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Ancillary benefits of reduced air pollution from climate policies: Impacts on greenhouse gas abatement costs and the flexible mechanisms of the Kyoto Protocol

A Master's Thesis submitted for the degree of
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supervised by
Dr. Markus Amann

Renaud Moisan

0727339

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Abstract

Due to the fact that many air pollutants and greenhouse gases have common sources and can interact in the atmosphere to form hazardous components, mitigation measures focusing on climate objectives may have important consequences in air quality. The aim of the present thesis is to analyze how these linkages could impact results of negotiations on GHG emission targets, supposing that they are fully taken into consideration by policy-makers. Based on data from the GAINS[1] model developed at the IIASA[2], we show that the inclusion of avoided abatement costs of air pollutants and avoided impacts on health can significantly change the economic incentives of parties to the UNFCCC[3]. Most countries see a reduction in their mitigation costs, except for regions which significantly supply the carbon market with permits. The inclusion of ancillary benefits in the assessment of GHG mitigation costs also tends to reduce the demand for carbon trading and Clean Development Mechanism credits. However, it is observed that these decreases in carbon prices do not seem to change significantly the repartition of quantitative abatement efforts among Annex I countries.

[1] Greenhouse Gas and Air Pollution Interactions and Synergies

[2] International Institute for Applied Systems Analysis

[3] United Nations Framework Convention on Climate Change

Introduction

The difficulties currently encountered by parties to the Kyoto Protocol to agree on quantified abatement targets plead in favor of new tools providing objective data on greenhouse gas (GHG) abatement potentials and associated costs. However, the complexity and the global dimension of climate change impacts on environment and societies hinder the development of reliable and widely accepted assessments. Among the challenges to be overcome stands the question of the complex links between climate and air quality policies. Given that many air pollutants and greenhouse gases share common sources and can interact in the atmosphere to form hazardous components mitigation measures focusing on climate objectives may have important consequences in air quality. The literature describes this as ancillary benefits. This thesis serves as an analysis of the effects that these linkages and their results have on policy makers in negotiations if these are fully taken into account.

In order to address the question of co-benefits from air pollution and climate policies and facilitate integrated approaches in the environmental field, the GAINS[4] model has been developed at the International Institute for Applied Systems Analysis (IIASA), Vienna, Austria. It provides a consistent framework for the analysis of these benefits in terms of emissions, mitigation costs and quantitative impacts on health and environment. Building on the results of this project, a specific tool designed to highlight to policy-makers the costs of GHG mitigation at national levels has been developed. It allows a comparison of mitigation efforts in Annex I parties to the UNFCCC[5] under different targets and flexibility schemes (carbon trading, clean development

[4]Greenhouse Gas and Air Pollution Interactions and Synergies
[5]United Nations Framework Convention on Climate Change

mechanism). With its system approach, the model also quantifies reductions in air pollutant emissions due to GHG abatement strategies. Economically the GAINS model includes ancillary benefits in terms of avoided air pollutant abatement costs, expenses which should have been incurred if climate measures had not been taken. The goal of this Master's thesis is to analyze the potential effects of such an inclusion and to add a new layer to the modeling by integrating economic benefits from reduced impacts on health and environment. This implies an analysis of the avoided impacts in quantitative and economic terms and their comparison with direct mitigation costs.

The first chapter looks into the main linkages between climate mitigation measures and air pollutant emissions. These are summarized through a literature review. The second chapter describes the GAINS model and its methodology, its main assumptions and current results. Finally, I analyze how the inclusion of ancillary benefits into GHG mitigation costs impacts respective efforts from Annex-I countries in climate agreements. In particular the consequences on equilibriums in the carbon markets are assessed.

CHAPTER 1

Ancillary benefits from climate policies

This chapter aims to describe potential benefits of climate policies in air quality in both quantitative and economic terms. This chapter will look at the academic literature to identify the theoretical backgrounds, methodologies and the results obtained from previous empirical studies.

1.1 Theoretical background

Terminology

The notion of ancillary benefits is used to describe social welfare improvements caused by a given policy without being originally intended. In the context of climate change, the term is used to depict benefits from climate policies other than those derived from the reduction of greenhouse gas emissions. Policies aiming at reducing such emissions have deep impacts in non-climate related policy areas such as air quality, public health, energy security, poverty reduction, or trade to name a few (see IPCC (2007), WPIII for a more detailed list). For the purpose of this paper, impacts on air quality issues are the only secondary benefits considered.

At this stage, it is important to mention that a clear distinction has been made in the literature between 'co-benefits and 'ancillary benefits'. The first term, also known as multiple benefits, is used to describe secondary effects which are explicitly incorporated in a policy from the outset (IPCC (2007)). For example, this notion is preferred when climate and air quality policies are analyzed in a integrated framework. It represents the fact that most complex policies have more than one rationale. In this context, potential synergies are seen as co-benefits. This differs markedly from the notion of ancillary benefits whereby impacts arise incidental to mitigation policies. It is relevant if only one particular policy, for example climate change, is analyzed. The characterization of such benefits is particularly challenging since they are by definition not explicitly foreseen and can affect a wide range of sectors and activities. In order to acknowledge the fact that such impacts can be either positive or negative vis--vis social welfare, the term 'ancillary impacts' is sometimes used. As an example of negative impacts, one can mention the promotion of biofuels as an alternative to classical fossil fuels. This new trend aims to reduce GHG emissions but leads to increased emissions in fine particulate matter and volatile organic compounds.

In conclusion, the term ancillary benefits will be used to describe the incidental impacts of climate policies on air quality, that is an overall reduction in air pollutant emissions and reduced impacts on health and environment.

Primary and ancillary benefits

Even if primary and ancillary benefits result from the same policies, three fundamental factors ensure there is a differentiation between these two effects:

- **Local Vs Regional**: : The spatial dimensions of global warming and air pollution effects substantively differ. For the latter, local air pollutant emissions affect populations and ecosystems at the local and regional scales, while the climate change phenomenum is truly global. Based on this distinction, ancillary effects could be seen as private goods for the policy-making region while climate effects have public good characteristics (non-rivaled and non-excludable, see Rubbelke (2002)). An exception to the private characteristic of air quality appears if greenhouse gases other than CO_2 are considered in policies. For example, abatement of chlorofluorocarbons (CFCs) would lead to an improvement in the protection of the stratospheric ozone layer, a global rather than a local issue.

- **Time Horizon**: the second main difference between primary and secondary benefits is the time scale on which these effects occur. Air pollution has direct and rapid effects on health and environment. For example, peak levels of pollution in urban cities are directly connected to levels of emissions. Any reduction has immediate impacts on air quality (Ekins (1996)). On the contrary, primary benefits are expected to occur in the future, possibly with a delay of about a half century

(Markandya & Rubbelke (2003)). This of course raises many questions regarding the most appropriate way to compare these two types of benefits. For example, choosing a high discount rate is advantageous for ancillary benefits. While some air pollution impacts such as acidification or eutrophication of ecosystems are long-term effects, the narrow economic literature has mainly focused on ancillary benefits from health pathways rather than in environmental issues(Krupnick *et al.* (2000)).

- **Scientific Knowledge**: scientific uncertainties about air pollutant emissions, its transport in the atmosphere and the effects on health and environment are nowadays lower than those associated with our understanding of the climate system. The same conclusion does not necessarily hold true when it comes to the economic valuation of its impacts. As we will see in the following pages discrepancies still exist regarding the application of this economic field to air pollution impacts.

1.2 Methodologies

Even if most studies are solely empirical and assess levels of ancillary benefits in particular regions and for particular sectors, it is of interest to mention briefly the conceptual framework behind these approaches. The most comprehensive theorization of ancillary benefits' analysis has been performed in Krupnick *et al.* (2000) and Rubbelke (2002). Figure 1.1 is an illustration of the main components to be considered in any assessment. A focus is put on the economic and institutional system which determines the links between climate policies and reduced air pollutant emissions.

In other words, the structure of the analysis of economic sectors and the technologies determine the correlations between policy measures and emission control. On the other hand, the actual physical effects are determined by the ecological system. Air pollutants have many impacts on health and environment which in turn affect human activities. The last step of the analysis is the determination of externalities generated by these feedbacks. Such externalities depend on the tax system and types of existing environmental regulations. Because of the the complexity of these linkages the literature employs a wide spectrum of methodologies to assess ancillary benefits. In practice, bottom-up or top-down approaches can be used to evaluate correlations between climate policies and reductions in air pollutant emissions. Some studies focus on particular industries while others look at the issue area in a multi-sector approach to identify economy-wide general-equilibrium effects. The studies show that variations exist between different countries

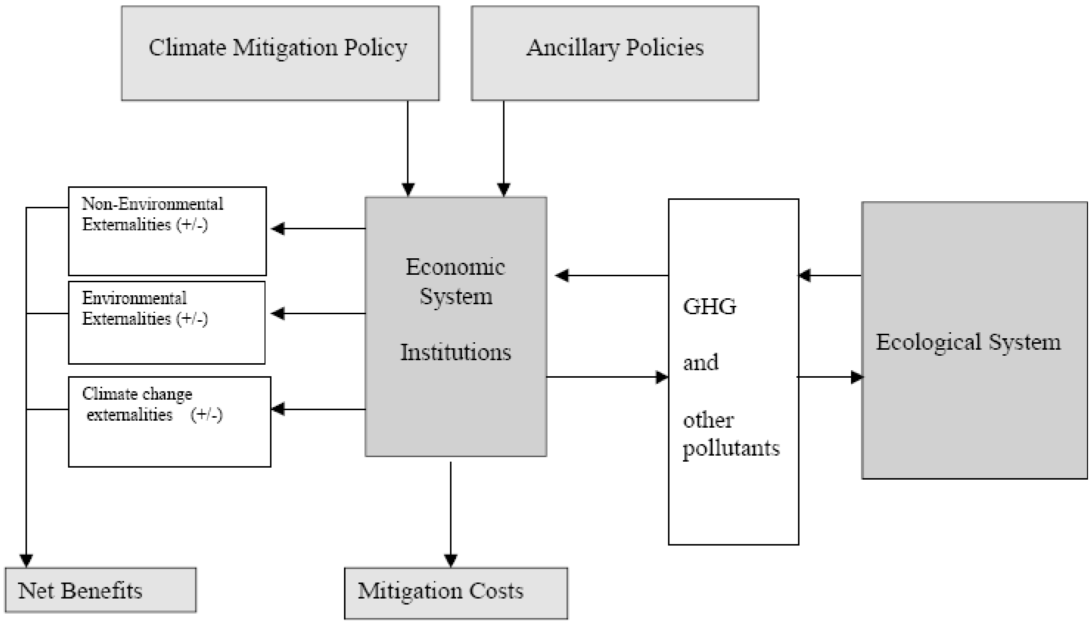


Figure 1.1: Conceptual framework for analyzing ancillary benefits and co-benefits from climate policies (IPCC (2007))

in terms of baseline scenarios of energy consumptions and GHG emissions. Consequences of emission reductions of air pollution are assessed by a wide variety of meteorological and dispersion models. While many epidemiological studies demonstrate negative impacts from air pollution on health, the quantification of the relationships is more uncertain. The same holds true with respect to environmental issues. Finally, the valuation of these impacts in monetary terms is probably the most problematic and controversial task. As we will see in the next section this field of economics is still subject to intense debate. This is due to the fact that evaluation techniques are associated with high degree of uncertainty.

