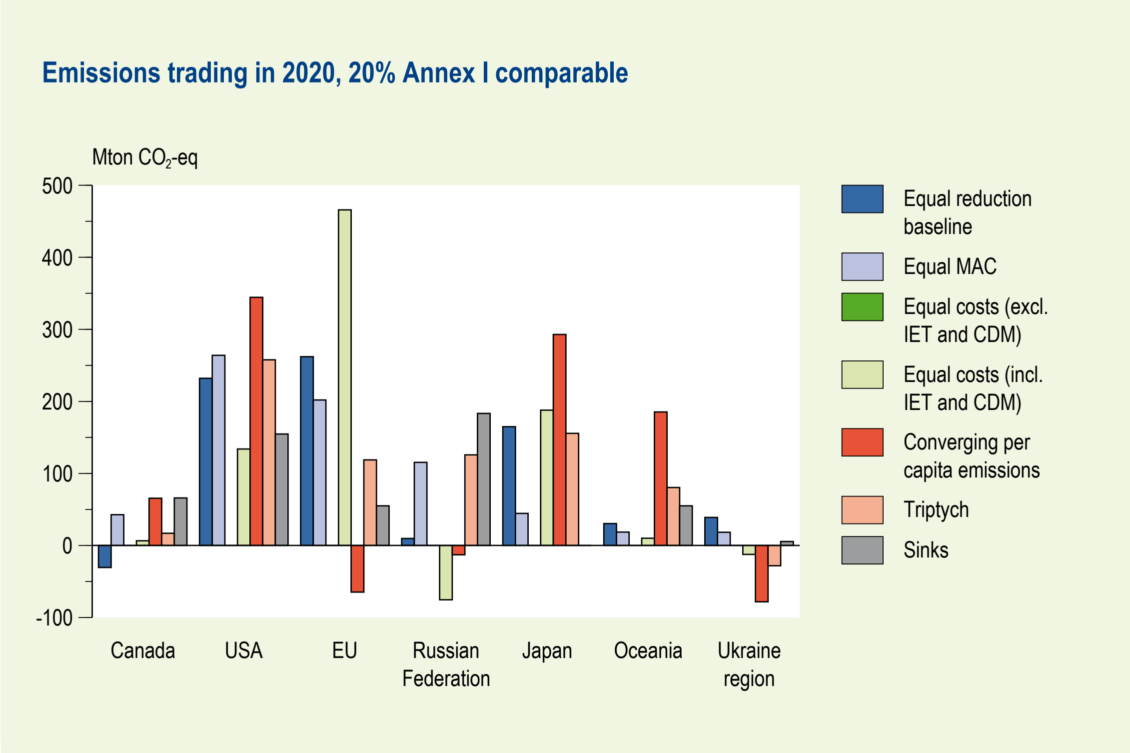


Figure 4.7 Emission trading, by 2020, under the '20% Annex I comparable' scenario, assuming emission trading with the coalition of Annex I regions and ADCs and CDM with the other developing countries.

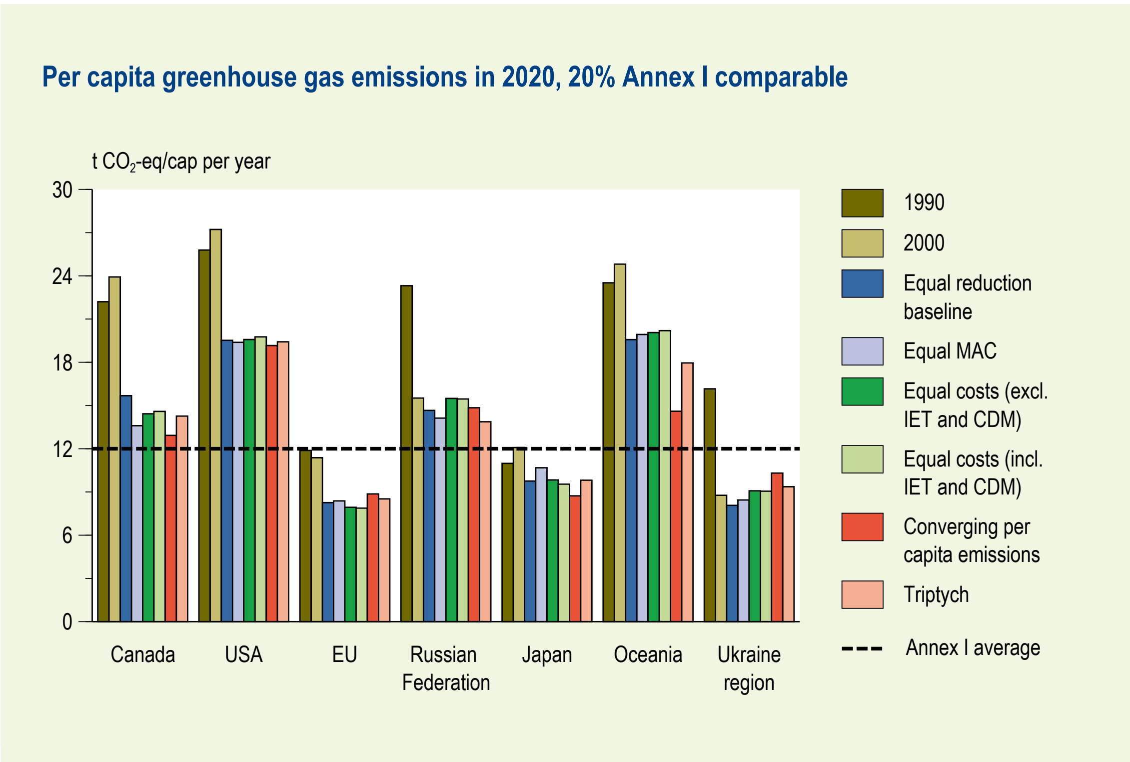


Figure 4.8 Per capita emissions in 2020 under the '20% Annex I comparable' scenario. Here also the Annex I and world average in 2020 are shown.

Emissions intensity in 2020, 20% Annex I comparable

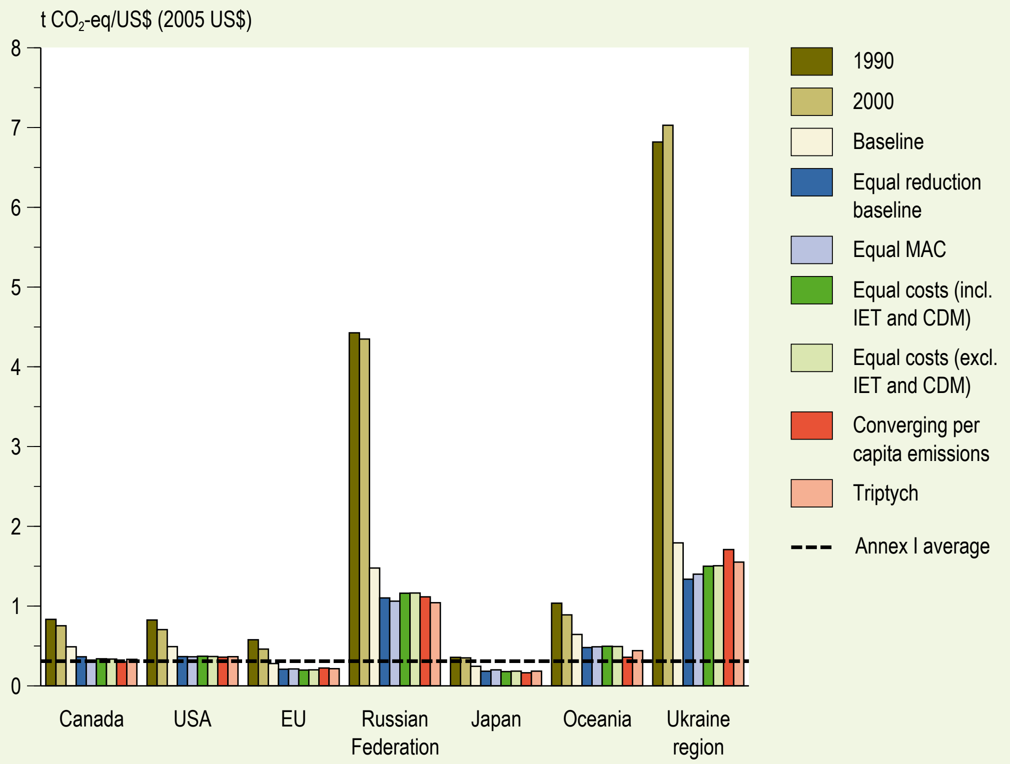


Figure 4.9 Emission intensity in 2020 under the '20% Annex I comparable' scenario. Here also the Annex I and world average in 2020 are shown.

example, for the converging per capita emissions approach, the Russian Federation, Ukraine and also the EU become sellers.

4.2.3 Other indicators

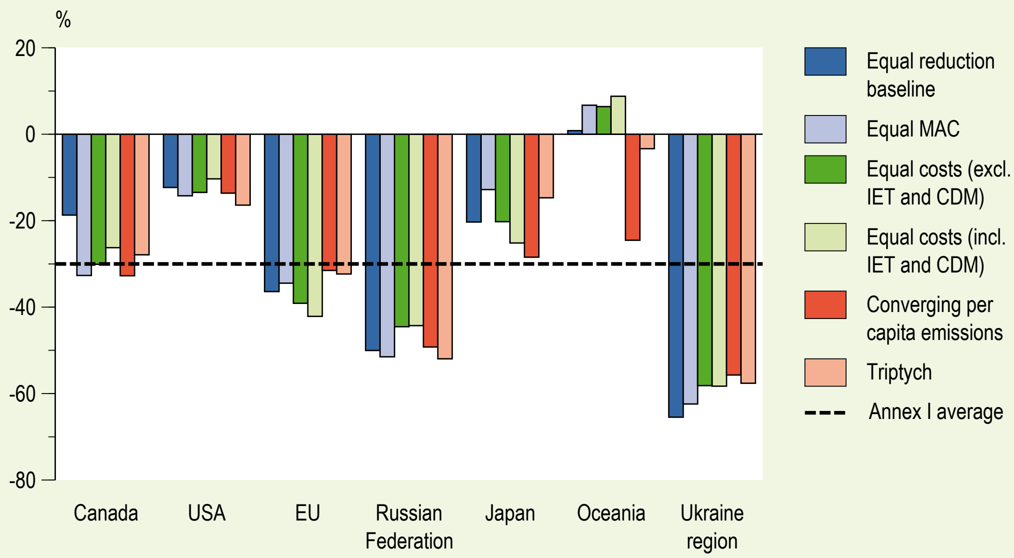
All of the cases show a reduction in per capita emissions for all Annex I countries (Figure 4.8), and the distance from the world average per capita emissions becomes less, although the Annex I per capita emissions are twice as high as the world average per capita emissions. The same convergence is seen for the emission intensity, except that the Annex I emission intensity, by 2020, is half that of the world emission intensity (Figure 4.9).

4.3 '30% Annex I comparable' scenario

4.3.1 Reduction targets for Annex I countries

The calculated reductions in the '30% Annex I comparable' case show a similar pattern to that in the '20% Annex I comparable' case. For all regions, the reduction has increased to match the higher reduction target of –30% for the Annex I as an aggregate. Here, only notable differences in each of the approaches with the '20% Annex I comparable' case will be discussed.

Reduction compared to 1990 emissions in 2020, 30% Annex I comparable



Reduction compared to 2000 emissions in 2020, 30% Annex I comparable

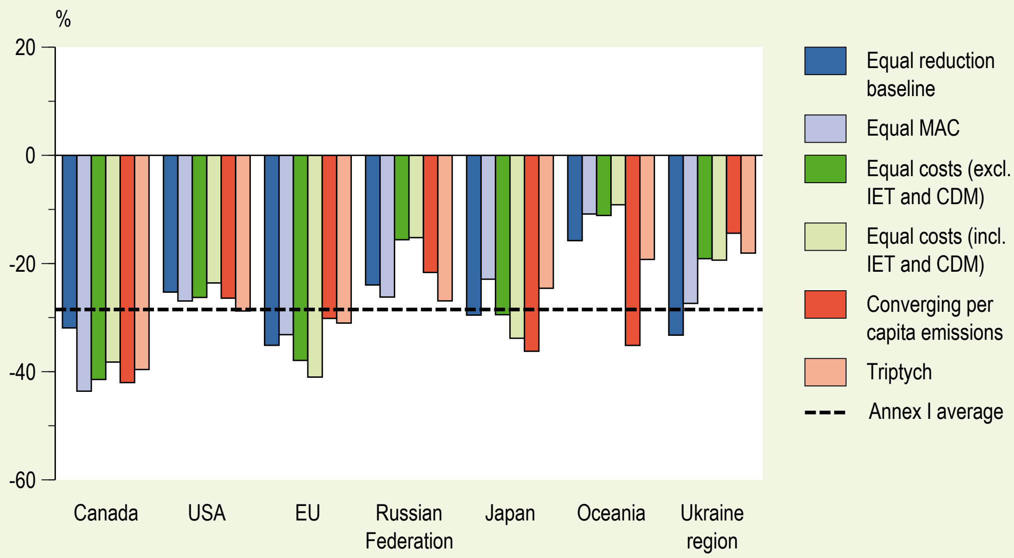


Figure 4.10 **Reduction compared to 1990 levels (upper) and 2000 levels (lower), by 2020, under the '30% Annex I comparable' scenario. The dotted line represents the Annex I average.**

Table 4.5 Reduction targets (%), compared to 1990 levels, by 2020, for the 'Annex I 30% comparable' scenario. The red cells indicate the approach using the highest reduction per country and the green cells indicate those with the lowest reductions.