1.3 Literature review of empirical studies

This literature review is mainly based on those performed in IPCC (2007), IPCC (2001), Pittel & Rubbelke (2008), and Markandya & Rubbelke (2003). Some recent studies were added to complete the survey (e.g. Rypdal *et al.* (2007), Bollen *et al.* (2009), Hordijk & Amann (2007)). The goal of this thesis is to include ancillary benefits into GHG abatement cost curves and comment on the changes induced in emission trading mechanisms. Thus, the focus of the review is put on the different methodologies used in the literature and the estimates of ancillary benefits expressed per unit of abated carbon. Most studies evaluated in this thesis are non-European and stem from other OECD countries. While various reports and articles dealing with linkages between air quality and GHG mitigation in Europe have been published, they usually deal with co-benefits rather than ancillary benefits. As explained in EEA (2006), the European studies usually develop medium to long-term socioeconomic scenarios and compare efficiencies of different types of environmental policies in an integrated approach. These can be seen as cost-effectiveness analyses as opposed to cost-benefit analyses from the non-European studies. The focus here will be placed on the latter type since the final part of this thesis will aim at including ancillary benefits in GHG mitigation measures without any changes in air pollution policies. An exception is the study van Vuuren *et al.* (2006) which adopts different scenarios and tools[1] to assess ancillary benefits in Europe from the implementation of the Kyoto Protocol.

The literature dealing with ancillary benefits from climate policies date back to the early nineties. A noteworthy study dealing with the early climate-policy cost- benefit analyses is Nordhaus (1991). Some economists soon noticed that these secondary benefits were missing in conventional climate studies, and that they could be substantial to compensate for a non negligible amount of climate-policy costs (Ayres & Walter (1991)). The following pages will aim to illustrate the various approaches and results from a series of studies conducted over the last two decades that specifically focused on ancillary benefits from different regions. Interestingly enough, given the variations in results, the studies all espouse a common message: health and environmental benefits represent a substantial fraction of direct mitigation costs. This holds true for both studies conducted in industrialized countries and in developing ones. This is a crucial point which strongly supports the need to coordinate air pollution strategies and climate policies if one wants to achieve the best results in an efficient way. Table 1.1, taken from IPCC (2007), provides a summary of all studies dealing with ancillary benefits with a short description of the main hypotheses, models used and results.

[1] In particular the 'Regional Air Pollution INformation and Simulation' (RAINS)-model developed at the International Institute for Applied Systems Analysis (Laxenburg, Austria), a precursor to the GAINS model described in Chapter 2

Table 1.1: Literature review of studies on ancillary benefits from climate change

Region	Source	Sectors	CO_2 abatement	Carbon price (US$/tC)	Pollutants	Health benefits (US$/tC)
Canada	Caton & Constable (2000)		All sectors	-9%	PM, NO_X, SO_2	11 (1277)
Chile	Cifuentes *et al.* (2000)		Energy efficiency		CO, PM, NO_X, SO_2	62*
	Dessus & O'Connor (2003)		-10% -20% -30%	67* 157* 284*	CO, $Lead$, NO_2, O_3, PM, SO_2	251* 254* 267*
China	Wang & Smith (1999)	Power sector Domestic sector	-15% -15%	11 1.4	PM, SO_2	
	Garbaccio *et al.* (2000)	29 sectors (4 energy)		1* 2*	PM, SO_2	52 52
	Gielen & Changhong (2001)				NO_X, SO_2	
	van Vuuren *et al.* (2003)				SO_2	

Region	Source	Sectors	CO_2 abatement	Carbon price (US$/tC)	Pollutants	Health benefits (US$/tC)
	OConnor *et al.* (2003)	All sources	-15%		PM, SO_2	52 52
	Morgensterr *et al.* (2004)	A Phase-out of small boilers	80%		PM, SO_2	38175
	Aunan *et al.* (2004)	Cogeneration Modified boiler design Boiler replacement Improved boiler management Coal washing Briquetting		-30 -6 -3 9 22 27	PM, SO_2	32 23 32 32 86 118
	Vennemo *et al.* (2006)	Power production, industrial boilers, steel making, cement, chemical industry	80-236 MtCO_2 annually	6 for the 80 Mt potential	TSP, SO_2	Avoided deaths:4.120; all health effects:544
EU	van Vuuren *et al.* (2006)	All sources	47%	6 for the 80 Mt potential	TSP, SO_2	Avoided deaths:4.120; all health effects:544

Region	Source	Sectors	CO_2 abatement	Carbon price (US$/tC)	Pollutants	Health benefits (US$/tC)
Hungary	Aunan *et al.* (2000a)				CH_4, CO, $NMVOC$, NO_X, N_2O, SO_2, TSP	
India	Bussolo & O'Connor (2001)	All sources	13-23% below BAU		PM, NO_X, SO_2	
USA	Burtraw *et al.* (2003)	Power sector		7	PM, NO_X, SO_2	2
Russian Federation	Markandya *et al.* (2003)				PM, NO_X, SO_2	

Air pollutant emissions

The first conclusions which can be drawn from this review concern the first step necessary to assess ancillary benefits, that is the quantification of reduced air pollutant emissions. While estimates can vary among studies, they all conclude that GHG mitigation measures tend to reduce air pollutant emissions due to increase in energy efficiency, reduction of energy demand and growing use of non-emitting energy sources such as wind power. Figure 1.2 from IPCC (2007) shows that many human activities responsible for GHG emissions are also responsible for air pollutant emissions. Any change in activity output or energy input induced by GHG mitigation measures will affect air pollutant emissions. Resulting effects turn out to be positive at national levels.

For moderate climate policies, i.e. policies which reduce GHG emissions by 10 to 20% by 2020-2030 in comparison with the baseline scenario SO_2 emissions are often reduced by the same factors. NO_x and PM emissions are less impacted by these policies and typically decrease by 5 to 10%. The effects of these reduction mechanisms are global. Even if quantitative results vary substantially among countries and between studies, it is worth noting that they all conclude that significant reductions in air pollutant emissions occur.
As mentioned above trade-offs exist with some climate strategies and air quality reduction, such as the promotion of biofuels and diesel. While biomass possesses advantages in terms of carbon emissions and are promoted to lower carbon emissions from transport or domestic heating, it can have negative impacts on air quality. The example given by Streets & Aunan (2005), concerning the combustion of coal and biofuels in Chinese households offers a good example on the basis that these accounted for 10 to 15% of the total global emissions of black carbon over the past two decades. The promotion of diesel powered vehicles rather than gasoline vehicles offers another example as it raises similar concerns regarding emissions of fine particles as $PM_{2.5}$, are significantly higher (HEI (1999)). Furthermore diesel particles are more carcinogenic on the basis that they are more aggressive towards lung tissue. Therefore promoting diesel vehicles to reduce GHG emissions puts a new burden on air pollution policies.

Impacts on health and environment

After reductions in air pollutant emissions have been quantified it is necessary to assess the effects of mitigation on public health. These effects depends on series of factors such as the localization of sources, the level at

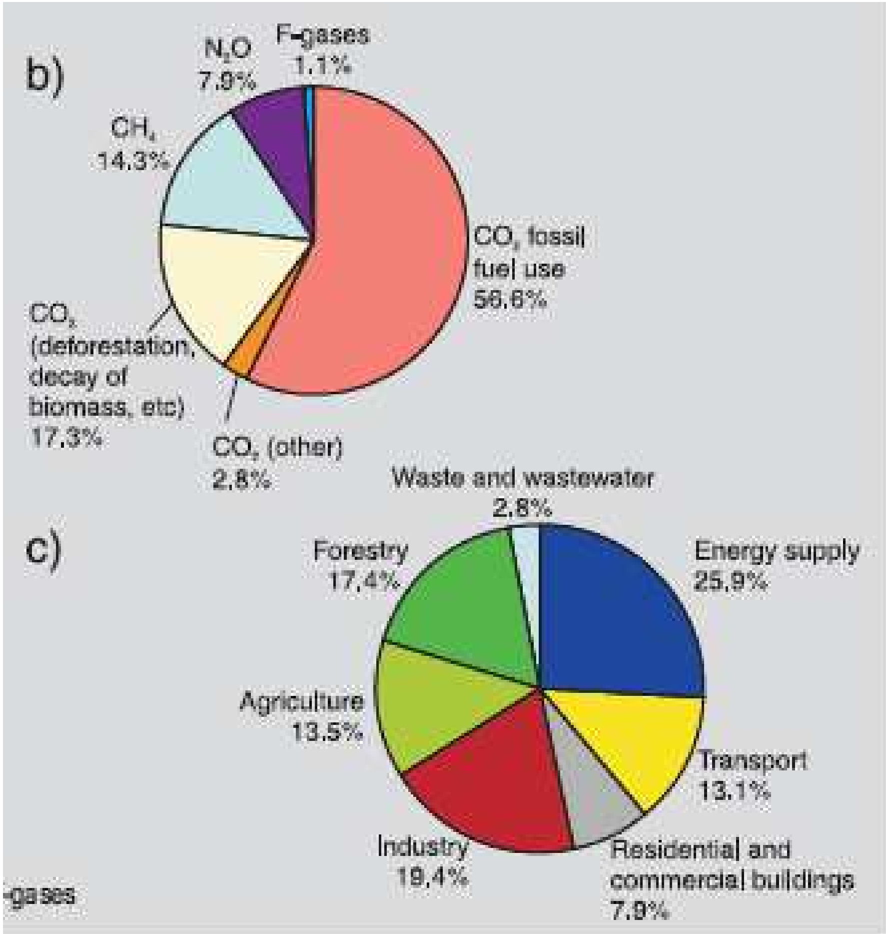


Figure 1.2: b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2-eq, c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation) (IPCC (2007))

which air pollution emissions are controlled and the overall contribution to global exposure of populations of the sectors concerned with ancillary effects to population exposure. Health impact studies suggest substantial impacts on premature mortality. According to studies conducted for Asian and Latin American countries tens of thousands of pre-mature deaths could be avoided if the necessary measures were taken (Wang & Smith (1999), Aunan *et al.* (2003), OConnor *et al.* (2003), Vennemo *et al.* (2006), Bussolo & O'Connor (2001), Cifuentes *et al.* (2000), Dessus & O'Connor (2003), McKinley *et al.* (2005)). In Europe, Korea and North America premature mortalities are much lower by comparison (Bye *et al.* (2002), van Vuuren *et al.* (2006), Caton & Constable (2000), Burtraw *et al.* (2003), Han (2001) and Joh *et al.* (2003)). However, they are still substantial and typically amount to several thousands per year. As mentioned earlier, these impacts depend upon the economic sector and the location where emission reductions occur. For example, measures that improve efficiencies of domestic stove applications (heating, cooking) can greatly improve indoor air quality. Such measures will have much bigger effects compared to reductions in centralized facilities such as power plants equipped with stacks (a factor of 40 is mentioned in Wang & Smith (1999)). Similar conclusions are drawn in Mestl *et al.* (2005) for China on differences between policies focusing on power plants and those concerning area sources and small industrial boilers. Finally, one must take into account the existing and planned air pollution regulations. A stark contrast on the impacts on public health exists in countries where air pollution regulations are loose or are not enforced dangers as opposed to those countries where they are enforced.

Only a few studies assessed potential ecosystem benefits from reduced air pollution. The most comprehensive study was conducted for the European region. This study found that with the entry into force of the Kyoto Protocol there would be a significant decrease in levels of acid deposition and nitrogen exposure as compared to a case where no specific climate change mitigation policies were adopted. These lower pollution loads would benefit the forest ecosystems whereby between 0.6 and 1.4 million hectares would be protected. For nitrogen deposition, an additional 2.2 to 4.1 million hectares would be protected (van Vuuren *et al.* (2006)).

Economic quantification of impacts

The last step in the quantification of ancillary benefits is to attribute monetary values to avoided impacts. This is necessary in order to compare these benefits with the direct costs of climate policies and their economic potential. The review of such estimates is particularly important for the purpose of this thesis since we expect to subtract these ancillary benefits from estimated GHG abatement cost curves. The main type of ancillary impacts which has been assessed in the literature is health impacts, and more specifically avoided premature deaths (IPCC (2007)).

Looking at the results from the various studies described in Table 1.1, a first comment is that monetary quantifications of ancillary benefits result in a wide spectrum of values, ranging from 2 US\$/tCO_2 (Burtraw *et al.* (2003), Joh *et al.* (2003)) up to a hundred or more US\$/tCO_2 (Han (2001), Aunan *et al.* (2004), Morgenstern *et al.* (2004)). Figure 1.3 gives a representation of ancillary benefits calculated per carbon unit (the x-axis represents the scenario assumptions used, that is the carbon tax in US$/tC). Each point represents the results of one particular study (see Table 1.1).

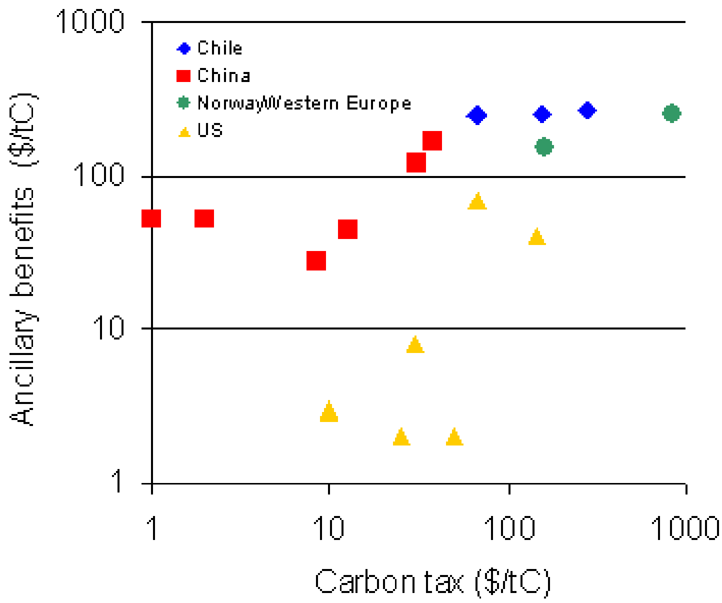


Figure 1.3: Ancillary benefits in US$/tC versus levels of carbon tax, adapted from IPCC (2001) and IPCC (2007)

The different methodologies and assumptions used by the various authors mentioned above explain these differentiated results. Some studies only consider one or two air pollutants while others include several pollutants. The inclusion of particulate matter in the assessment is especially crucial since its impact on health is critical. Differences in mortality evaluation methods are also a major source of discrepancies. We will analyze shortly the differences in methodologies leading to these different results.

A first noteworthy example is reflected in studies dealing with Chile. Cifuentes *et al.* (2000) estimate ancillary benefits at about $62/tC by while Dessus & O'Connor (2003) considers a fourfold higher value ($250/tC). For the latter, half of the benefits are derived from impacts of lead on Intelligence Quotient. This type of impact is simply not considered by Cifuentes *et al.* (2000) as it is not a direct consequence of greenhouse gas mitigation. Another difference lies in the values used for the Value of a Statistical Life (($2.1 million in Dessus & O'Connor (2003) and $0.78 million for Cifuentes *et al.*

(2000)). This is due to the use of different methods to convert a US VSL into a value representative for Chile. Cifuentes et al used 1995 per capita income differences and the exchange rate in force at that time. Alternatively, Dessus and OConnor used the technique of Purchasing Power Parity (1992 levels). These differentiated approaches illustrate the difficulties to create general guidelines which are to be followed when it comes to estimating ancillary benefits.

Differences also appear among studies analyzing benefits in industrialized countries. In the USA for example, Abt (1999) and Burtraw *et al.* (2003) respectively find that ancillary benefits amount to $68/tC and $1.5/tC for similar carbon taxes ($67/tC and $50/tC). The reasons behind these very large disparities vary. A first obvious difference is that Burtraw et al. study only deals with the electricity sector, which has lower impact on population exposure due to the high stacks. NO_x emissions per unit carbon from electricity are lower than those from other activities (Davis *et al.* (2000)). Second, the mortality factors for NO_x used in these two studies differ by a factor of three. Finally, Burtraw et al. do not take into consideration that new regulations on PM and ozone emissions are to be implemented soon a, consideration that Abt's study takes into account. These factors result in lower ancillary benefits for the latter since lower amounts of PM and ozone will are abated with current legislation. Discrepancies between studies dealing with Europe and the USA may also be the consequence of geographic differences (Burtraw *et al.* (2003)). Spatial patterns of air pollutant transport are significantly different, the proportion of off-shore deposition being higher in the US than in Europe. As mentioned by Pittel & Rubbelke (2008), other factors can also explain these discrepancies: the more aggregate level of modeling in European studies, higher economic valuations of environmental impacts (Morgenstern *et al.* (2004), Burtraw *et al.* (2003)), or the use of a fixed coefficient procedure in European studies.

Despite the fact that estimates of ancillary benefits in the literature exhibit a large spectrum of values, all studies conclude that they can potentially represent a significant share of mitigation costs. This is an important conclusion which has policy-relevant implications. An integration of such benefits should facilitate the decision-making process necessary to engage in ambitious mitigation programs. Such co-benefits could range from 30 to 50% of greenhouse gas mitigation costs (Burtraw *et al.* (2003), Proost & Regemorter (2003)) up to almost three times these expenses in some cases (Aunan *et al.* (2004), McKinley *et al.* (2005)). As said before, benefits in developing countries are higher and could entirely compensate direct mitigation costs, and constitute 'no-regret' measures. These results are confirmed by advanced computable general equilibrium models which allow to include feedbacks from the economy (in contrast with bottom-up approaches which do not consider these responses). Without any welfare losses, countries such as India could for example adopt policies to reduce their GHG emissions by 13 to 23% thanks to ancillary benefits (Bussolo & O'Connor (2001)). The same conclusions can be drawn for China which could reduce GHG emissions without net costs by 15 to 20% (OConnor *et al.* (2003)). For Thailand, Li (2006) estimated that inclusions of health impacts could reduce net mitigation costs by 45%.

With regards to the potential benefits from reduced air pollution impacts on agriculture, few studies exist. Air pollutants such as ozone can have negative impacts on plant tissues and crop yields. Chameides *et al.* (1994) estimated that between 10 and 35% of the worlds grain production can be affected by high levels of tropospheric ozone. OConnor *et al.* (2003) estimated that benefits from reduced exposition to ozone and improved crop yields are of the same order of magnitude as health benefits. In total, China could therefore achieve a 15 to 20% CO_2 reduction without welfare loss. The inclusion of benefits for agriculture has very important impacts on the distribution of social welfare. Rural areas depending on agricultural activities willprofit from this if it is included. Rural households could benefit from climate policies up to a ten percent abatement rate. This is an important conclusion since it balances the picture drawn in most studies consisting in attributing almost all ancillary benefits to urban populations. Finally, whereas impacts on ecosystems from reduced air pollution can be substantial, the lack of common tools to assess the corresponding economic benefits has led to the exclusion of these aspects in most studies (IPCC (2007)). A generally accepted method is still required in order to include benefits on natural ecosystems into a comprehensive monetary cost-benefit calculation of mitigation measures.

Avoided air pollutant abatement costs

The analysis of the literature on ancillary benefits shows that reductions in air pollution impacts are especially high in developing countries due to a lack of proper air pollution abatement technologies. Any measure which could for example improve energy efficiency will have therefore a large impact on air pollutant emissions. Concluding that ancillary benefits are higher in developing countries would however be incorrect without taking into account the high amount of expenditures spent by developed countries to improve air quality. Indeed, the existence of stringent and costly regulations on air pollution in industrialized countries also implies that any reduction in emissions induced by climate policies leads savings in abatement expenditures. This type of ancillary benefits is the result of avoided air pollutant abatement costs.

A growing number of studies demonstrates that these benefits can be significant and can help meeting other environmental targets at a lower cost. This is for example the case in Europe where policies which promote energy efficient measures lead to a decrease in costs to comply with national ceilings for air pollutant emissions. In van Vuuren *et al.* (2006), it is shown that the implementation of the Kyoto Protocol in Europe without use of flexibility mechanisms would imply savings on air pollution control costs of 9.4 billion US$ per year. If carbon trading were to be allowed, these savings would fall by 2.4 billion US$ per year for countries buying permits and selling ones would save an additional 0.7 billion US$. Selling countries would implement at home new GHG mitigation measures and would then directly benefit from reductions in air pollutant emissions. Another study in Europe demonstrated that EU national emission ceilings could be reached with lower control costs (-10 to -20%) if low-carbon strategies were to be adopted (Syri *et al.* (2001)). If long-term perspectives are considered, air pollution policies implemented without climate objectives could even be more expensive than an integrated approach including both policies (van Harmelen *et al.* (2002)). Finally, another study conducted for the United States showed that a 31% reduction in CO_2 emissions could drive prices of SO_2 allowances to zero due to major reductions in emissions. The ancillary benefits per unit of abated carbon could represent about 12 US$/t$CO_2$ for a 7 US$/t$CO_2$ tax (Burtraw *et al.* (2003)). These values are comparable with those presented previously for the United States, that is the benefits from reduced health impacts. However, avoided abatement costs are easier to assess and appear to be much more tangible for policy-makers. Their inclusion is therefore critical to the achievement of comprehensive assessments of climate policies.

CHAPTER 2

The GAINS - Annex I model

The purpose of this chapter is to introduce a model developed at the International Institute for Applied Systems Analysis (Laxenburg, Austria), which directly deals with the interaction between climate and air quality policies. Data and results shall be the basis for the analysis conducted in Chapter 4.

2.1 Purposes of the GAINS model

The aim of the GAINS-Annex I model developed at the IIASA is to assess the potential for mitigation of GHG emissions and the corresponding abatement costs in Annex I countries[1]. It is based on an extension of the Greenhouse gas Air pollution Interactions and Synergies (GAINS) model. GAINS was developed as a policy tool to help negotiators comparing possible policies for reducing GHG emissions and air pollution in an integrated way. It explores synergies and trade-offs between the control of local and regional air pollution and mitigation of global greenhouse gas emissions in quantitative and monetary terms. GAINS can be used to assess the impacts of GHG abatement measures on air pollutant emissions since these measures are fully

[1]Signatories to the UNFCCC who are to reduce their emissions of greenhouse gases: Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, United States of America.

embedded in the model. A bottom-up approach is adopted considering all possible mitigation measures for each country. With a given abatement target, the model determines the portfolio of measures which allows the target to be reached at the lowest possible cost. Such an approach enables the calculation of GHG marginal abatement cost curves for Annex I countries. These curves can then be used to assess mitigation costs for parties under various different scenarios (different targets and possible use of flexible mechanisms such as carbon trading and Clean Development Mechanisms(CDM)). In this chapter I will present the methodology used to calculate emissions, abatement costs and mitigation efforts of Annex I parties.

2.2 Methodology

The GAINS model considers emissions of carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x), nitrous oxide (N_2O), particulate matter (TSP, PM_{10}, $PM_{2.5}$ and PM_1), sulfur dioxide (SO_2), volatile organic compounds (VOC), ammonia (NH_3), carbon monoxide (CO), and fluorinated greenhouse gases ($F-Gases$). For each country and type of pollutant, emissions are determined using this formula:

$$E_{i,p} = \sum_k \sum_m A_{i,k} ef_{i,k,m,p} x_{i,k,m,p}$$

where

- i, k, m, p: Country, activity type, abatement measure, pollutant, respectively
- $E_{i,p}$: Emissions of pollutant p in country i
- $A_{i,k}$: Activity level of type k (e.g., coal consumption in power plants) in country i
- $ef_{i,k,m,p}$: Emission factor of pollutant p for activity k in country i after application of control measure m
- $x_{i,k,m,p}$: Share of total activity of type k in country i to which a control measure m for pollutant p is applied.