Regions	2010 reduction target*	Equal reduction baseline	Equal MAC	Equal costs (excl. IET & CDM)	Equal costs (incl. IET & CDM)	Converging per capita emissions	Triptych
Canada	–6	–19	–33	–30	–26	–33	–28
USA	26	–12	–14	–13	–10	–14	–16
EU	–8	–36	–34	–39	–42	–32	–32
Russian Federation	–28	–50	–51	–45	–44	–49	–52
Japan	–6	–20	–13	–20	–25	–28	–15
Oceania	7	1	7	6	9	–25	–3
Ukraine region	–40	–65	–62	–58	–58	–56	–58
Annex I	–1.5	–30	–30	–30	–30	–30	–30

*: For 2010 we assume that all Annex I countries (except the USA) reach the minimum of their Kyoto target or their reference emissions by 2010.

Equal percentage reduction below a reference scenario – If we compare the outcomes with the '20% Annex I comparable' case, we see that countries or regions, such as Canada, USA and Oceania, with a relatively low reduction target compared to the Annex I overall reduction target of 20%, now have to reduce substantially more (compare Figure 4.4 with Figure 4.10. For example, for the USA, the reductions below 1990 levels are no longer around zero but instead are around 15%; for Oceania, there is no longer any growth relative to the 1990 levels, as calculated in the '20% Annex I comparable' case, and instead this region now stabilises around the 1990 levels. However, we see the opposite trend for countries with relative high reduction targets under the '20% Annex I comparable' scenario, such as the Russian Federation and Ukraine. For the Ukraine region, we find an increase of only 5 percentage points, compared to the '20% Annex I comparable' scenario, although this region still has the highest reductions, compared to 1990 levels.

Equal MAC – The carbon price needs to increase to about 150US$(2005) per tCO_2 equivalent, by 2020, to meet the required Annex I –30% emission reductions without emission trading. The inclusion of trading in the calculations reduces the permit price to some 90US$(2005) per tCO_2 equivalent (see Table 4.3). The general picture found for the '20% Annex I comparable' scenario still holds. This case leads to the lowest reductions for Japan, which has fewer low-cost options than most other Annex I countries, and to the highest reductions for Canada and the Russian Federation, both of which have relatively more low-cost reduction options. Similar to the earlier case, we see a stronger increase in the reductions for the USA and Canada, that is, an increase of 15 percentage points compared to the 20% Annex I comparable case, whereas for the Ukraine, this is only a few percentage points. The EU now shows a reduction of –35%, below 1990 levels (instead of –25%, as before).

Equal abatement costs as percentage of GDP (excluding emission trading) – Similar to our results with the '20% Annex I comparable' scenario, we see that moving from *equal* MAC to *equal costs per* GDP *excluding trade,* introduces the element of welfare and, therefore, leads to lower reductions for the Russian Federation and the Ukraine and to higher reductions for the EU and Japan. Similar to our earlier results, we also see approximately a 15 percentage points higher reduction for the USA and Canada.

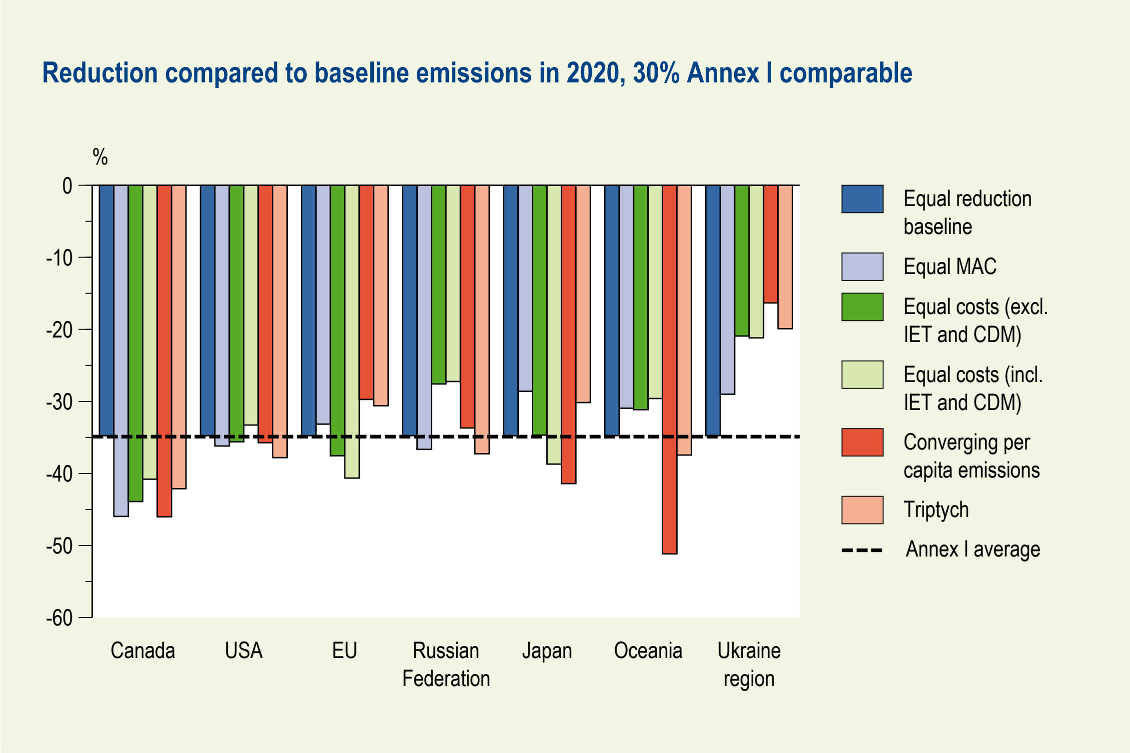


Figure 4.11 Reduction compared to reference or baseline emission levels, by 2020, under the '30% Annex I comparable' scenario.

Equal abatement costs as a percentage of GDP *(including emission trading)* – This approach still leads to the highest reductions for the EU and Japan and to the lowest reductions for Oceania – in comparison to 1990 (see Table 4.5). Only the Japan region shows a difference worth mentioning: while for the '20% Annex I comparable' case the reduction against 1990 levels lies around the Annex I average, it now has a reduction target higher than average.

Converging per capita emissions approach – In this approach, the patterns also differ little from those of the '20% Annex I comparable' case. Only for the Ukraine region do the reduction targets converge with the other approaches, becoming less of an outlier on the low reduction-level side. This change is most visible in the reduction compared to 2000 levels.

Triptych approach – This approach assigns one of the largest reductions to the USA, unlike in the '20% Annex I comparable' scenario (see also Figure 4.11). This increased reduction for the USA provides room for slightly lower reductions for the EU and Japan.

Looking at all cases, the model results show findings that are similar to those found for the '20% Annex I comparable' scenario. For example, both scenarios show that the reductions below the 1990 level are high for the EU and low for the USA and Oceania. However, there are a number of findings that exclusively relate to the '30% Annex I comparable' scenario:

- In the '30% comparable scenario', the EU in most cases reduces more than its multi–lateral 30% reduction target. This scenario is compatible with the EU 2 degree target, for which the EU reduces to 25 to 38% below 1990 levels. This scenario offers a reasonable chance (over 50%) of achieving the EU climate target of limiting global temperature increase to 2°C, as the global emissions of 25% above 1990 levels resemble a 450 ppm CO_2-eq scenario.

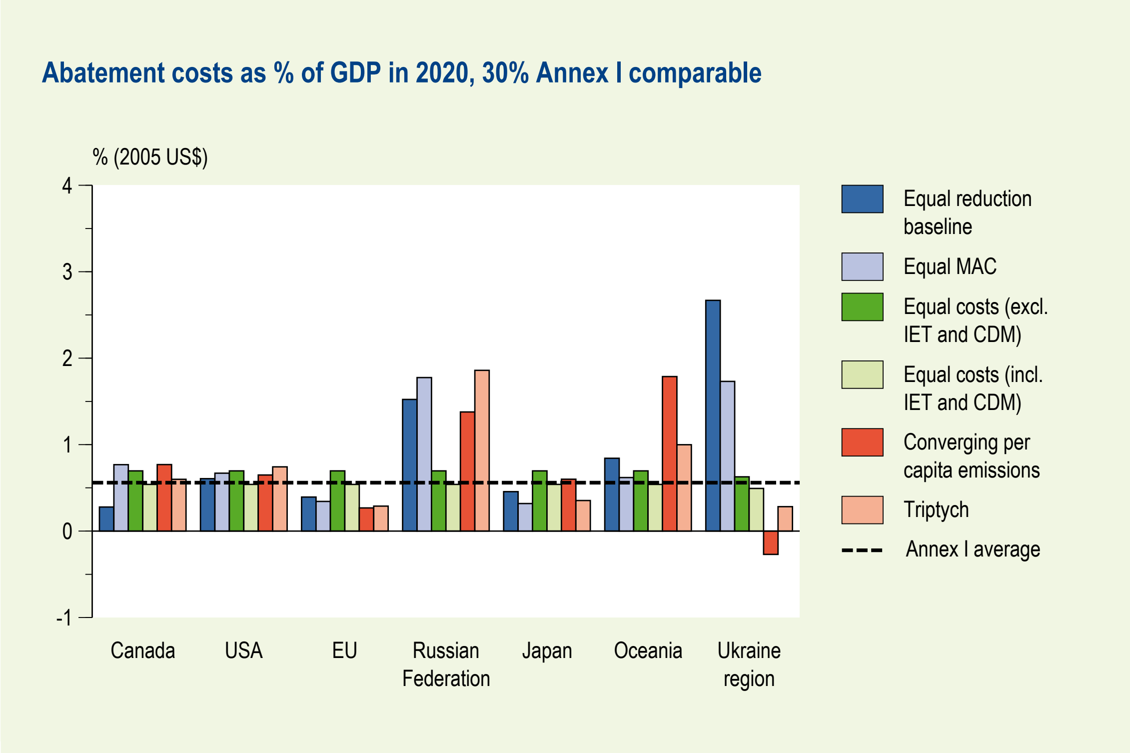


Figure 4.12 Abatement costs as a percentage of GDP, by 2020, under the '30% Annex I comparable' scenario, assuming emission trading with the coalition of Annex I regions and ADCs and CDM with the other developing countries [except for the equal costs case (excl. trade) for which we assume no trade and no CDM].

4.3.2 Abatement costs

For the '30% Annex I comparable' scenario, the Annex I average cost level has risen threefold to about 0.55%. This also leads to higher trade volumes (Figure 4.12). The Annex I countries now increase their buying of carbon credits by 50% (see also Table 4.3 and Figure 4.13. For most regions, the cost differences among approaches have increased, relative to the '20% Annex I comparable' scenario (compare the highest and the lowest for each region in Figure 4.12 and Figure 4.6, except for the Ukraine, which shows smaller differences.

4.3.3 Other indicators

This scenario leads to an even stronger convergence in per capita emissions and emissions intensity (Figure 4.14 and Figure 4.15).