Three main variables need to be assessed and computed, namely the type of activity considered, the emission factor of the control measure, and finally, to which extent the control measure is used in this particular activity. Total emissions of one pollutant at a national level are calculated by summing all individual emissions. This bottom-up approach allows us to keep track of sources for all kinds of emissions, which is particularly interesting for policy-making. For example, it is possible to analyze sector by sector mitigation potentials and have a targeted policy, an analysis which cannot be performed with highly aggregated models. Differentiation between countries is also possible and enables policies to be adapted to local structural peculiarities. On the other hand, the main challenge associated with a bottom-up model is to cover all relevant measures, their respective emissions and costs, in a comprehensive and rigorous way.

Mitigation measures

The database of the GAINS model contains a comprehensive list of possible measures to be taken in a country in order to cut GHG emissions. These measures are grouped by sectors of activity and are characterized by information on technical and economic specifications, mitigation efficiencies, applicability and costs across countries. One key feature is that impacts on air pollutant emissions are also considered. This allows assessing ancillary benefits from climate policies in a comprehensive in terms of reduced air pollution abatement costs.
Three different types of mitigation measures are considered in GAINS:

- End-of-pipe measures which refer to technologies aiming at physically capturing greenhouse gases before their emissions to the atmosphere and new technologies which produce less GHG such as hybrid vehicles and renewable energy. A good example for end-of-pipe technologies is the capture and sequestration of CO_2 in power plants after the combustion process. Other examples are methane recovery, catalytic reduction of N_2O, and incineration of F-gases. It is important to mention that these measures do not affect activity levels of the corresponding sector and only modify costs.

- Efficiency measures to reduce fuel consumption and the use of low-carbon content fuels instead of fossil fuels (e.g. substitution of gasoline with biomass or coal with wood). These are referred to as structural measures since they significantly impact the way goods are produced. Levels of energy services, however, are not modified.

- Behavioral changes induced by command-and-control approaches (e.g., legal traffic restrictions) or economic incentives such as taxes on polluting goods. This category of policies is not part of the list of measures but is taken into consideration in the design of scenarios.

Tables 2.1 and 2.2 respectively show the types of structural and technical measures used to reduce GHG emissions in the GAINS model.

Sector	Measure
Power plants	◦ Use of renewables such as - wind - solar photo-voltaic - large hydro power plants - small hydro power - geothermal power instead of fossil fuels. ◦ Gas-fired power plants instead of coal-fired power plants. ◦ Biomass power plants instead of fossil fuel plants. ◦ Combined heat and power (CHP) systems to substitute electric power plants on the one hand, and either industrial boilers or residential boilers. CHP systems increase the overall energy system efficiency. ◦ Efficiency measures that reduce electricity consumption in industry and the residential/commercial sector that reduce electricity consumption
Residential sector	◦ Energy saving packages (3 stages each) for heating, cooling, air conditioning for - existing houses - new houses - existing apartments - new apartments ◦ Energy saving packages (3 stages each) for - water heating - cooking - lighting - small appliances - large appliances
Commercial sector	◦ Energy saving packages (3 stages each) for heating, cooling, air conditioning for - existing houses - new buildings ◦ Energy saving packages (3 stages each) for - water heating - cooking - lighting - small appliances - large appliances
All industries	◦ Gas-fired boilers instead of coal-fired boilers ◦ Combined Heat and Power instead of industrial boilers
Cement production	◦ Energy saving packages (3 stages)
Iron and steel industry	◦ Energy saving packages (3 stages)
Paper and pulp industry	◦ Energy saving packages (3 stages)
Non-ferrous metals	◦ Energy saving packages (3 stages)
Chemicals	◦ Energy saving packages (3 stages)
All transport	◦ Substitute fossil fuel with bio-fuels

Table 2.1: Major groups of structural measures to reduce emissions of air pollutants and greenhouse gases considered in GAINS (Amann *et al.* (2008))

Sector	Measure
Power plants	◦ IGCC (Integrated Gasification Combined Cycle) instead of conventional coal fired power plants ◦ Carbon capture and storage
Passenger cars	◦ Advanced internal combustion engines ◦ Hybrid vehicles ◦ Plug-in hybrids ◦ Electric vehicles ◦ Hydrogen fuel-cell vehicle ◦ Non-traction related efficiency improvements
Light-duty trucks	◦ Advanced internal combustion engines ◦ Hybrid vehicles ◦ Plug-in hybrids ◦ Electric vehicles ◦ Hydrogen fuel-cell vehicles ◦ Non-traction related efficiency improvements
Heavy-duty trucks	◦ Advanced internal combustion engine ◦ Non-traction related efficiency improvements
Buses	◦ Electric vehicle ◦ Hydrogen fuel-cell vehicle ◦ Non-traction related efficiency improvements (2 stages)
Motorcycles	◦ Advanced internal combustion engine

Table 2.2: Major groups of technical measures to reduce emissions of CO_2 considered in GAINS (Amann *et al.* (2008)).

Parallel to the inventory of mitigation measures, it is necessary to build up a relevant representation of the different sectoral activities and emissions in all countries. For this purpose, emissions reported to UNFCCC for 2005 are reconstructed for Annex I parties. This facilitates a good overview of the current situation and acts as a consolidated starting point for future emission scenarios. The baseline scenario is designed for the year 2020 and takes into consideration two main factors, namely exogenous changes in activity levels and changes in emission factors resulting from targeted policies. The World Energy Outlook from the International Energy Agency is used for the former and helps in the formation of sound assumptions about possible exogenous factors (IEA (2008)). With regard to the second factor, existing legislation and activity projections are used for all countries. This scenario serves as the reference against which all alternative policies are compared.

The last modeling step consists in the determination of the most cost-effective policies to be adopted given a specific mitigation target. Costs for all measures are compiled and an optimization is run for each country so as to obtain the final results (e.g. 15% reduction in GHG emissions compared with 1990 levels) at the lowest cost. This optimization does not only consider costs of all measures but also other factors such as the end-use demand for (energy) services as planned in the activity projection, the scope for replacement of existing infrastructure and the potential secondary impacts in terms of air pollutant emissions. As a result of such an optimization a portfolio of mitigation measures is derived. Running the optimization for all possible mitigation targets allows to obtain national cost curves for all Annex I countries. Figure 2.1 is an example of a marginal cost curve for the European Union and Figure 2.2 provides total mitigation costs. It is important to notice that total costs are not absolute but are relative to the baseline scenario.

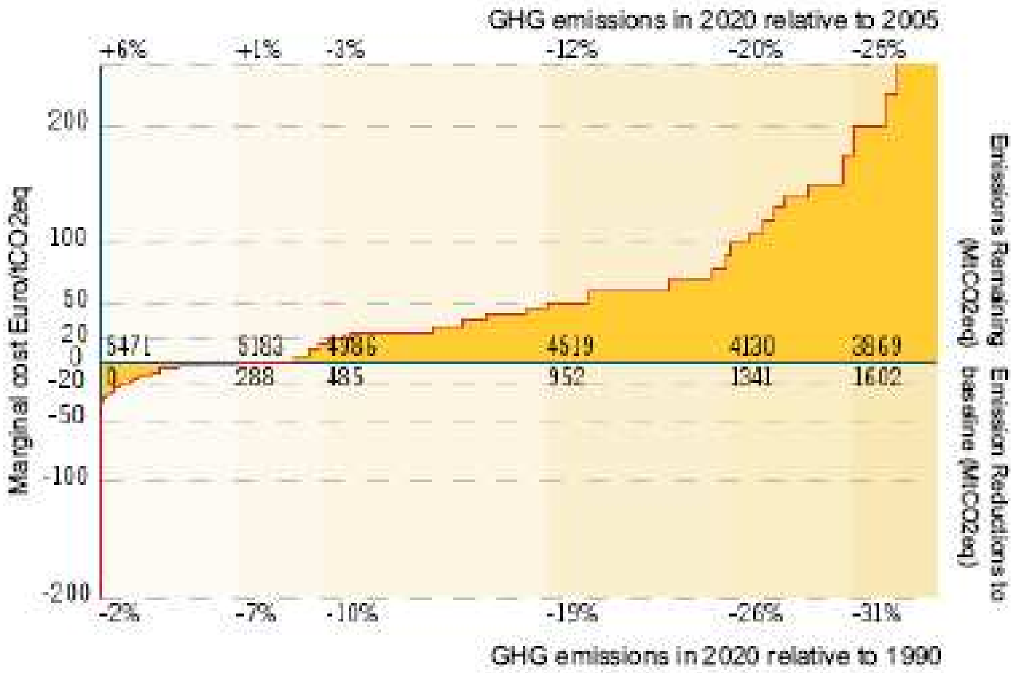


Figure 2.1: Marginal abatement cost curve in EU27 (reference year: 2020, IIASA (2009))

Improvements in energy efficiencies

The GAINS model includes in its database a comprehensive list of energy efficiency measures in the industrial, commercial and domestic sectors for

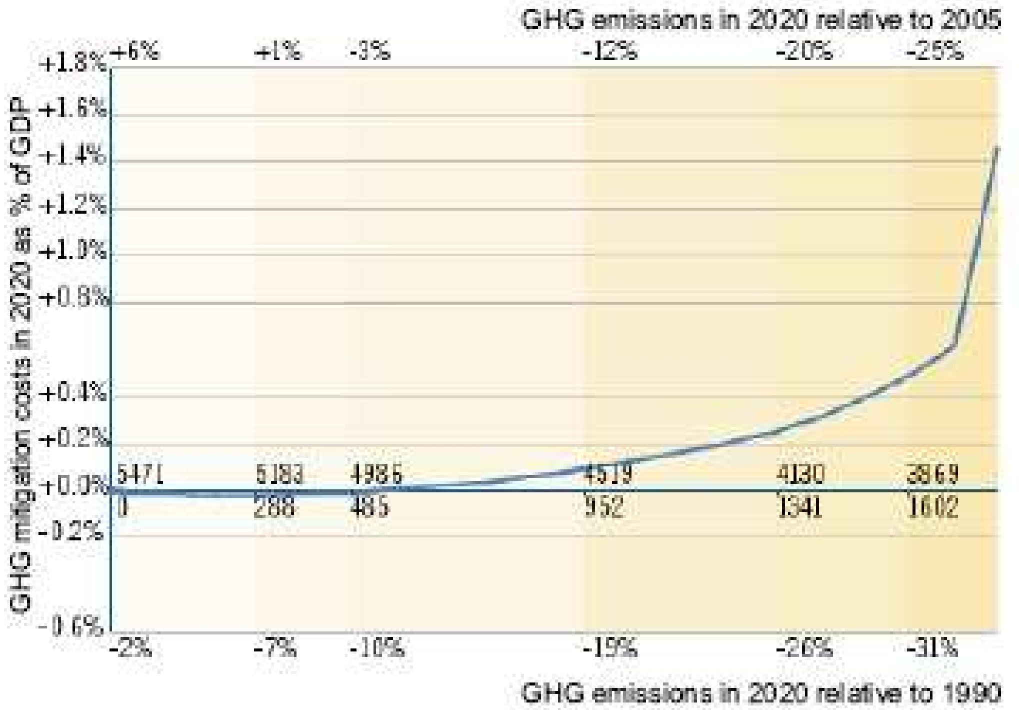


Figure 2.2: Total costs of GHG mitigation in EU27 (reference year: 2020, IIASA (2009))

all Annex I countries. In a first step, energy statistics for the year 2005 are used to evaluate current implementation rates of a specific portfolio of energy efficiency measures for the various end use categories. These energy statistics are reproduced using activity data from economic statistics. The result is a sound estimate of energy intensities per country. The second step is to use this identification of potentials to match energy projections used in the baseline scenario. Baseline implementation rates of energy efficiency measures by 2020 are determined to fit these scenarios. The potentials for each sector are analyzed as follows:

Industrial sector

As a major energy consumer, the industrial sector is a key contributor to GHG emissions. A substantial number of opportunities to reduce emissions has been identified in this sector (IEA (2008)). The sub-sectors included in the GAINS model are iron and steel, non-ferrous metals, chemicals, nonmetallic minerals, pulp, paper, paper products and printing, and other non-key industries. Two main sources have been used to assess these potentials, namely Worrell et al. (2007), in which some best-practices in the manufacturing industry are detailed and Capros & Mantzos (2006) which analyzes responses from the industrial sector when faced with different carbon prices. The latter study allows the identification of the best measures adopted by the industry to reduce costs associated with fossil fuel consumption. For more details on the methodology used for the industrial sector, please refer to Amann *et al.* (2008).