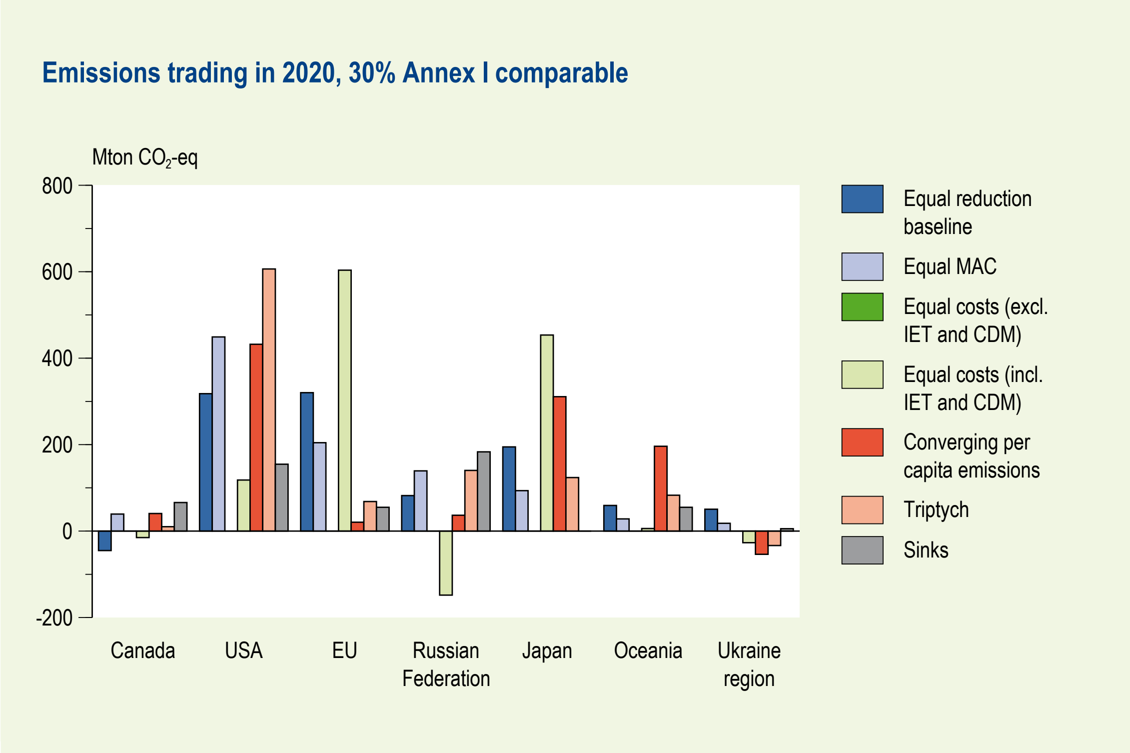


Figure 4.13 Emission trading, in 2020 under the '30% Annex I comparable' scenario, assuming emission trading with the coalition of Annex I regions and ADCs and CDM with the other developing countries.

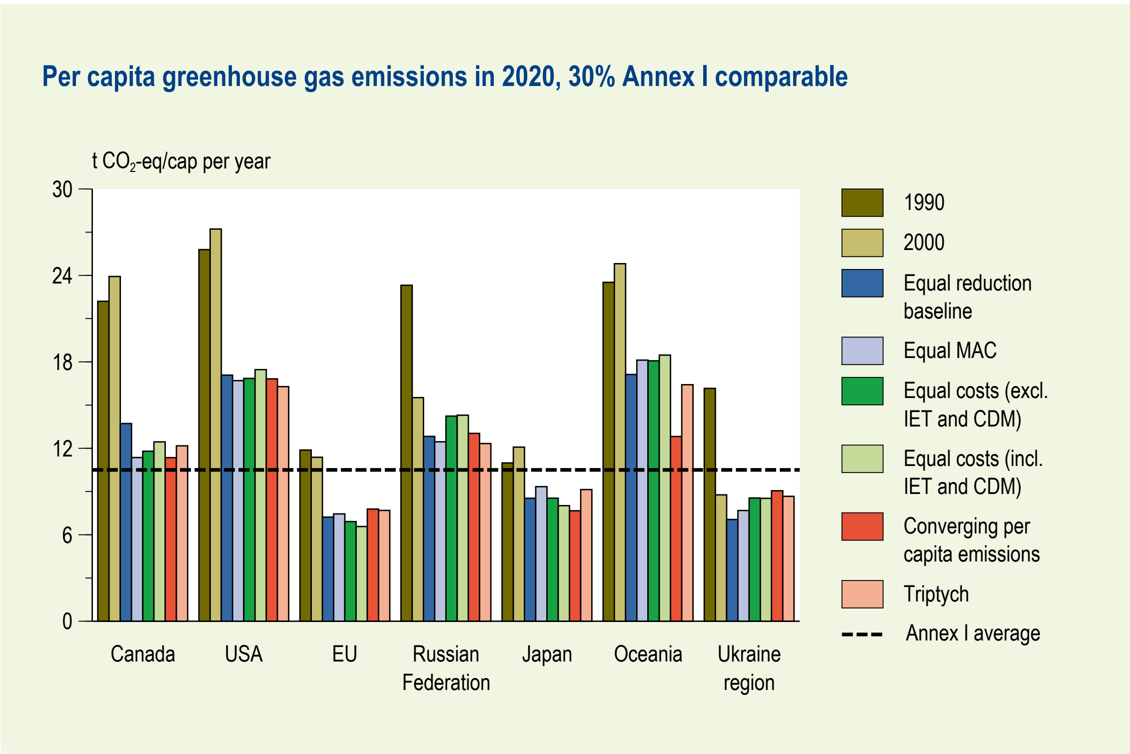


Figure 4.14 Per capita emissions, by 2020, under the '30% Annex I comparable' scenario. Here also the Annex I and world average for 2020 are shown.

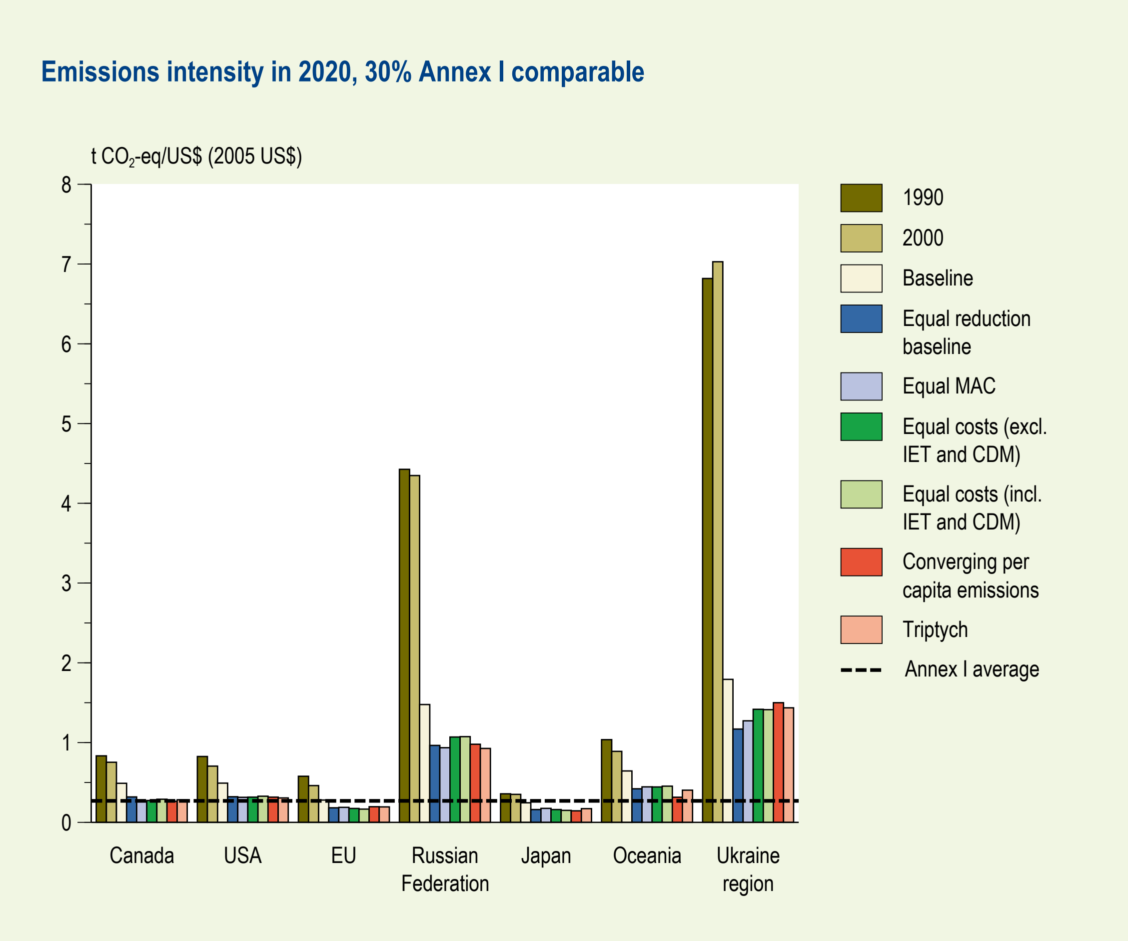


Figure 4.15 Emission intensity, by 2020, under the '30% Annex I comparable' scenario. Here also the Annex I average for 2020 is shown.

4.4 '40% Annex I comparable' scenario

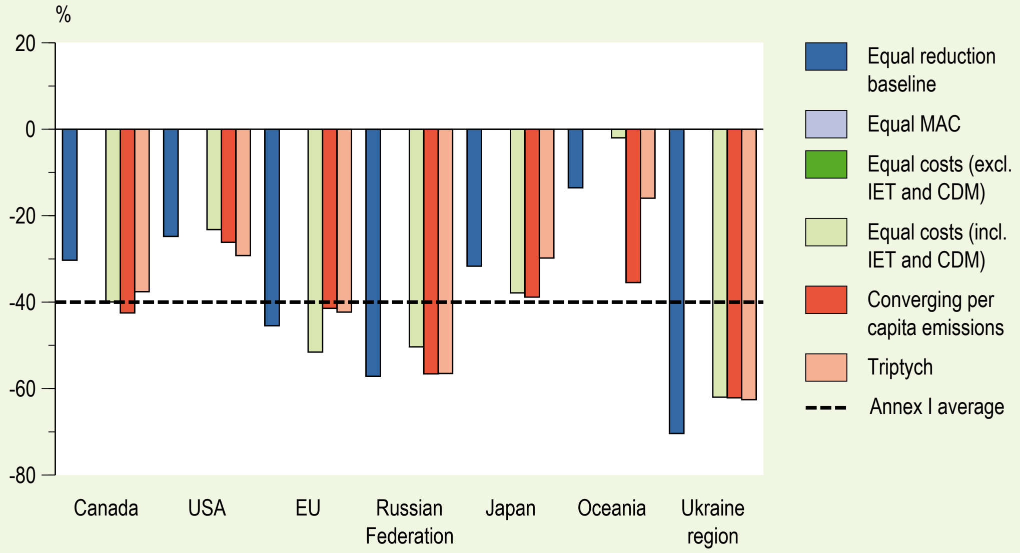
4.4.1 Annex I countries' reduction targets

The calculated reductions for the '40% Annex I comparable' scenario show a similar pattern to those for the other two scenarios (Figure 4.16, Figure 4.17 and Table 4.6). As above, here also only notable differences in the reductions for each of the approaches are discussed.

Equal percentage reduction below a reference scenario – The pattern remains the same with this approach, resulting in more than average reductions for the Russian Federation and the Ukraine region, when compared to 1990 levels. When compared against 2000 levels, the reductions are more than average for Canada, the EU and the Ukraine region.

Equal MAC – This approach is not available for the '40% Annex I comparable' case with our model parameters. Given the MAC curves we have used, the reductions reached by individual regions at a maximum tax level of 1000 US$(2005)/t carbon equivalent (about 272 US$(2005)/t CO_2 equivalent) are not sufficient for reaching the desired levels. This is particularly evident for reductions at high prices, where the MAC curves used in the model are stretched to their limits. The higher the price level, the less reliable and less complete the estimate for emission reduction options.

Reduction compared to 1990 emissions in 2020, 40% Annex I comparable



Reduction compared to 2000 emissions in 2020, 40% Annex I comparable

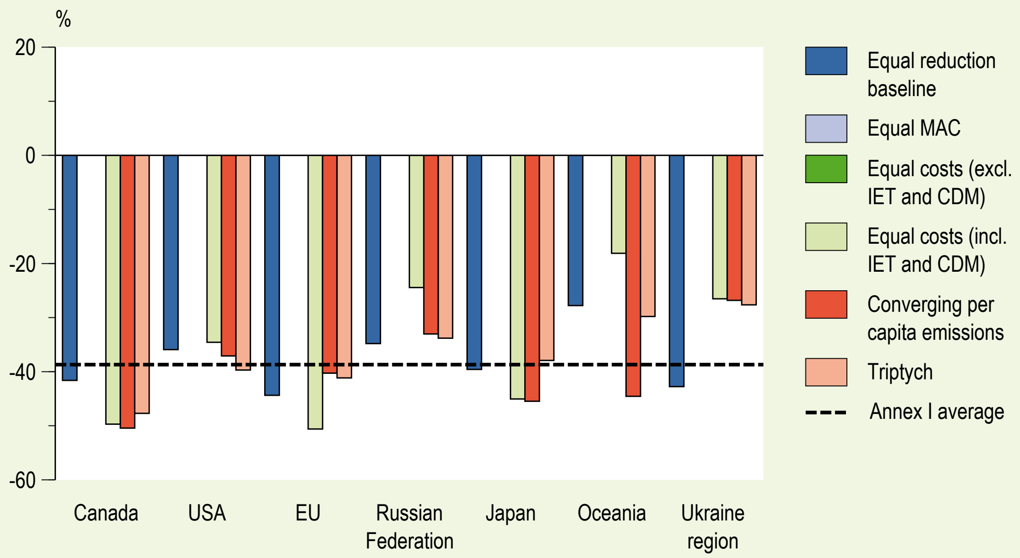


Figure 4.16 Reduction compared to 1990 levels (upper) and 2000 levels (lower), by 2020, under the '40% Annex I comparable' scenario. The equal MAC case and equal costs case (excl. IET and CDM) cannot be attained under a 40% Annex I reduction target and, therefore, no results are shown here. The dotted line represents the Annex I average.

Table 4.6 Reduction targets (%) compared to 1990 levels, by 2020, for the 'Annex I 40% comparable' scenario. The red cells indicate the approach with the highest reduction per country/region and the green cells indicate those with the lowest reductions. The equal MAC case and equal costs case (excl. IET and CDM) cannot be attained under a 40% Annex I reduction target, therefore, no results are shown here (N.A. =F Not Attainable).

Regions	2010 target*	Equal reduction baseline	Equal MAC	Equal costs (excl. Trade)	Equal costs (incl. Trade)	Converging per capita emissions	Triptych
Canada	–6	–30	N/A	N/A	–40	–43	–38
USA	26	–25	N/A	N/A	–23	–26	–29
EU	–8	–45	N/A	N/A	–52	–41	–42
Russian Federation	–28	–57	N/A	N/A	–50	–57	–57
Japan	–6	–32	N/A	N/A	–38	–39	–30
Oceania	7	–14	N/A	N/A	–2	–35	–16
Ukraine region	–40	–70	N/A	N/A	–62	–62	–63
Annex I	–1.5	–40	N/A	N/A	–40	–40	–40

* For 2010, we assume that all Annex I countries (except USA) reach the minimum of their Kyoto target or their reference emissions by 2010.

Equal abatement costs as a percentage of GDP *(excluding emission trading)* – Also for this approach, available mitigation measures in the model are insufficient for individual regions to attain the required reduction level. Emission trading and CDM are needed for meeting the 40% overall Annex I reduction target.

Equal abatement costs as a percentage of GDP *(including emission trading)* – The availability of IET and CDM allows regions with limited reduction potentials to still meet the required 40% reduction target for Annex I. The Oceania region may still stabilise emissions around 1990 levels, indicating the limited availability of domestic reduction measures. For Japan, the reduction under this approach has become the most significant, in part caused by the high GDP levels in this region.

Converging per capita emissions approach –No significant changes occur for this approach, with an increase in the Annex I reduction levels to 40%.

Triptych approach – No significant changes occur for this approach, with an increase in the annex I reduction levels to 40%.

Looking at all cases, the model results show the following:

- *A 40% Annex I reduction objective can only be met when* CDM *and emission trading are allowed*, but high reduction targets and costs would still be introduced (see next section) for all Annex I regions. The USA would need to reduce its emissions by more than 20% below 1990 levels, and for the EU this would be 40% to 50% below 1990 levels.

4.4.2 Abatement costs

The abatement costs as a percentage of GDP further increases for the 40% Annex I reduction target, with the average Annex I costs almost doubling, relative to the '30% Annex I comparable' scenario and reaching around 1% of GDP. For the Russian Federation and Oceania, in particular, the abatement costs lie considerably above the Annex I average, with the exception of the *equal costs* case (Figure 4.18). The import of emission permits from the non-Annex I

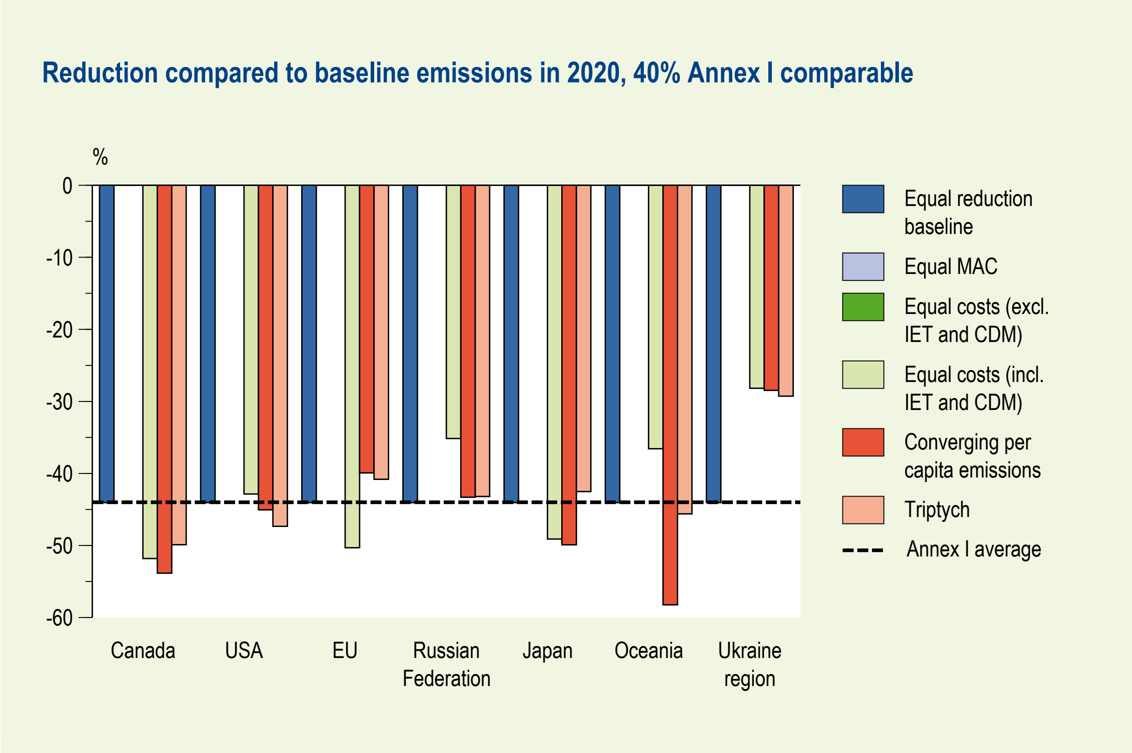


Figure 4.17 Reduction compared to reference or baseline emission levels, by 2020, under the '40% Annex I comparable' scenario.

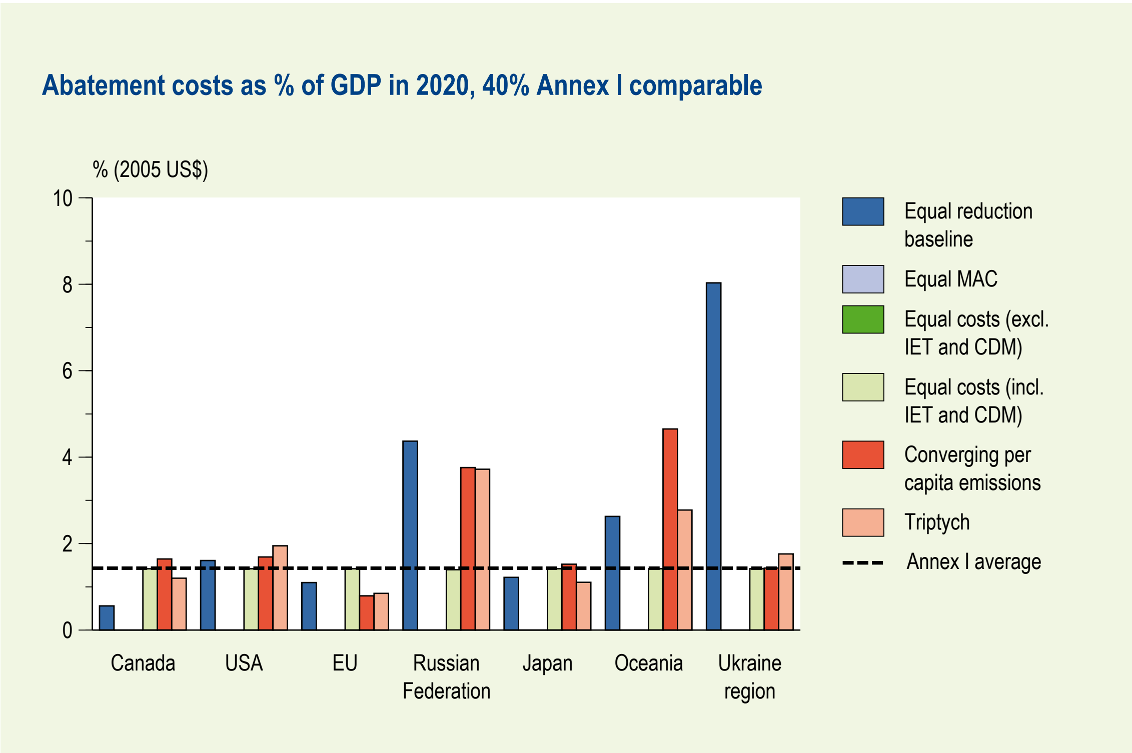


Figure 4.18 Abatement costs as a percentage of GDP, by 2020, under the '40% Annex I comparable' scenario assuming emission trading with the coalition of Annex I regions and ADCs and CDM with the other developing countries [except for the equal costs case (excl. Trade) for which we assume no trade and no CDM].

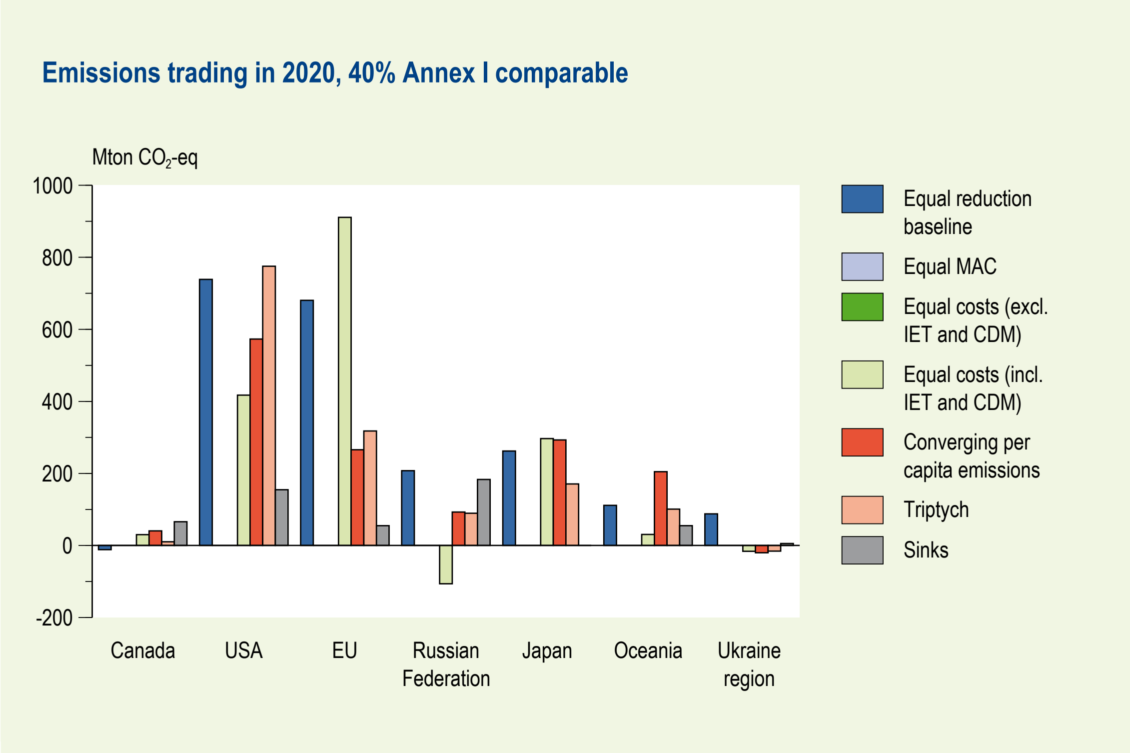


Figure 4.19 Emissions trading, by 2020, under the '40% Annex I comparable' scenario assuming emission trading with the coalition of Annex I regions and ADCs and CDM with the other developing countries.