Residential and commercial sectors

A number of uses and energy needs are associated with the domestic sector. The GAINS model subdivides the domestic sector into three main fields (residential, commercial and others such as military) to track all GHG emissions back to their activity sources. Table 2.3 gives a list of the types of energy uses considered in GAINS.

Sector/Need	Activity variable
Residential sector	
◦ Heating, ventilation and air conditioning	Living space
- Space heating	Living space
- Space cooling	Living space
◦ Water heating	Housing unit
◦ Cooking	Housing unit
◦ Lighting	Housing unit
◦ Large appliances (refrigerators, freezers, washing machines, dishwashers, dryers)	Housing unit
◦ Small appliances (computers, TV sets, audio and other electronic equipment)	Housing unit
Commercial sector	
◦ Heating, ventilation and air conditioning (HVAC)	Building space
- Space heating	Building space
- Space cooling	Building space
- Space ventilation	Building space
◦ Water heating	Building space
◦ Cooking	Building space
◦ Lighting	Building space
◦ Large appliances (refrigerators, freezers, washing machines, dishwashers, dryers)	Building space
◦ Small appliances (office equipment, other electronic equipment)	Building space
◦ Other needs (not included separately)	Building space

Table 2.3: Specific uses/energy needs in the residential and commercial sectors that are considered in the GAINS analysis (Amann *et al.* (2008)).

The first modeling step is to assess the share of all these energy needs in the total energy consumption at present time and in the future. This is done by using available national data or by adopting as first approximations simple constant shares. Once these shares are determined, a listing of all potential efficiency measures along with their unit cost, energy demand reduction efficiency, and maximum possible penetration in the corresponding market is performed. In order to assess the evolution of energy demand in sub-sectors over time and to build sound scenarios, possible penetration rates are also assessed. The resulting formula used to calculate the energy consumption of an energy use is:

$$EC_{j,k,n,c,r} = A_{j,k,n,r} M_{j,k,n,r} enin_{j,k,n,c} \sum_{t} (1 - \gamma_{j,k,n,t,c}) X_{j,k,n,t,r}$$

where

- n energy need type (e.g., space heating)

- t energy efficiency technology/option
- $A_{j,k,n,r}$ value of activity variable used to assess energy consumption for need n in subsector k of sector j in time period r,
- $M_{j,k,n,r}$intensity multiplier for need n in sub-sector k of sector j in time period r,
- $enin_{j,k,n,c}$ consumption of energy type c by need n in sub-sector k of sector j in time period r without energy efficiency measures,
- $X_{j,k,n,t,r}$ implementation rate of technology t for need n in sub-sector k in time period r,
- $\gamma_{j,k,n,t,c}$ reduction in consumption of energy type c used to satisfy need n in sub-sector k caused by application of technology t.

2.3 Costs of mitigation

As with any bottom-up model, GAINS calculates total mitigation costs by aggregating costs from individual technologies, processes and sectors. However, the specificity of this model lies in its system-approach which enables to represent interactions between different sectors, for example the impacts of energy savings in one specific sector on the others.
With regards to cost calculations, the GAINS methodology considers costs at the production level rather than at the level of consumer prices. This is in accordance with the main goal which is to assess directly the actual resources used to reduce emissions, excluding transfers of resources such as taxes or subsidies. By doing so, real changes in social welfare are correctly approximated.

Calculation procedure

Costs calculated in GAINS are restricted to incremental costs that occur in comparison to the baseline scenario. Hence, the overall costs of energy systems and of the mitigation measures set in the baseline scenario are not assessed. The procedure described in this section is used to calculate costs at national levels assuming that no flexible mechanisms are used. Because of the system approach used in GAINS, this also implies that cost changes in full life cycle emissions that are caused by a specific measure in a sector abroad are included in the national account. This approach has the advantage of avoiding any leakage of greenhouse gas emissions from Annex I countries to

non-Annex I countries. In other words, countries are fully responsible for the emissions occurring at any stage of a product cycle and do not benefit from outsourcing polluting activities to other countries.
In the next section I will analyze the three main steps to calculate GHG mitigation costs, namely the determination of unit costs, the optimization of measures' portfolio and finally the construction of national marginal cost curves.

Unit costs

The first step is to calculate unit costs of GHG emission reductions for each measure in each sector. Expenditures are grouped into three categories, namely investments, operating and maintenance costs, and cost savings. The unit cost of abatement of one mitigation measure is of the following form:

$$ca_{i,k,m} = \frac{I^{an}_{i,k,m} + OM^{fix}_{i,k,m}}{A_{i,k}} + OM^{var}_{i,k,m}$$

where I^{an} are annualized investments, OM^{fix} fixed operating costs, OM^{var} the variable operating costs, m the technology used, i the country and k the activity type.
With a view to building national abatement cost curves, it is interesting to express these unit costs in relation to the achieved emission reductions. To do so, the following formula is used:

$$cn_{i,k,m,p} = \frac{ca_{i,k,m}}{ef_{i,k,0,p} - ef_{i,k,m,p}}$$

where cn is the cost per unit of abated emissions and $ef_{i,k,0,p}$ the uncontrolled emission factor in absence of any emission control measure (m=0). One of the difficulties with such an approach is to account for multi-pollutant technologies. Indeed, in such a case, there is a risk of allocating arbitrary costs across several pollutants. The GAINS model therefore adopts a multi-pollutant optimization approach by which cumulative effects on all affected pollutants are compared with measure costs.

Optimization of the portfolio

Once unit costs are assessed, the model calculates the most cost-effective portfolio of measures for a given mitigation target. This optimization is performed by minimizing the cost function, that is:

$$C = \sum_{i,k} \left(\sum_{m} c^{x}_{i,k,m} x_{i,k,m} + \sum_{k'} c^{y}_{i,k,k'} y_{i,k,k'} \right)$$

where the first term represents total end-of-pipe technology costs, and the second term total substitution/energy efficiency costs. A number of constraints exist on the different variables in order to take into consideration physical limitations to the implementation of mitigation measures. Activity data $x_{i,k}$ and $y_{i,k}$ represent for example lower and upper values due to limitations in applicability, availability of technologies, or fuel types. Finally, emissions at a national level for a pollutant p are calculated as follows:

$$E_{i,p} = \sum_k \sum_m ef_{i,k,m,p} x_{i,k,m}.$$

National cost curves

By running the optimization routine described in the previous section for gradually tightened mitigation targets, the GAINS model generates national mitigation cost curves which link GHG emission targets with national marginal costs. These marginal costs reflect the costs for increasing an emission constraint by one unit. Thus, they correspond to the costs of the most expensive measure of the portfolio. Global mitigation costs are calculated by integrating marginal costs over the whole range of mitigation targets. An example of such a curve is given in Figure 2.1. The list of mitigation measures included in each portfolio is also accessible through the model. Datasheets for Annex I countries containing such information are available on IIASA's website (http://gains.iiasa.ac.at/index.php/gains-annex-1).

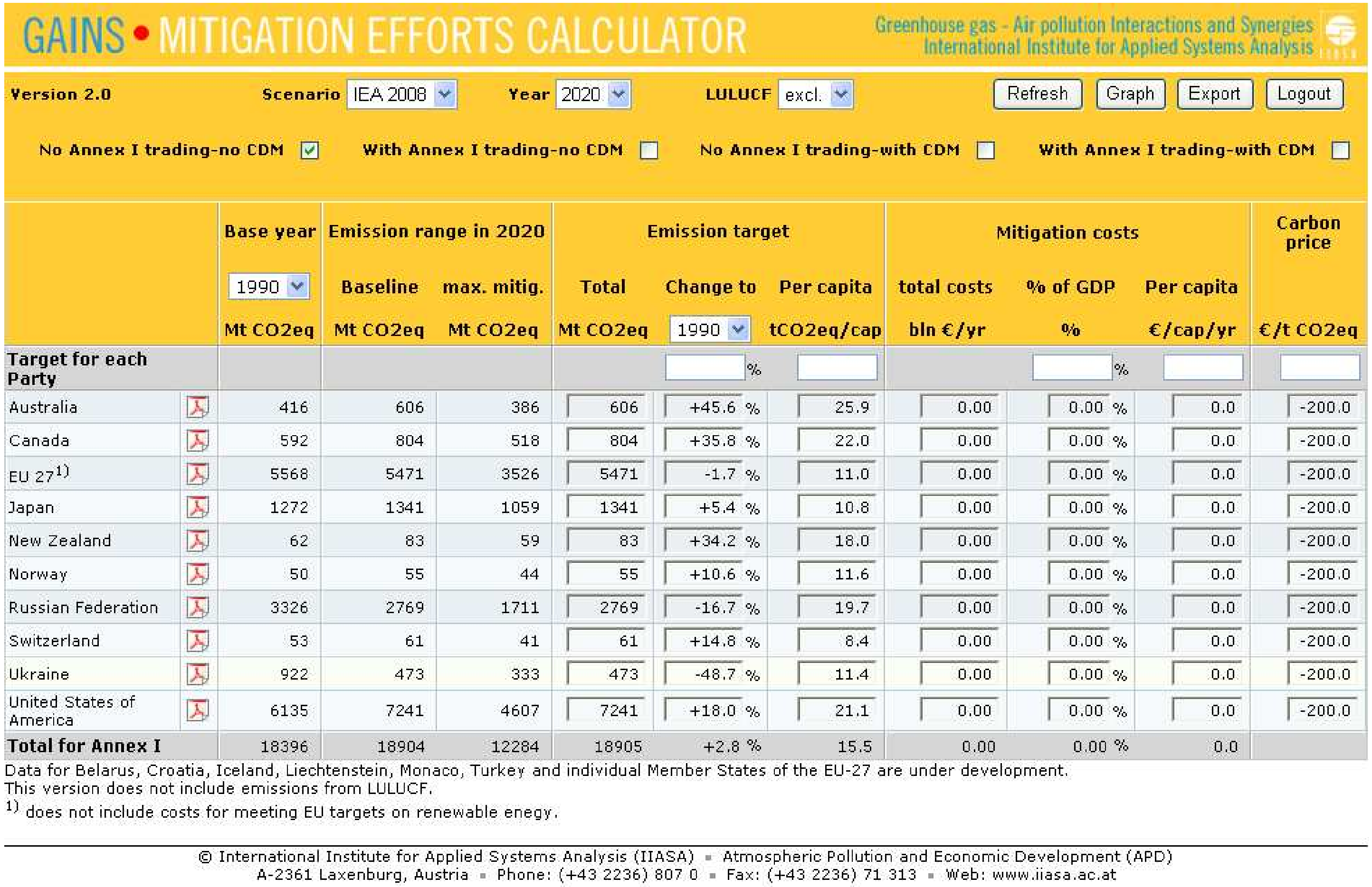
As previously stated, GAINS cost curves reflect social costs of mitigation polices compared with the baseline scenario. This approach implies that targets can have negative costs as shown on Figure 2.2. This reflects the fact that for some policies cost savings (e.g., from reduced fuel consumption) over the full technical life time are higher than the initial investments and operating costs. The reason why such measures are not taken voluntarily by firms or economic actors is that they may not be beneficial at an individual level. Global costs considered in the GAINS model are not representative of market actor perspectives. This aspect clearly appears in the choice to assume an interest rate in the model of 4%. As described in Amann *et al.* (2008), this rate is in accordance with conclusions drawn in IPCC (2007) for economic assessments of climate policies from a societal perspective. In order to allow users of the model to analyze mitigation costs from the standpoint of economic actors, an interest rate of 20% can also be chosen for calculations. This better reflects the high discount rates adopted by private firms when assessing the profitability of projects.

Ancillary benefits in air pollution

Particularly relevant to the present thesis is the inclusion of ancillary benefits from climate measures in air quality. As a systems model, GAINS quantifies these benefits in terms of avoided abatement costs. In a first step, reductions in air pollutant emissions due to mitigation measures are assessed on the basis of current and planned regulations in air quality. In a second step, avoided abatement costs are attributed to these reductions based on costs of standard air pollution control technologies. This means that national cost curves described in the previous section already include ancillary benefits for air pollution controls in terms of avoided abatement costs. However, while avoided impacts on human health, agricultural crops and ecosystems are quantified in physical terms by the model, no economic valuation of such benefits is considered. As a consequence, most of the ancillary benefits described in the literature review in Chapter 1 are not included in GAINS. A preliminary work to include these economic benefits from avoided impacts on health and environment will be conducted in the last chapter of this thesis.

2.4 GAINS GHG mitigation efforts calculator for Annex I countries

Based on the methodology previously described, a tool was developed by IIASA to calculate mitigation efforts of Annex I countries under different frameworks (Figure 2.3). I will now briefly analyze the different options available in terms of impacts on market equilibrium prices and overall costs for countries.



	Base year	Emission range in 2020		Emission target			Mitigation costs			Carbon price
	1990	Baseline	max. mitig.	Total	Change to 1990	Per capita	total costs	% of GDP	Per capita	
	Mt CO2eq	Mt CO2eq	Mt CO2eq	Mt CO2eq	%	tCO2eq/cap	bln €/yr	%	€/cap/yr	€/t CO2eq
Target for each Party					%			%		
Australia	416	606	386	606	+45.6 %	25.9	0.00	0.00 %	0.0	-200.0
Canada	592	804	518	804	+35.8 %	22.0	0.00	0.00 %	0.0	-200.0
EU 27 1)	5568	5471	3526	5471	-1.7 %	11.0	0.00	0.00 %	0.0	-200.0
Japan	1272	1341	1059	1341	+5.4 %	10.8	0.00	0.00 %	0.0	-200.0
New Zealand	62	83	59	83	+34.2 %	18.0	0.00	0.00 %	0.0	-200.0
Norway	50	55	44	55	+10.6 %	11.6	0.00	0.00 %	0.0	-200.0
Russian Federation	3326	2769	1711	2769	-16.7 %	19.7	0.00	0.00 %	0.0	-200.0
Switzerland	53	61	41	61	+14.8 %	8.4	0.00	0.00 %	0.0	-200.0
Ukraine	922	473	333	473	-48.7 %	11.4	0.00	0.00 %	0.0	-200.0
United States of America	6135	7241	4607	7241	+18.0 %	21.1	0.00	0.00 %	0.0	-200.0
Total for Annex I	18396	18904	12284	18905	+2.8 %	15.5	0.00	0.00 %	0.0	

Data for Belarus, Croatia, Iceland, Liechtenstein, Monaco, Turkey and individual Member States of the EU-27 are under development.
This version does not include emissions from LULUCF.
1) does not include costs for meeting EU targets on renewable enegy.

© International Institute for Applied Systems Analysis (IIASA) ▪ Atmospheric Pollution and Economic Development (APD)
A-2361 Laxenburg, Austria ▪ Phone: (+43 2236) 807 0 ▪ Fax: (+43 2236) 71 313 ▪ Web: www.iiasa.ac.at

Figure 2.3: GAINS mitigation efforts calculator, version 2.0 (2009), (http://gains.iiasa.ac.at/MEC)

Case I: No trading within ANNEX I countries and no CDM projects

This case is the simplest one. Each country reduces its emissions domestically. This means that mitigation costs for Annex I countries are directly derived from calculated national cost curves. The tool allows choices to be made between different constraints which represent different possible agreements on targets. One can choose a common abatement target for all countries, fix a common average abatement cost or determine the equilibrium corresponding to similar efforts in terms of GDP percentage points. Figure 2.4 shows how the two first cases (Ia and Ib) are calculated using a theoretical framework with three countries (A, B, C) possessing different cost curves. In case Ia, abatement targets vary among countries while in case Ib, carbon prices in each country can differ.

Case II: Carbon trading within ANNEX I countries without CDM projects

Carbon trading within Annex I countries is now allowed. This implies that marginal costs in countries are all equal to the carbon price on the market. Countries with high abatement costs will have an incentive to buy permits on the market as soon as the marginal cost of the next measure to be taken is higher than the market price. Conversely, countries with low marginal costs will have an incentive to sell permits on the market if marginal costs of all measures necessary to fulfill their abatement targets are lower than the price on the market. Figure 2.5 shows in a theoretical framework the main results of such a scheme for three countries possessing different cost curves. In this case, countries A and B will buy permits on the trading market and country C will sell some. In terms of economic efficiency, carbon trading allows to make sure that abatement measures are taken in countries with the lowest abatement costs. This implies that a global abatement target will be attained with a maximal efficiency if carbon trading is allowed.

Case III: Carbon trading within ANNEX I countries with CDM projects

In this last case, Clean Development Mechanisms as defined in the Kyoto Protocol are allowed. Because of a lack of data concerning abatement costs in developing regions, cost curves for non-Annex I countries are not included in the model. The carbon price on the CDM market is an exogenous value set by the user. Countries will engage in such projects if, for a similar

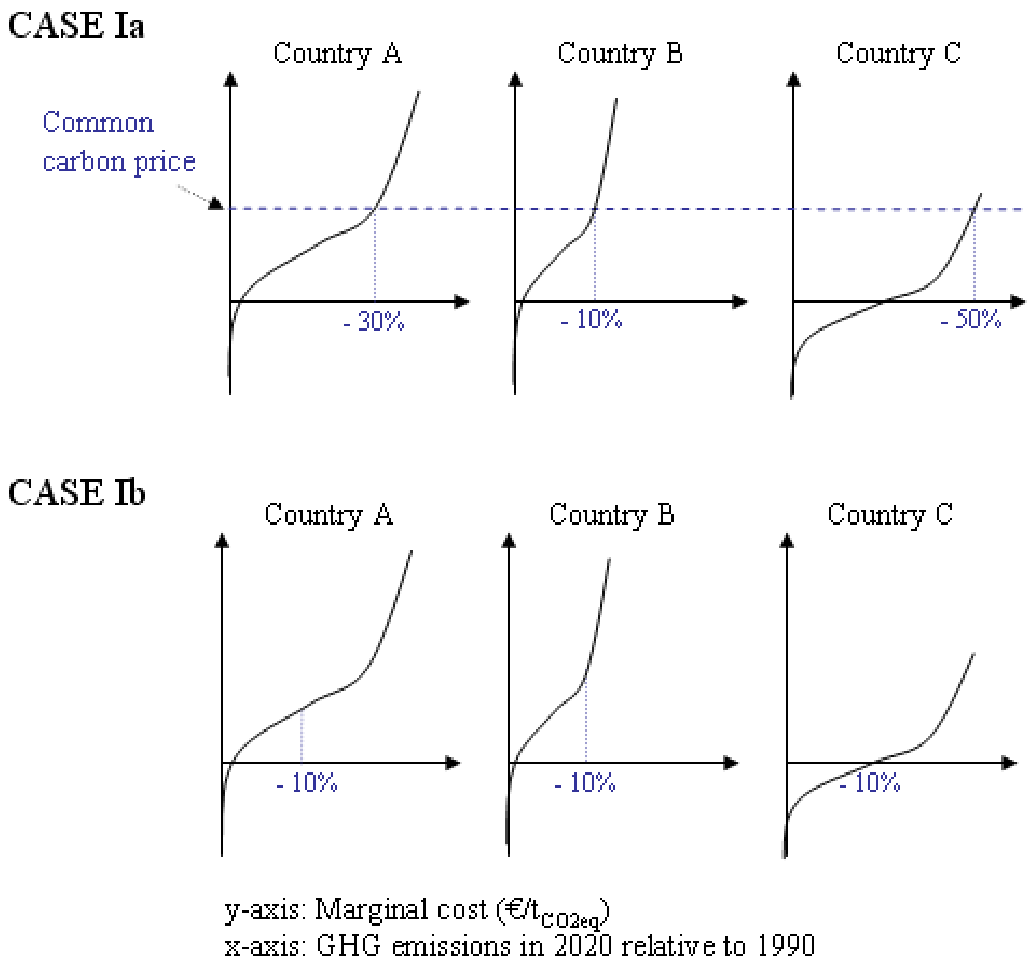


Figure 2.4: Schematic comparison of GHG mitigation efforts. Case I: without carbon trading and CDM projects (Ia: common carbon price, Ib: common abatement targets)

target, the CDM price is lower than the one on the internal trading market without CDM (Case II). In such a case, the carbon price will be equal to the one in the CDM market. Using again a theoretical model, Figure 2.6 shows that both countries A and B will buy CDM credits and trading permits while country C will only sell permits on the internal market. The specificity of this case is that it is a priori not possible to determine which amount of permits countries A and B will respectively buy on the internal and the CDM markets since prices are equal. What is known is only the sum of these two demands. However, this does not prevent us from calculat-

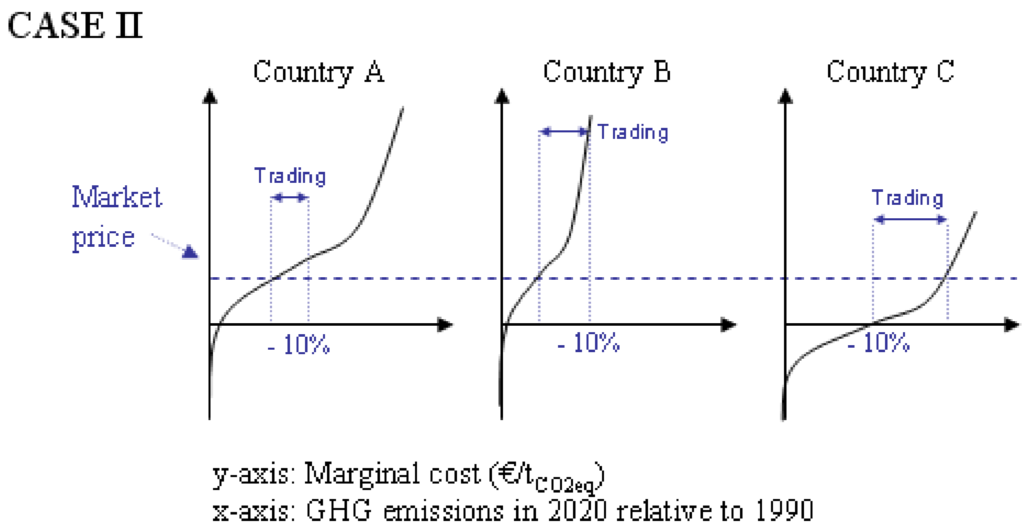


Figure 2.5: Schematic comparison of GHG mitigation efforts. Case II: with carbon trading and without CDM projects

ing total mitigation effort for each country, which is the main goal of the tool.