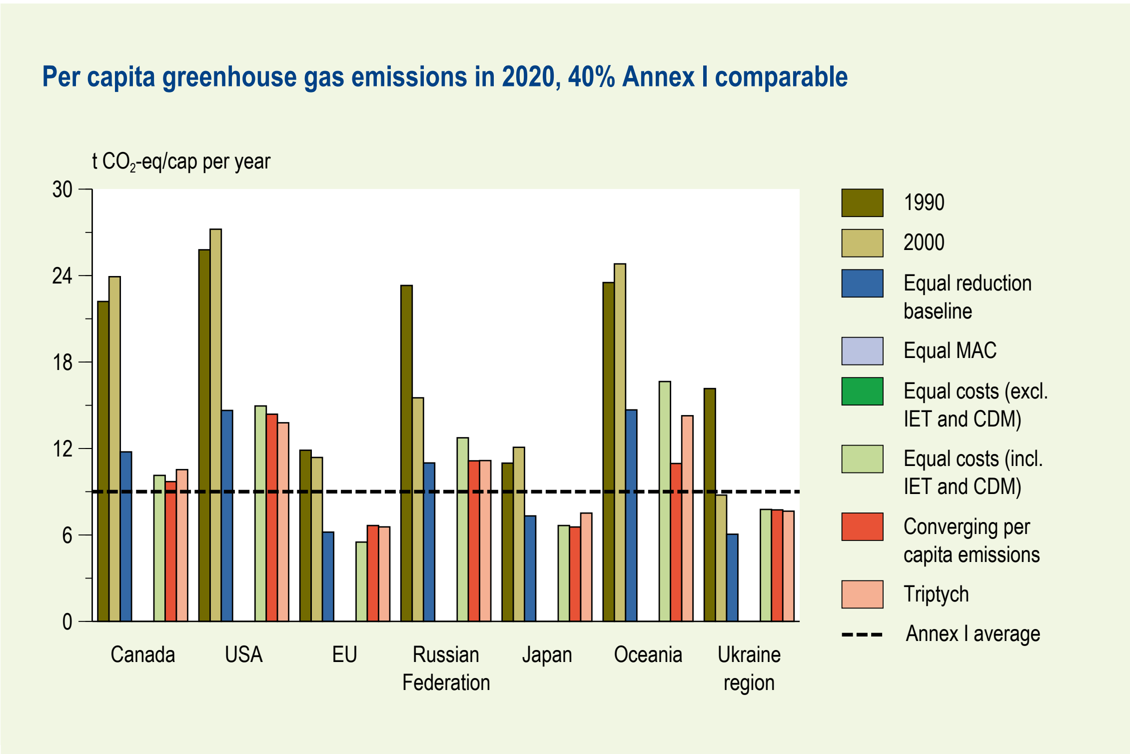


Figure 4.20 Per capita emissions, by 2020, under the '40% Annex I comparable' scenario. Here also the Annex I and world average for 2020 are shown.

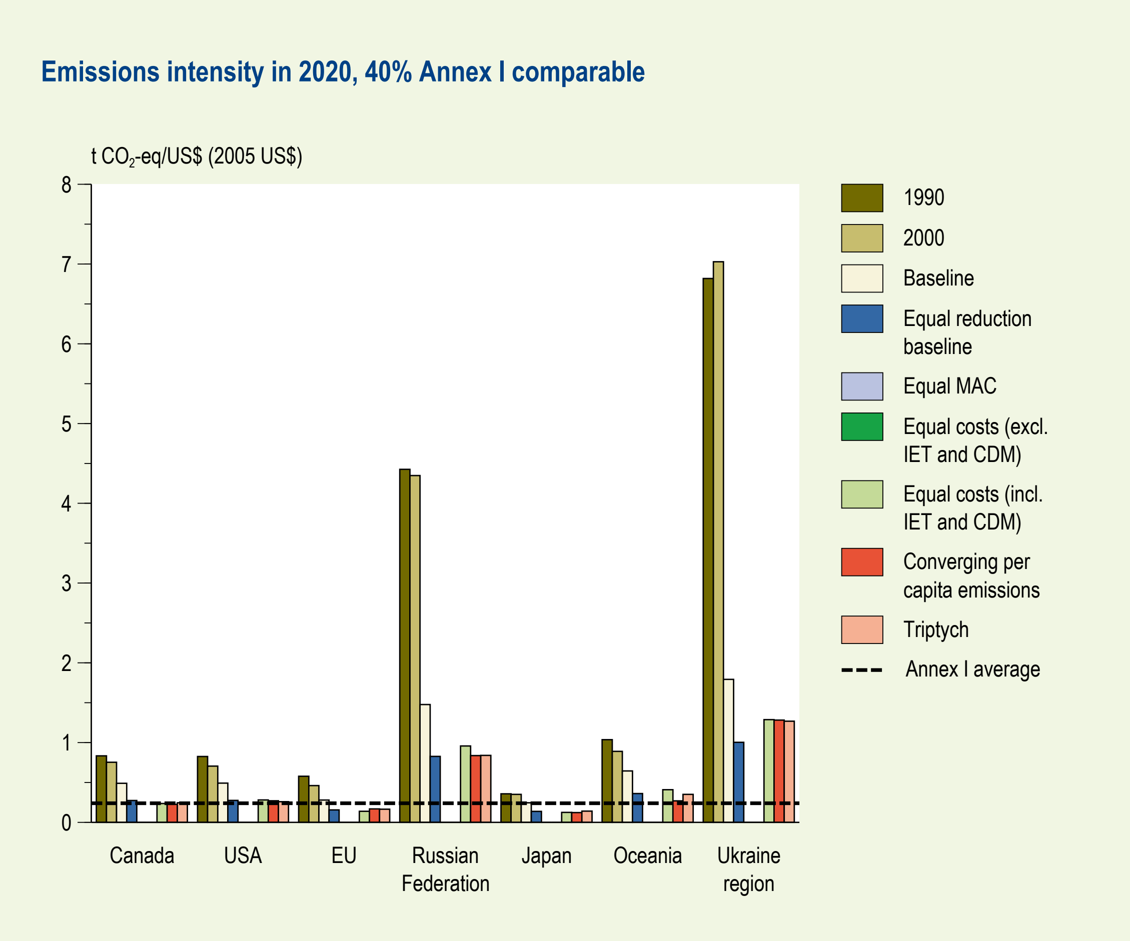


Figure 4.21 Emission intensity, by 2020, under the '40% Annex I comparable' scenario. Here also the Annex I average for 2020 is shown.

regions increases still further, with the USA and the EU being the largest buyers (Figure 4.19). Some Annex I regions may still act as exporters of emissions permits, but their exported traded volumes are much less than those under the '20%' and '30% Annex I comparable' scenarios.

4.4.3 Other indicators

For the '40% Annex I comparable' case, per capita emissions and emission intensity also decrease further (Figure 4.20 and Figure 4.21).

4.5 Comparison of the 20%, 30% and 40% Annex I comparable scenarios

Figure 4.22 shows the reductions, compared to 1990 levels, for the three scenarios for all individual Annex I regions. We have already concluded that the differences between the approaches are slight for large countries and relatively larger for small countries, due to the presence of specific national circumstances that are significantly different from the average. More specifically, for the USA, the EU and the Russian Federation, the differences in emission allowances in the various approaches is determined to be 5 to 10 percentage points for all three scenarios. For Canada, the differences are around 10 to 15 percentage points for all three scenarios, and for Japan, they are even more, that is, 20 to 25 percentage points. For Oceania, the magnitude of the

Figure 4.22 Comparison of the three scenarios.

difference depends highly on whether we include or exclude the c*onverging per capita emissions* approach, that is, 35% versus 15%, respectively.

To summarise, we present a number of general conclusions, based on our results:

- *The choice of the overall Annex I reduction level (20%, 30% and 40%) is of major importance* – For most Annex I countries, the differences in the magnitude of the reductions between the Annex I 20%, 30% and 40% reduction scenarios are usually larger than the differences in the reduction targets between the various approaches.
- *The reduction targets (compared to 1990 levels) for Canada, the* USA *and Japan are for most approaches more than 10 percentage points higher when opting for the 10% higher Annex I reduction target (compare the reductions under the '30%' with the '20% Annex I comparable' scenario), whereas for the Russian Federation and the Ukraine, the reduction targets are less (average of 5 percentage points).* Choosing a more stringent Annex I reduction target, such as the 30% instead of the 20% reduction scenario, leads to reduction targets that are 12 to 15 percentage points higher (see also Figure 4.22) for those countries with less stringent reduction targets (compared to 1990 levels), such as Canada, the USA and Japan. This also holds, to a lesser extent, for Oceania. For the EU, the reduction targets increase by about 10 percentage points. For countries with relatively high reduction targets, that is, the Russian Federation and the Ukraine, the increase is less.
- *Emissions need to be reduced* – For an overall Annex I reduction of 20% and 30%, significant reductions below 1990 levels for all approaches are necessary, for all Annex I countries (except Oceania), to meet the overall Annex I reduction target (20% and 30%). The 40% reduction targets can only be met when both domestic and international efforts are implemented.

5 Robustness of results

This chapter discusses the robustness of the 2020 emission reduction targets for the Annex I countries, specified in this report, in terms of a number of the key assumptions, such as
- baseline scenario
- MAC curves (i.e. from the POLES energy model)
- initial (2010) emissions
- choice of the approaches
- parameterisations of the approaches

Only the first key assumption is analysed further, by using model simulations with alternative choices for the MAC curves, that is, the MAC curves from the POLES energy model (Criqui et al., 1999).

5.1 The impact of the baseline scenario

Den Elzen et al. (2007a, 2008a, 2005) and Höhne et al. (2007, 2005) have extensively analysed the impact of the baseline scenario on post-2012 Annex I emission reductions, for all allocation approaches of this study, with the exception of the *equal* MAC and *equal abatement costs* approaches. Höhne et al. (2007 (Figure 15)) have also analysed this effect for the '20% Annex I comparable' and '30% Annex I comparable' scenarios for individual Annex I countries. They concluded that the impact of the baseline scenario on the reductions, compared to 1990 levels, is limited to the order of a few percentage points for most Annex I countries included in the present study, except for the Russian Federation (about 5 percentage points). This small effect is apparently the result of the uniform characteristics of the baseline scenario for all Annex I countries (a higher economic growth in the baseline scenario leads to higher economic growth rates for all Annex I countries) and the overall Annex I reduction targets of 20% and 30%.

This study uses two baseline scenarios for the sensitivity analysis (see the case *equal reduction baseline* in Figure 5.1). In accordance with the results of the earlier studies mentioned above, the differences found in our sensitivity analysis are also only a few percentage points for most countries, except for the USA (about 5 percentage points) and Oceania (almost 10 percentage points) (see Table 5.1). Our study does not analyse the impact of the baseline scenario for the costs-allocation approaches in further detail, but for the same reason as above, it is expected that for these approaches also, the impact is small for most countries.

5.2 The impact of the MAC curves: POLES

Here we analyse the impact of using POLES MAC curves in combination with the associated POLES baseline scenario This baseline is consistent with our default IMAGE/TIMER baseline, as both scenarios are constructed for the ADAM project (Van Vuuren et al., 2008 (in preparation), by combining and harmonising the reference scenarios of the POLES and IMAGE/TIMER model. For the model analysis of the MAC curves we focus on the '20%' and '30% Annex I comparable' scenarios and the following three cases:
1. equal percentage reduction below a baseline scenario
2. equal MAC
3. equal abatement costs as a percentage of GDP, by 2020 (including IET & CDM)
4. converging per capita emissions approach

Table 5.1 Reduction targets (%), for 2020, compared to 1990 levels, for the '20% Annex I comparable' (upper) and '30% Annex I comparable' (lower) scenarios for the POLES (right) and IMAGE/TIMER MAC curves (left).

	IMAGE/TIMER MAC curves				POLES MAC curves			
Regions	Equal reduction baseline	Equal MAC	Equal costs (incl. IET and CDM)	converging per capita emissions	Equal reduction baseline	Equal MAC	Equal costs (incl. IET and CDM)	converging per capita emissions
20% Annex I Comparable								
Canada	–7	–19	–14	–23	–9	–15	–13	–23
USA	0	0	1	–2	–4	–9	–3	–4
EU	–27	–26	–31	–22	–26	–18	–28	–22
Russian Federation	–43	–45	–40	–42	–44	–51	–42	–39
Japan	–9	0	–11	–18	–4	8	–7	–18
Oceania	15	17	19	–14	5	–8	4	–15
Ukraine region	–61	–59	–56	–50	–61	–65	–58	–55
Annex I	–20	–20	–20	–20	–20	–20	–20	–20
30% Annex I Comparable								
Canada	–19	–33	–26	–33	–20	–29	–24	–33
USA	–12	–14	–10	–14	–16	–20	–15	–16
EU	–36	–34	–42	–32	–35	–26	–38	–32
Russian Federation	–50	–51	–44	–49	–51	–60	–47	–46
Japan	–20	–13	–25	–28	–16	–6	–22	–28
Oceania	1	7	9	–25	–8	–19	–8	–25
Ukraine region	–65	–62	–58	–56	–66	–70	–61	–61
Annex I	–30	–30	–30	–30	–30	–30	–30	–30

The *Triptych* approach is not analysed here in further detail, as the results only depend on the assumed parameters and baseline activity developments, and these effects are extensively analysed in Den Elzen et al. (2008a). The *equal abatement costs approach (excluding* IET *&* CDM*)* is also not analysed any further, as the results using this approach are very similar to those of the *equal abatement costs including* IET *&* CDM (see Chapter 4). Figure 5.1 shows the reduction targets calculated for the three cases (see also Table 5.1), as well as a comparison of the results under our default settings, that is, the IMAGE/TIMER MAC curves and baseline scenario.

The *equal reduction below the baseline scenario* gives very similar results under our default baseline scenario and the POLES baseline scenario , except for Oceania, for which POLES gives higher reduction targets.

The *equal* MAC approach gives different reduction targets for most of the Annex I countries for the POLES MAC curves, compared to our default TIMER MAC curves. The POLES MAC curves lead to lower reduction targets for Canada, the EU (even below the Annex I average!) and Japan, but to higher reductions for the USA, the Russian Federation, Oceania and the Ukraine. The general pattern of lower reduction targets for countries with lower mitigation potentials than the Annex I average, such as Japan, still holds. We also find higher reduction targets for the other countries with higher mitigation potentials, such as the Russian Federation, Canada and the USA. In general, this result clearly shows that the reductions under the constraints of this approach are highly dependent on the specified assumptions on marginal abatement costs and baseline emissions.

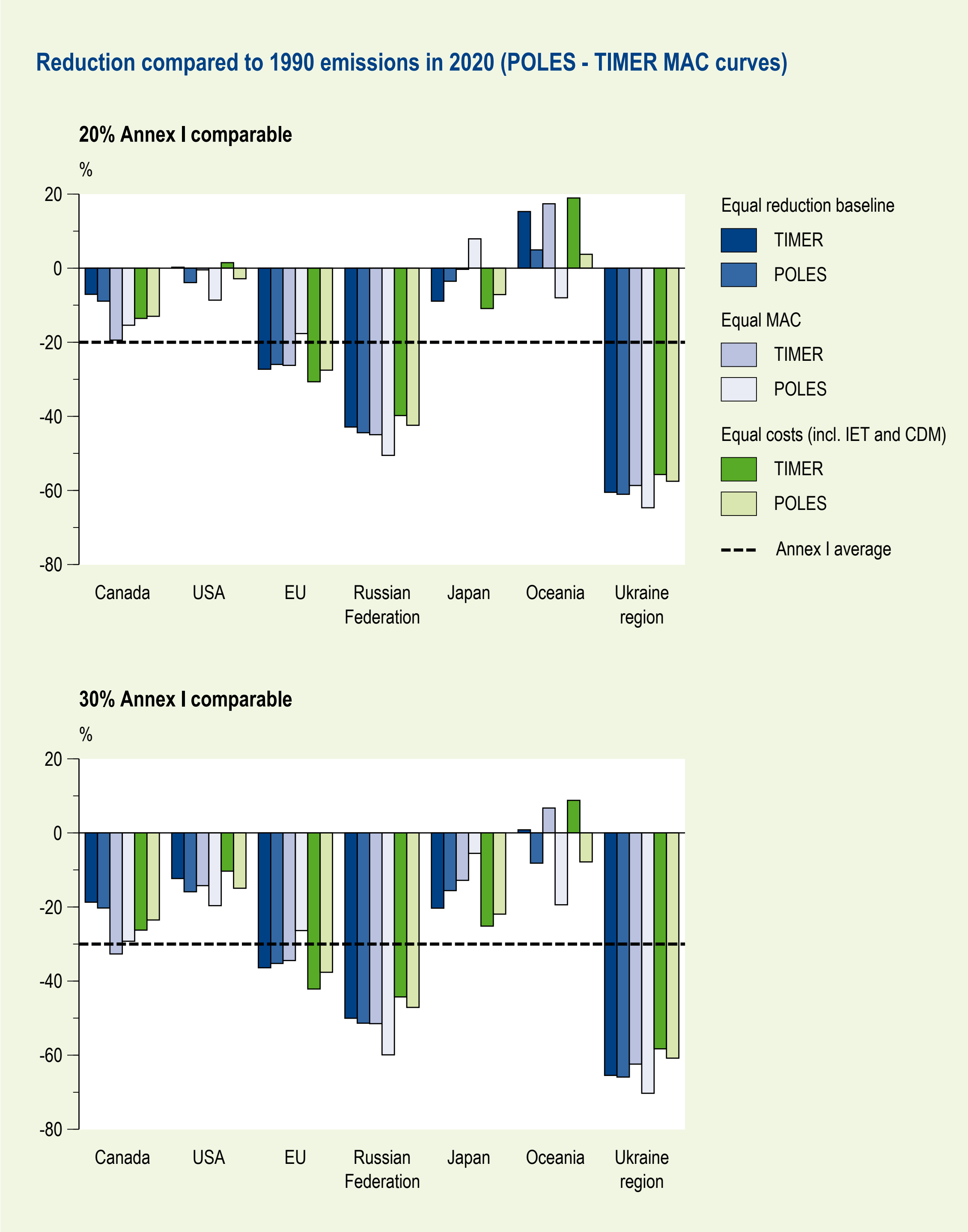


Figure 5.1 The reduction, compared to 1990 levels, by 2020, under the '20% Annex I comparable' scenario (upper) and '30% Annex I comparable' scenario (lower) for the POLES MAC curves and IMAGE/TIMER MAC curves.

The *equal abatement costs as a percentage of* GDP, *by 2020 (including* IET *&* CDM) approach gives similar change in reductions for countries, compared to the *equal* MAC approach, for the POLES MAC curves as for the TIMER MAC curves, that is, lower reductions for the Russian Federation and the Ukraine, and higher reductions for Japan and the EU. However, a slightly lower tax of 48US$(2005) per tCO_2 equivalent, by 2020, is needed to reach these results. The most significant changes among the regions are those for the USA and Oceania. Whereas under the

Table 5.2 Sensitivity analysis of the main indicators, by 2020, for the three scenarios for the '20% Annex I comparable scenario' (upper) and '30% Annex I comparable' scenario (lower). The results presented below are for the 'equal reduction below baseline' scenario, but the other scenarios give very similar results as we focus here on the Annex I and non–Annex I countries as groups.

	Default: IMAGE/TIMER MAC curves and baseline	POLES MAC curves and baseline
20% Annex I comparable		
Permit price (in US$(2005)/t$CO_2$)	49	26
Costs (%–GDP)		
Annex I	–0.22	–0.16
Non-Annex I	–0.09	+0.02
Global	–0.17	–0.10
30% Annex I comparable		
Permit price (in US$(2005)//t$CO_2$)	88	43
Costs (%–GDP)		
Annex I	–0.54	–0.35
Non-Annex I	–0.26	+0.03
Global	–0.44	–0.122

IMAGE/TIMER MAC curves, for the USA a small increase is allowed, compared to 1990 emission levels, under the POLES MAC curves, this becomes a small decrease. For Oceania, a considerable increase is allowed under TIMER MAC curves, while under POLES MAC curves, this is significantly reduced, although growth is still allowed against 1990 emissions. The differences between the assumptions for the MAC curves are not as great as those for the *equal percentage reduction below a baseline approach,* but the very existence of these differences supports our conclusion that the assumptions for marginal abatement costs are of considerable influence.

The *converging per capita emissions* approach gives very similar reductions for the POLES baseline scenario and IMAGE/TIMER baseline scenario, as both are based on the same population scenario which mainly affects the results.

To summarise, the assumptions in the POLES model result in a higher reduction range for both Oceania and the USA and a lower range for the EU and Japan. For example, under the '30% Annex I comparable' scenario reduction, the EU reduction range becomes 25 to 42% below 1990 levels (see Table 5.1), instead of the 30 to 40% that was calculated by using our default (IMAGE/TIMER MAC) calculations (full range as presented in Chapter 4). For the USA, under the same 30% Annex I reduction, the range becomes 15 to 20% below 1990 levels, instead of 10 to 15%.

The abatement costs for the Annex I, non-Annex I and the world are given in Table 5.2. This table shows that the permit price on the international carbon market, as well as the costs, are much lower for the POLES MAC curves than for the TIMER MAC curves. The costs results even shows small gains for the non-Annex I countries as a group under the '20% Annex I comparable' scenario. A similar pattern of lower costs can be seen for the Annex I countries when costs are calculated as a percentage of GDP (Figure 5.2).

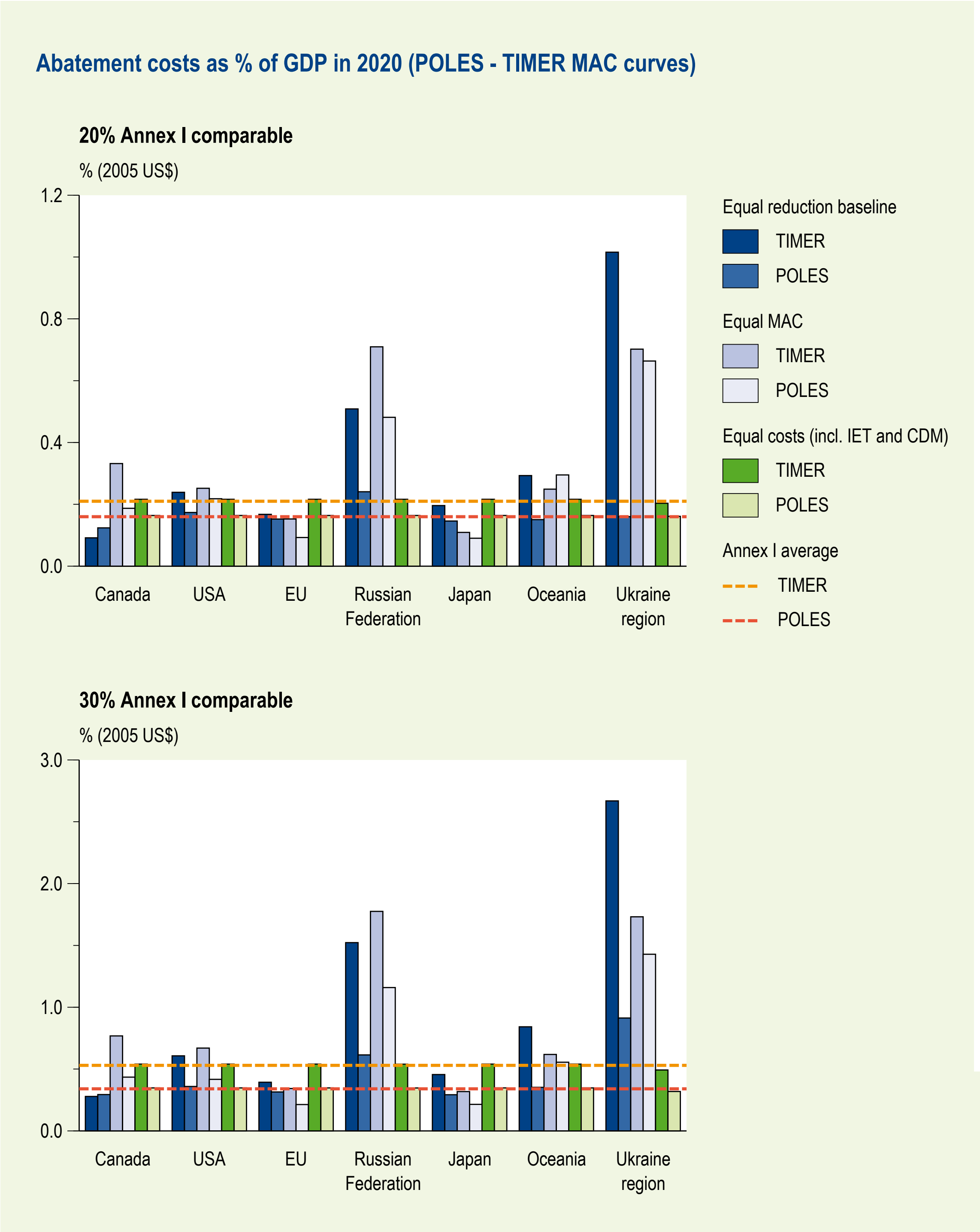


Figure 5.2 The impact of the use of POLES MAC curves on the abatement costs as a percentage of GDP, by 2020, under the '20% Annex I comparable' scenario (upper) and '30% Annex I comparable' scenario (lower). The dotted line represents the Annex I average costs for the POLES and IMAGE/TIMER MAC curves (default calculations).