The last part of this thesis will build upon the analysis of the GAINS model and the conclusions drawn in previous chapters to analyze the inclusion of ancillary benefits from climate policies into mitigation costs.

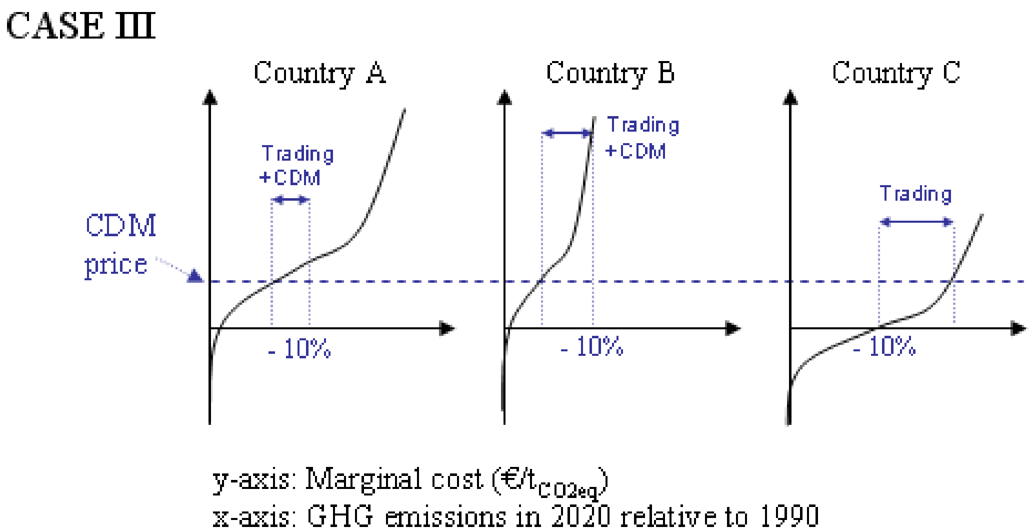


Figure 2.6: Schematic comparison of GHG mitigation efforts. Case III: with carbon trading and CDM projects

CHAPTER 3

Ancillary benefits and the flexible mechanisms of the Kyoto Protocol

Among the key factors determining the attitude of industrialized countries toward climate policies, GHG mitigation costs play a crucial role. Impacts of national measures taken to reduce GHG emissions on the energy sector, on industries, or on the competitiveness of domestic firms in the international competitive market are regarded more and more as key drivers for decision-making. As described in Chapter 2, the GAINS model for Annex I countries allows for the calculation of mitigation costs under different abatement targets and flexibility conditions. Moreover, thanks to the systems approach adopted for the model, ancillary benefits in air pollution are accounted for in terms of avoided abatement costs. The analysis conducted in Chapter 1 showed that these ancillary benefits can potentially compensate a substantial part of climate policies' costs and that thus their inclusion in a full analysis of GHG abatement costs is necessary. Our aim in this last chapter is to analyze the impacts of this inclusion on respective mitigation efforts of Annex I countries. First we shall only consider ancillary benefits that are included in the GAINS model, that is reduced air pollution abatement costs. These benefits will be calculated for each region by using available data on costs of air pollution control technologies. Subtracting these estimates from the national GHG cost curves, we shall calculate new equilibria in the carbon market. By comparing them with outputs from the original GAINS calculation, we shall draw preliminary conclusions on how the consideration of such effects would influence the setting of GHG mitigation targets in Annex

I countries. In a second step, we shall go further in this assessment by adding ancillary benefits from reduced impacts on health.

3.1 National GHG abatement cost curves without ancillary benefits

As described previously, the GAINS model for Annex I countries includes avoided costs for air pollution abatement in its assessment. For each GHG abatement target, the model calculates reductions in air pollutant emissions. Figure 3.1 shows aggregated results for Annex I countries in 2020. Patterns of emission reductions are clearly non linear because of the variety of technologies used. This is demonstrated in Figure 3.2 which displays the disaggregation of SO_2 emissions in all Annex-I countries. Curves showing the highest slopes represent countries where measures taken to cut GHG emissions have the biggest impacts on air pollutant emissions. This is particularly true for eastern regions where the focus is put on energy efficiency measures and alternatives to coal power plants. In the Russian Federation, up to 50% of SO_2 emissions could be saved in relation to 2020 levels of the Baseline scenario for a decrease of 20% in GHG emissions relative to 1990 levels.

The second step adopted for the calculation of ancillary benefits is the determination of avoided abatement costs in each country. This type of data is directly available in the database of the GAINS model. For all Annex-I regions, abatement cost curves of the main air pollutants can be derived. Figure 3.3 illustrates abatement costs in Annex-I countries for each additional reduction in emissions relative to Baseline levels in 2020. Countries such as Ukraine and the Russian Federation have lower marginal costs due to a large potential in cheap measures to increase energy efficiency and implement SO_2 capture units. In contrast, countries such as Norway or Switzerland have already reached high levels of energy efficiencies and stringent regulations on air pollutant emissions. The potential to reduce SO_2 emissions in a cheap way is very limited.

Based on the assessment of the correlation between GHG abatement targets and air pollutant emissions combined with the determination of marginal cost curves, it is possible to subtract avoided abatement costs from GHG cost curves. All data and calculations presented in this section are derived from the GAINS model. In the original version, the extended database allows to calculate variations in abatement costs for each hundredth of percentage

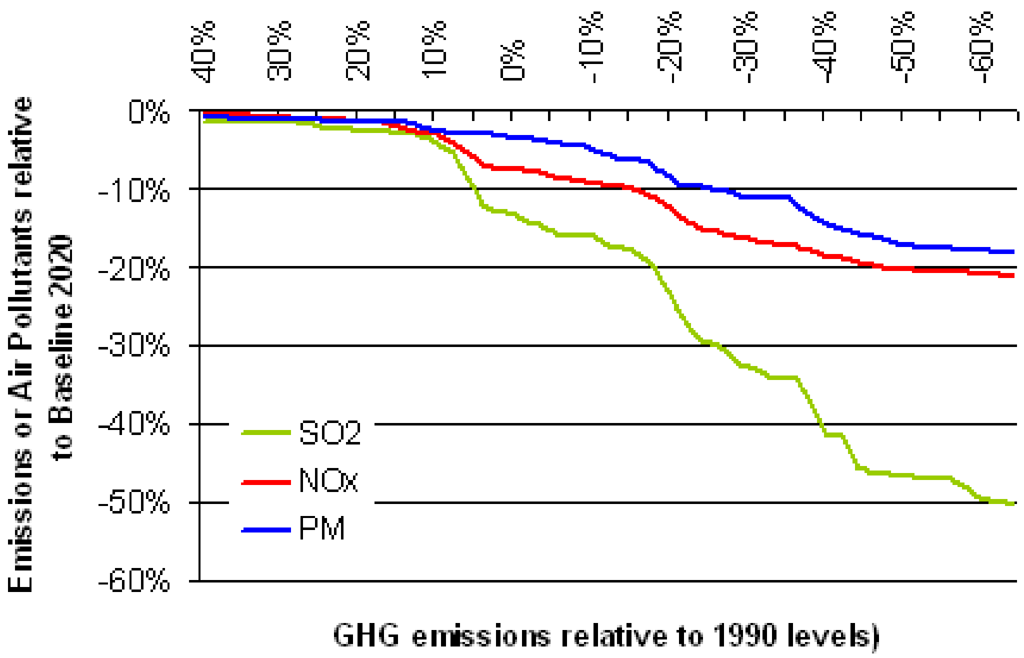


Figure 3.1: Ancillary benefits in air pollutant emissions in 2020 in Annex-I countries (IIASA (2009))

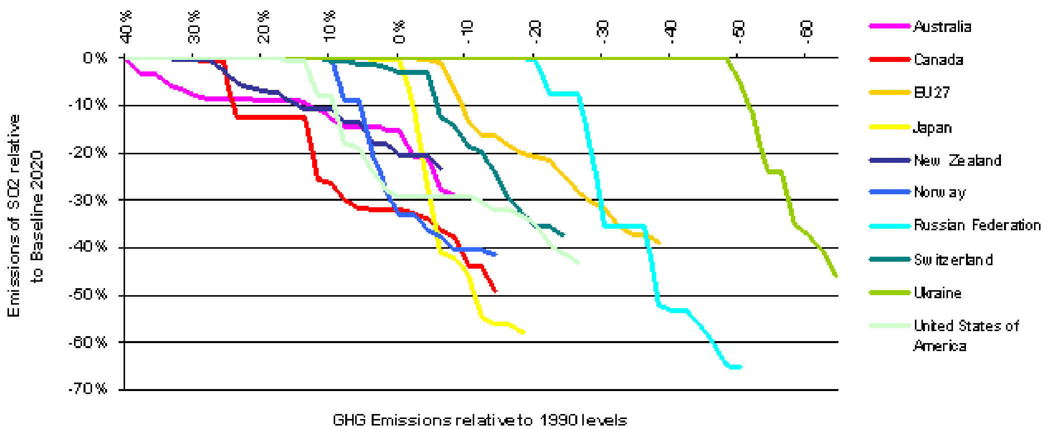


Figure 3.2: Ancillary benefits in SO_2 emissions in 2020 in Annex-I countries (IIASA (2009))

point of GHG emissions. To simplify calculations and limit the amount of data used, all cost functions are in the following discretized next into incre-

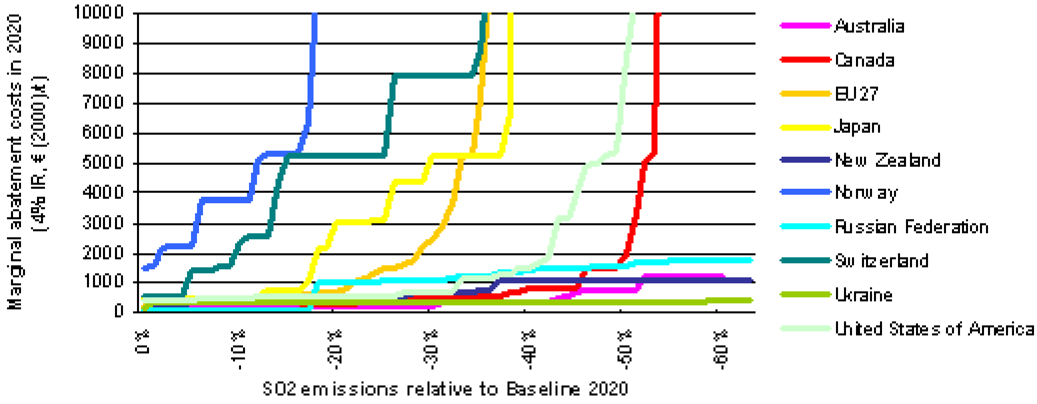


Figure 3.3: SO_2 Marginal abatement costs in 2020 in Annex-I countries (IIASA (2009))

mental steps of one percent. Moreover, values used for marginal abatement costs of air pollutants do not account for the possibility of multi-pollutant control measures. As described on the GAINS website, on-line data only report total costs under the main abated pollutant. For example, if a technology reduces NO_x, SO_2 and PM emissions, all costs will be reported under the first pollutant. This is true for the on-line data but not for the original model whose 'technology-based' approach allows to precisely account for differentiated abatement costs. The consequence is that the marginal costs and ancillary benefits calculated in this section do not precisely reflect the costs used in the model but should be considered as rough estimates. This is not in contradiction with our purpose which is to draw qualitative conclusions on trends induced by the inclusion of ancillary benefits. It is not meant to calculate precisely respective mitigation efforts in all Annex-I countries.