5.3 The impact of the initial (2010) emissions

Another important parameter is the starting year for the calculations, being the 2010 emissions, since this starting point may also affect future commitments. We have assumed here that all countries start in 2010 at their Kyoto target, for the first commitment period. Exceptions are made for the USA with their national target (assumed here to be 23% above the 1990 level) and for the economies in transition, that is, the Ukraine and the Russian Federation (reference emissions by 2010 are below the Kyoto target). Ultimately, these de-facto political decisions may influence the results – depending on the approach.

For the approaches that focus on equal future burden, such as *equal reduction below a baseline* and *equal abatement costs*, and do not consider efforts that have been made in the past, the 2020 reduction targets are only slightly affected by the assumed 2010 emission levels. For example, the reductions by 2020, under the *equal reduction below a baseline* approach, are independent of the assumed 2010 emission levels. The same holds, to a large degree, for the equal costs approaches – *equal* MAC or *equal abatement costs*. Even if the USA were to implement Kyoto within the next 5 years, this would not lead to completely different MAC curves, although such a change would clearly affect its baseline projection and, therefore, the 2020 reductions. Annex I countries with baseline emissions by 2010 that are much lower than their Kyoto targets, such as the Russian Federation and the Ukraine, would benefit from more excess emission allowances if they were to start from their Kyoto targets. However, under an equal costs approach, this leads to higher 2020 reduction targets, as the gains from additional excess emission allowances are taken into account.

For the options that strive for an equal endpoint, beyond 2020, being the *converging per capita emissions* and the *Triptych* approach, the results also depend on the assumptions on reaching or missing the Kyoto targets, by 2010 (see also discussions in Höhne et al., 2007). More specifically, implementation of the Kyoto targets for all Annex I countries leads to a higher reduction target for the USA and lower reduction targets for the Russian Federation and the Ukraine with their excess emission allowances; it also leads to slightly lower reduction targets for the other Annex I countries, as the additional reduction target for the USA is somewhat higher than the additional excess emission allowances. This is illustrated for the *Converging per capita emissions approach* in Table 5.3, which shows that the reduction target for the USA increases with about 20 percentage points, that is, to –23% below 1990 levels instead of –2%. The table also gives the effect of when only the USA would start at their Kyoto target.

As mentioned in Chapter 4, we overestimate the 2010 emissions of the USA, as we assume that they follow their national targets (+26% above 1990 levels), whereas the currently reported (2006) emissions by the USA are lower (around 2000 emissions, about 15% above 1990 levels). Table 5.3 also gives in its last column the impact when the USA remains at its 2000 emissions around 2010. We see that the impact is very limited (compare with Default case). For the Converging per capita emissions approach the reduction target for the USA increases with only 3 percentage points, to 5% below 1990 levels instead of 2% below 1990 levels under the default case. We have also calculated the USA reductions targets for the equal reduction below baseline and Triptych approach (not shown here), which gives a similar increase in the reduction targets for the USA.

In conclusion, the initial (2010) emission target has a very limited effect on the 2020 reduction targets for most countries under the 'equal future burden' approaches – in fact, much less than

Table 5.3 The impact of assuming that all Annex I countries start at their Kyoto target for the '20% Annex I comparable' scenario for the 'converging per capita emissions' approach.

	Default	USA starts at Kyoto target	All Annex I countries start at Kyoto target	USA stabilises at 2000 emissions
US	National target	Kyoto target	Kyoto target	2000 emissions
Russian Federation and Ukraine	Baseline emissions (2010)	Baseline emissions (2010)	Kyoto target	Baseline emissions (2010)
Regions				
Canada	–23	–15	–22	-22
USA	–2	–17	–23	-5
EU	–22	–13	–19	-20
Russian Federation	–42	–36	–20	-41
Japan	–18	–10	–17	-17
Oceania	–14	–4	–12	-12
Ukraine region	–50	–44	–19	-48
Annex I	–20	–20	–20	-20

would be expected beforehand. For the 'equal endpoint' approaches, however, the differences may be large, and for some countries, this difference may influence the results more than the choice of the future approach.

5.4 The impact of the choice of the approaches

A further important parameter is related to the choice of the approaches that have been included in the present analysis, because alternative approaches may be proposed in the upcoming post–2012 discussions. Ultimately, five approaches have been analysed here, varying from a simple approach, such as *equal percentage reduction below a baseline,* to more sophisticated approaches, such as the *Triptych* and the *equal costs* approaches. All of these approaches have been proposed in the past during the negotiations on the Kyoto targets. It is expected that most other approaches will be within the range found here.

5.5 The impact of the parameterisations of the approaches

Another important factor influencing the results is the choice of parameters for the different approaches that have been modelled here. Almost all approaches leave room for altering the balance of burden between high and low per-capita emission countries, by allowing variance in some of the parameters. For the *equal percentage reduction below a baseline*, the only parameter is the reduction. The *converging per capita emissions* approach depends on the convergence year. The outcomes for the *converging per capita emissions* approach are highly dependent on the assumed convergence year (here 2050). An earlier convergence year would assign even more stringent reductions to the USA and Canada. The results of the *Triptych* approach, particularly, depend on the choice made among the many parameters – that is, assumed parameters and baseline activity developments; this effect is extensively analysed in Den Elzen et al. (2008a) and Höhne et al. (2007). Here, we have aimed for a balanced set of parameters but, ultimately, this remains a subjective choice. For the e*qual costs* approaches, the results will largely depend on the assumptions for the MAC curves used. In addition, the outcomes could be different if they are not based on abatement costs but on macroeconomic impacts.

6 Discussion

Important limitations of the current study
This study uses an integrated modelling framework (FAIR) to explore the regional emission reduction targets and abatement costs for the Annex I countries. However, there are a few important limitations to the study that are essential to interpreting the results.

First, the results are based on model data and projections. Such data do not always represent official reporting data and national projections of the UNFCCC, due to the fact that models remain simplified representations of reality that do not cover all sectors and are not always calibrated at the national level. Consequently, models are only partially able to reproduce these data. This is not only true for the IMAGE set of models but for most regional and global models, as well. This shortcoming could be mitigated by including official national data and projections, but the inclusion of such information would result in internal inconsistencies (e.g. between baselines and MACs). The impact of using different datasets has already be analysed in Höhne et al. (2007), who showed it to be limited.

Second, emissions from Land Use, Land Use Change and Forestry (LULUCF) are not included in the calculations, and not in the MAC curves for Annex I countries. These emissions constitute a large share of the emissions of some Annex I countries. The inclusion of the LULUCF sectors in a more elaborated approach could have a significant impact on the range of mitigation targets, particularly those with large forest areas, being the USA, Canada, Australia, New Zealand and Russia. The accounting rules for LULUCF are currently under discussion and can also have a large impact.

Third, the cost concept used in this study refers to direct abatement costs, only on the basis of MAC curves derived from underlying expert models – and does not capture the macroeconomic impacts of climate policy. Macroeconomic cost measures (such as consumption or GDP losses, but also sectoral impacts) may, in some cases, be larger, as they also include effects, such as the loss of competitiveness, impacts on fuel trade, and combined effects of climate policy and existing taxes, among many others. Conversely, they could also be smaller, since there will always be sectors and industries that profit from climate policy and there may be benefits from recycling the revenues of carbon taxes.

Finally, there is a need for much more extensive model comparison. In our analyses, we used our own IMAGE/TIMER costs and baseline emission estimates, as well as those of the POLES energy mode – and our comparison of these results reveals a number of significant differences in outcomes. Therefore, in order to arrive at more robust outcomes, we conclude that it would be better – in terms of arriving at more robust results – to include the results of calculations carried out within the framework of other energy system or macroeconomic models or, alternatively, based on baselines and MAC curves derived from these. Such models include the GEM–E3 model (University of Athens, Greece), the POLES model (University of Grenoble, France and Joint Research Centre, Spain), the GAINS model (IIASA), the AIM model (NIES, Japan), the MERGE model (Stanford University, USA), the REMIND model (PIK, Germany) and the E3MG model (Barker, UK), to name only a few. The inclusion of different baseline scenarios and other MAC curves from these models into our analysis would probably automatically result in a more extensive sensitivity analysis.

7 Conclusions

In this report we have analysed the concept of 'comparable efforts' between Annex I countries in a future international agreement on climate change. Our first step in this analysis was to describe the conceptual approaches currently in use to assess the comparability of Annex I country GHG mitigation efforts. Subsequently, we assessed the pros and cons of each approach. Six approaches (*equal reduction below a baseline*; *equal* MAC; *equal abatement costs as a percentage of the* GDP *by 2020 (excluding* IET *and* CDM*)*; *equal abatement costs as a percentage of the* GDP *by 2020(including* IET *and* CDM*)*; *converging per capita emissions*; *Triptych)* were selected for quantification based on the criteria of representation of efforts and technical feasibility. The report analyses the implications of the approaches in terms of the emission allowances for Annex I countries (all Kyoto GHGs) and the abatement costs for meeting the overall Annex I reduction goal of 20%, 30% and 40%, below 1990 levels, by 2020. We found that the emissions for non-Annex I countries as a group would have to be below their baseline by 10%, 16% and 22%, by 2020, to achieve concentration stabilisation at 550, 450 and 400 ppm CO_2eq, respectively. We calculated emission allowances (before emission trading) and abatement costs (after emission trading) on a regional level and assessed the difference between the various approaches. To test the robustness of the results for alternative key assumptions – i.e. the MAC curves – we also carried out a selective sensitivity analysis.

In the first conceptual part, we categorised the approaches used to arrive at 'comparable efforts' into two groups:
- **Equal future burden:** This rather common approach defines the problem as a burden that needs to be shared between the countries. The efforts to be compared are here defined as the level of *change from the current state* or level of *change from a likely reference development* – for example, equal reduction below a baseline. This perspective focuses on future efforts and usually neglects action that has taken place in the past.
- **Equal endpoint:** The second approach looks at efforts needed to reach *the same state in the future*, defined in terms of efficiencies – for example, converging per capita emissions in the target year (this study: 2050). Countries that are already closer to this endpoint, including those that are closer due to efforts already undertaken in the past, will have to undertake less effort in the future.

We argue that approaches that focus on equal future burden, such as *equal reduction below a baseline* and *equal mitigation costs*, have several disadvantages:
- They are based on future reference scenarios, which are, in turn, based on many assumptions. These assumptions will be the source of major disagreement, and there will an incentive to inflate projected assumptions.
- They often do not consider efforts that have been made in the past.

Approaches that focus on the equal endpoint, such as *converging per capita emissions*, the *Triptych* approach or equal efficiencies per sector, do not depend on a reference scenario and do acknowledge past actions. However, they do not always account for structural differences in national circumstances. For their implementation, indicators need to be defined (per capita emissions or sectoral efficiencies), and common endpoints need to be chosen. The results also depend on the assumptions on reaching or missing the Kyoto targets, by 2010.

Based on the results of our analysis, we draw a number of main conclusions on the different indicators analysed:

- *The choice of the aggregate Annex I reduction level is of major importance.* The choice of the overall Annex I reduction target is for most countries of major importance, as the difference in reductions between the 20%, 30% and 40% Annex I reduction scenario is usually larger than the difference between the various approaches aiming at the same Annex I reduction target..
- For all Annex I countries and under all six approaches, significant reductions from baseline levels are necessary for meeting the aggregate Annex I reductions.
- *Purely looking at reductions below 1990 levels is not a measure of comparable efforts.* Historical development since 1990 and assumed future reference emissions are significant determinants of the reductions, compared to 1990 levels. In comparison to 1990 emission levels, the highest reductions are found for the Ukraine and the Russian Federation, since their emissions have declined since 1990, and for the calculations we have to assume that their initial (2010) emissions start at the reference or baseline emissions, which are well below their Kyoto targets. The next highest reductions are found for the EU, whose emissions have levelled off since 1990 and do not grow much in the baseline. The EU is followed by Canada and, to a lesser extent, by Japan and the USA, whose emissions have all significantly increased since 1990 and are expected to continue to grow. In the '20%' and even the '30% Annex I comparable' scenarios, Australia and New Zealand are, in most cases, still allowed an increase from 1990 levels, but this could be different if land-use emissions were to be fully included in the analysis. The *Triptych* and *converging per capita emissions* approaches show relatively stringent reductions for the USA, Canada and Oceania (only the *convergence* approach) and relatively less stringent reductions for the EU and Japan (only *Triptych*) as these approaches acknowledge past actions. The outcomes for the *converging per capita emissions* approach are highly dependent on the assumed convergence year (here 2050). An earlier convergence year would assign even more stringent reductions to the USA and less stringent ones to the EU. Approaches based on mitigation potentials (equal marginal costs) assign stringent reductions to the emission-intensive (but less rich) regions, such as the Ukraine and the Russian Federation, while assigning less stringent reductions to Japan and the EU.
- *The abatement costs (as a percentage of* GDP*) also show a wide range for all Annex I countries.* The abatement costs (as a percentage of GDP) for the Annex I countries generally range between 0.1% and 0.3 % of GDP for the '20% Annex I comparable' scenario, between 0.3% and 0.6% of GDP for the '30% Annex I comparable' scenario and between 0.5% and 1.5% of GDP for the '40% Annex I comparable' scenario. Total abatement costs per GDP mostly tend to be relatively high in all approaches for Canada, the USA and Oceania (regions with the highest per capita emissions) and somewhat lower for the EU and Japan (regions with medium per capita emissions). There is a wide range of costs between the approaches explored, particularly for the *equal* MAC and *Triptych* cases. The abatement costs (and reduction targets) for the Russian Federation and the Ukraine are particularly sensitive to the allocation approach chosen. It should be noted that these costs only capture the direct costs of the abatement action and do not take into account macroeconomic impacts [due to sectoral changes and (fuel) trade impacts].
- The USA has relatively low reduction targets for 2020, compared to 1990 levels, when starting from their national target in 2010 and not from their Kyoto target. Emission reduction efforts for the USA would consist of a range of reduction targets of near 0%, 10 to 15% and 25 to 30% below 1990 levels, for the '20%', '30%' and '40% Annex I comparable' scenarios, respectively. The relatively modest USA reduction targets – in comparison to those of

other developed countries – are a direct result of the assumption that the USA will start, in 2010, at their national target, which is far above their Kyoto target. If the USA were to start at their Kyoto target, their reduction targets for 2020 would generally be more stringent.

- Reductions by the EU of at least 30% combined with comparable efforts by other Annex I countries and support for developing countries to keep emissions substantially below baseline (about 15 to 30%) are sufficient to secure the climate goal of 2°C. The emission reduction targets for the EU, for the cases explored, range from about 20 to 30%, 30 to 40% and 40 to 50% below 1990 levels, for the '20%', '30%' and '40% Annex I comparable' scenarios, respectively. For some of the approaches, the EU would have to reduce its emissions more than the average Annex I level. This implies that if the EU were to reduce its emissions by 30% below the 1990 level, by 2020, and if other Annex I countries would undertake a 'comparable effort' according to the approaches analysed here, the overall reduction for Annex I countries would be between 20% and 30% below the 1990 level. This target would be at the lower end of the 25 to 40% reduction range considered by the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP). However, it would still be consistent with the EU long-term climate goal of limiting the global temperature increase to 2°C above pre-industrial levels, as this range corresponds with the stabilisation of GHG concentrations at 450 ppm CO_2eq, provided that emissions in developing countries also deviate substantially from baseline (about 15 to 30%). The ranges found are also dependent on the cases explored and on the model and cost assumptions made.
- The reductions and costs of the various approaches presented above are dependent on the many assumptions on parameter settings, baseline and MAC curves used. As such, the equal percentage reduction from a baseline and equal abatement costs [equal MAC; equal abatement costs as a percentage of GDP by 2020 (excluding IET and CDM); equal abatement costs as a percentage of GDP by 2020 (including IET and CDM)] approaches depend on the assumed baseline and marginal abatement costs, the converging per capita emissions approach depends on the assumed convergence year and the Triptych approach depends on the assumed parameter settings and baseline activity levels. Our assessment of the sensitivity of the outcomes of using one set of alternative MAC curves (and baselines projections) from the POLES model shows that, while the pattern of reductions found seems to be rather robust, different assumptions on MAC can have a considerable influence on regional targets and, therefore, require further study. The assumptions in the POLES model result in a higher reduction range for both Oceania and the USA and a lower range for the EU and Japan. For example, under the 30% Annex I reduction, the EU reduction range becomes 25 to 38% below 1990 levels, instead of the 30 to 40% determined by using our default (IMAGE/TIMER MAC) calculations. For the USA, under the same 30% Annex reduction, the range becomes 15 to 20% below 1990 levels, instead of 10 to 15%. The results show a considerable uncertainty in the overall costs for Annex I countries in terms of meeting a 20% and a 30% overall reduction, by 2020, and even a greater uncertainty at the country level, such as for Canada. These uncertainties are also related to differences in baseline projections.
- The outcomes also depend on the selected approaches and other factors, such as land-use emissions. Apart from uncertainties related to the baseline assumptions and MAC curves used, the ranges found need to be used cautiously as they are contingent on the approaches included in the analyses and the modelling assumptions made. Moreover, (detailed) inclusion of land use and land-use change emissions – possibly according to different rules – could affect the outcomes, particularly for Annex I countries with a significant share in these emissions, such as Australia, Canada and the Russian Federation.

We also draw some general conclusions:

- *Emissions need to be reduced.* Significant reductions below 1990 levels for all approaches are necessary for all Annex I countries (except Oceania), if they are to meet the overall Annex I reduction target (20% and 30%). The 40% reduction target can only be met when both domestic and international efforts are combined, leading to high reduction costs.
- *In most approaches, the reduction targets for Canada, the USA and Japan (compared to 1990 levels) are over 10 percentage points more stringent when opting for an aggregated Annex I reduction target that is 10% more stringent (compare reductions under the '30%' and '20% Annex 1 comparable' scenarios), whereas for the Russian Federation and the Ukraine they are lower (on average, by 5 percentage points).* Choosing a more stringent Annex I reduction target – for example, 30% instead of 20% – leads to reduction targets that are 12 to 15 percentage points higher for those countries with relative low reduction targets (compared to 1990 levels), such as Canada, the USA and Japan. To a lesser extent, this also holds for Oceania. For the EU, the reduction targets increase by about 10 percentage points, whereas for countries with relatively high reduction targets, that is, the Russia Federation and the Ukraine, the increase is less.
- *Reductions below baseline are less stringent for countries that expect and/or report high growth and neglect past activities* – Countries for which more growth in emissions is projected will have to reduce less emissions below the 1990/2000 level. This is the case for the USA, Canada and Oceania. Countries for which a lower emissions growth is projected have to reduce more emissions below 1990/2000 (EU, Japan). Past actions to reduce emissions are not acknowledged.
- *Differences between the six approaches are smaller for large countries and larger for small countries.* For most countries and regions, the differences in emission allowances between the different approaches are relatively small, in particular for the USA and the EU, which dominate the average due to their sizes. The difference may be larger for a number of smaller countries and regions (in particular Japan, but also Canada and Oceania) because of specific national circumstances that are significantly different from the average.
- *The equal marginal abatement costs approach explicitly considers the availability of mitigation options, but its calculation depends on many assumptions.* – This approach leads to less stringent reduction targets for Japan (compared to the reduction below baseline approach), since Japan (in our modelling) has fewer low-cost reduction options than the average Annex I country, partly due to past efforts for improving energy efficiency. For other countries, such as the Russian Federation, the Ukraine and Canada, this approach leads to more stringent reduction targets compared to the *equal reduction below a baseline* approach. The EU has slightly fewer low-cost reduction options and the USA slightly more, but the effect is very small. Agreement on the appropriate cost estimates may be difficult, as their calculation depends on many assumptions, including not just projections but also MACs. In this respect, it would be important to include additional models in a future comparable analysis that would also enable additional testing of the robustness of the results.
- Equal abatement costs as percentage of GDP combines most aspects: reference emissions, reduction opportunities and level of welfare – GDP is relatively low for the Russian Federation and the Ukraine, leading to less stringent reduction requirements compared to equal MAC and to relatively high requirements for Japan and the EU, leading to more stringent reductions. The effect on the USA is minimal.
- Inclusion of the use of emission trading and CDM in the equal abatement costs as a percentage of GDP approach results in reduced obligations that account for targets being met more cost-effectively but mitigation outside of the country. The inclusion of trading has the largest implications for Japan, given its high level of welfare and limited relative low-cost mitigation

potential, while it has less impact on the targets for other countries. However, the inclusion of emission trading and CDM significantly reduces average mitigation costs across the Annex I countries.

- Results of approaches for 2020 that lead to equal endpoints, beyond 2020 (i.e. Triptych and convergence per capita emission), depend on assumptions made on the emissions of the countries, up to 2010. This applies in particular to Canada (which is likely to miss the Kyoto target) and the USA (did not ratify Kyoto). In our default calculations, we assume that Canada meets its Kyoto target, whereas the USA implements its national target (far above the earlier Kyoto target), leading to a much more stringent reduction target for Canada (for example, about 10 to 20% below the 1990 level for the 20% Annex I comparable scenario) than for the USA (return to 1990 levels). The assumption that both countries reach their respective Kyoto target (Canada) and earlier Kyoto target (USA) requires significantly more stringent reductions, by 2020, for both countries, about the same as the default Canada reductions. In the case of meeting the Kyoto targets, the reductions for Canada and the USA are more stringent for the equal endpoint approaches than for the approaches focusing on equal future burden.
- Of the approaches focusing on (converging to) an equal endpoint, equal per capita emissions may be too simplistic, Triptych more demanding and equal efficiencies per sector very data intensive, although still more transparent than approaches based on cost estimates. We, therefore, see merit in further exploring these approaches.
- Differences in per capita emissions and emissions intensity, but tendency toward convergence. There is some convergence in per capita emission levels and emission intensities, but often only in absolute terms (smaller range) – not in relative terms (indexed).

This study has been a first attempt to explore how comparable efforts could be defined. Further analyses involving more and different models, including macroeconomic models, are desirable for arriving at more robust results and common insights.

Based on the results of our analyses, we conclude that a compromise is probably the most attractive approach for all countries. This study tested several approaches, varying from the very simple (equal percentage reduction) to the very complex (equal costs approach). Each approach has characteristics that make it more – or less – attractive to any one (or more) of the Annex I countries. It would appear that any simple approach can, therefore, only serve as a general indicator of direction. The final agreement on an international climate change regime and also on the concept of burden-sharing between the Annex I countries is likely to be based on an approach using a complex formula that accounts for various national concerns. As such, it will ultimately be a negotiated compromise and comprise a multi-faceted or multi-layered system that will have been developed following an iterative process, involving the proposals and counter-proposals of various countries and the assessments of these proposals. The political deal will also include targets other than the reduction of domestic emissions, such as R&D expenditures, financial contribution to adaptation and avoidance of deforestation. The intention of the authors of this report is to provide data that can offer some relevant insight(s), as well as support to countries during this process.

Future work should consider including additional models into similar analyses and tests on the robustness of the results. This is particularly relevant for the analysis of the indicators related to costs (that is, have similar indicators analysed by additional modelers to be able to add to the robustness of the results and better frame the quantitative results). One could also compare model input data with data reported by different countries. Finally, one could explore the options of including more national data, projections and cost curves in the analyses.

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For all Annex I countries, reductions are necessary to meet climate goals

EU Heads of State and Government agreed in March 2007 that the EU will reduce its greenhouse gas emissions to 30% below 1990 levels by 2020 within a global and comprehensive post-2012 climate agreement. This commitment is provided that other developed countries commit to comparable reductions.

Within this context, this report first explores the pros and cons of possible conceptual approaches to assess the comparability of the greenhouse gas mitigation efforts by Annex I countries. Six approaches were selected for quantification based on the criteria of representation of efforts and technical feasibility, such as equal costs in terms of percentage of gross domestic product and equal marginal abatement costs. The implications of each of these six approaches were analysed in terms of the future reductions and abatement costs that must be made by different Annex I countries to meet the aggregate Annex I reduction targets of 20%, 30% and 40%, respectively, below 1990 levels.

The results of the analyses indicate that – under all approaches – significant reductions are necessary for all Annex I countries to meet their reduction targets. The highest reductions, calculated for 2020 and compared to the 1990 emission levels, will be achieved in the Russian Federation and Ukraine, because their emissions have declined since 1990. The next highest reductions will be achieved in the EU, followed by Canada. Behind Canada, to a lesser extent, are Japan and the USA, for the latter of which emissions have significantly increased since 1990. This study shows that reductions by the EU of at least 30%, combined with comparable reduction efforts by other Annex I countries and concrete support of developed countries for developing countries to keep their emissions substantially (about 15–30%) below baseline, are sufficient to secure the climate goal, that is, limiting the global temperature increase to 2°C above pre-industrial levels.

Netherlands Environmental Assessment Agency, December 2008