The following equation is used to calculate the marginal ancillary benefits per carbon unit (MAB):

$$MAB_{i,Tg} = \sum_{p} \frac{AB_p(Tg-1) - AB_p(Tg)}{E_{i,GHG,Tg} - E_{i,GHG,Tg-1}}$$

Where

- i is the country and p the air pollutants (SO_2, NO_x, PM)
- Tg is the GHG abatement target expressed in %

- AB is the ancillary benefits expressed in M€ (2000)
- $E_{i,GHG,Tg}$ is the total emissions of GHGs for the target Tg in 2020 expressed in Mt.

Figure 3.4 shows total ancillary benefits expressed in b€/year (IR4%, Reference year: 2000) for the year 2020. These have been derived from the marginal ancillary benefits by calculating integrals over mitigation targets. All regions but two benefit from at most 3 b€/year. Expressed in percentage points of original mitigation costs as used in the GAINS model, they range from 1 to 10% for the lowest targets. Marginal ancillary benefits can go up to 30 €/tCO_2. These costs represent a non negligible part of total costs and impact national cost curves. This range of marginal costs is in accordance with results from other studies presented in the literature review. Two notable exceptions are the European Union and the USA. For GHG abatement targets stringer than -30%, reductions in SO_2 emissions are higher than 35% in Europe. In that case, marginal costs to reduce SO_2 emissions are extremely high and can reach 1 M€ per ton of air pollutant (see Appendix for details on costs). Hence, ancillary benefits increase sharply up to 400 b€ per year for the most stringent targets (beyond -30%). These benefits are of the same order of magnitude as total GHG costs of abatement in the EU. This means that national cost curves without ancillary benefits will be substantially shifted upward. The same logic holds true for the USA where SO_2 emissions are reduced by more than 50%. Air pollution abatement costs are in that case as high as 0.1 M€ per ton of SO_2. This results in ancillary benefits amounting to 8 b€ per year for GHG targets stringer than -25%.

Having built mitigation cost curves for all Annex-I countries, one can now look at the effects of such changes on mitigation efforts under different frameworks. We will adopt the following terminology: scenario 1 stands for a framework where ancillary benefits are not included in the calculation of mitigation costs. Scenario 2 refers to a case where they are (i.e. the original GAINS model). We shall compare here two different cases as defined in Chapter 2, namely cases II and III (with trading and without CDM, with trading and with CDM respectively). Figure 3.5 shows differences in mitigation efforts of Annex-I countries between scenario 1 and scenario 2 in case II. The first conclusion to be drawn is that the carbon price in scenario 1 is always higher than in scenario 2 (see Appendix). This is expected since marginal GHG abatement costs are higher in all countries when ancillary benefits are not considered. Differences in prices range from 0 to 5 €/tCO_2 for targets between 0 and -27% but can reach more than 200 €/tCO_2 for targets close to -30%. As mentioned before, marginal ancillary benefits in the

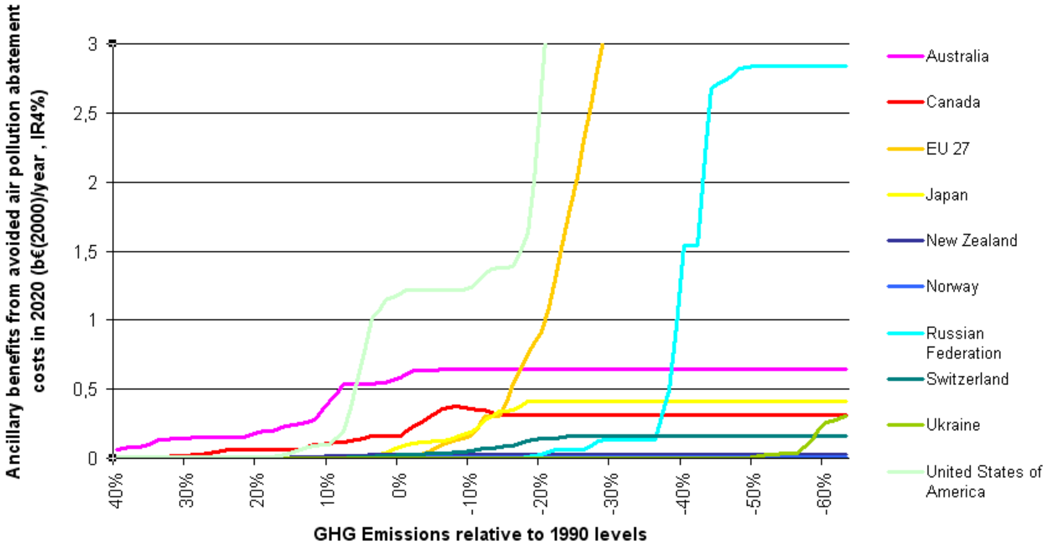


Figure 3.4: SO_2 Total ancillary benefits in 2020 in Annex-I countries (based on IIASA (2009))

EU-27 and the USA are very high in this range of GHG targets. This leads to a higher demand for permits and higher prices on the market. This can also be seen on Figure 3.5 where the difference of mitigation efforts between scenarios 1 and 2 can reach a 100 b€/year in Europe and 150 b€/year in the USA. Without including ancillary benefits, these regions need to buy a substantial amount of permits on the market at a high price. For a -30% GHG abatement target, these regions benefit the most from the inclusion of avoided air pollutant control costs. While one could a priori expect that the inclusion of ancillary benefits lowers mitigation efforts for all countries, it turns out that some specific abatement targets lead to different results.

For the most ambitious targets, almost all countries are better off with scenario 2 since they benefit from reduced local abatement costs. Two exceptions are worth mentioning, namely Ukraine and the Russian Federation. These countries have low marginal abatement costs and are both suppliers to the carbon market. As explained before, the largest difference in carbon prices between the two scenarios occurs at around -28% GHG mitigation because of a steep increase in ancillary benefits for the EU and the USA. The consequence is that suppliers to the market can generate more profits from trading in scenario 1 compared to scenario 2. The difference in profits amounts to approximately 40 b€/year in Ukraine and 160 b€/year in the Russian Federation. These amounts happen to be higher compared to the ancillary benefits in these two regions. The result is a net welfare loss in scenario 2 compared with scenario 1 of about 50 b€/year in the Ukraine and 150 b€/year in the Russian Federation (Figure 3.5). To conclude, the Ukraine and the Russian Federation would profit from the non inclusion of ancillary benefits in the accounting of GHG mitigation costs since they could sell their permits at higher prices. This is important and shows that even if the inclusion of ancillary benefits usually lowers domestic mitigation costs, some individual countries may be worse off due to lower benefits from carbon trading.

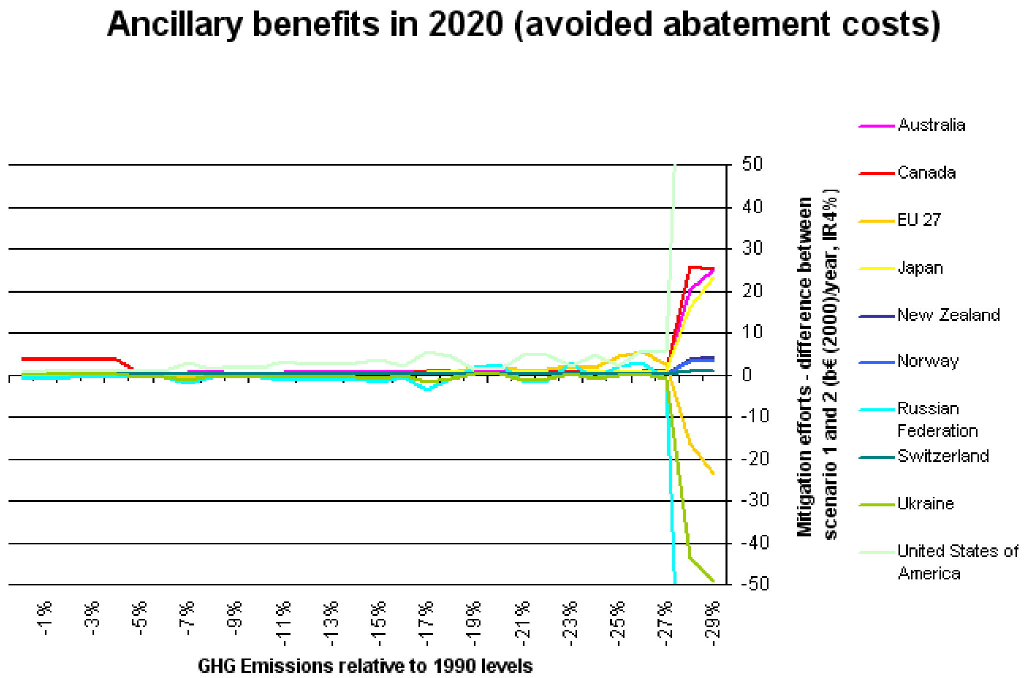


Figure 3.5: Total mitigation costs in 2020 in Annex-I countries in Case II: difference between scenarios 1 and 2 (based on IIASA (2009))

Another interesting aspect is related to the use of Clean Development Mechanism as described in Case III, Chapter 2. For example, fixing a price on the CDM market at 45€/tCO_2, the price on the trading market is below the CDM price as long as the abatement target is more flexible than -17%. As a consequence, CDM opportunities are not used and results are equivalent to those of case II. For more stringant targets, countries which cannot sufficiently reduce their GHG emissions to achieve the assigned targets can

buy credits on the CDM market. The volume of CDM credits exchanged under scenario 2 happens to be smaller since lower marginal abatement costs lead to a decrease in demand for CDM credits. Annex-I countries can reduce more emissions domestically up to a carbon price of 45€/tCO_2. The resulting difference in numbers of CDM projects between the two scenarios represents about 10% of total CDM credits in scenario 2 (about 100 MtCO_2 out of 1100 MtCO_2). This is an important conclusion in terms of financial transfers from developed to developing countries, one of the key issues of current climate negotiations. By considering ancillary benefits in mitigation costs, Annex-I countries have a higher incentive to reduce their emissions at home and buy less credits on the CDM market.
The comparison between scenarios 1 and 2 in case III also sheds light on another important role played by CDM credits. As discussed previously for case II, the Ukraine and the Russian Federation could be worse off in scenario 2 for GHG abatement targets near -30%, due primarily to lower carbon prices on the trading market. This is no longer true when CDM projects are introduced at a price of 45€/tCO_2. Annex-I countries will make use of CDM credits as soon as the GHG abatement target reaches -17%. The price on the carbon market is then fixed at 45€/tCO_2 for any target more stringent than -17%. There is therefore no difference in carbon prices between scenarios 1 and 2 for ambitious targets, and Eastern countries do not see any welfare loss on the trading market. They even benefit from the inclusion of ancillary benefits since they see lower abatement costs while the market price remains the same. In conclusion, the introduction of CDM credits leads to a clearer comparison between the two scenarios. All countries are better off under scenario 2 for abatement targets more stringent than -17% due to a decrease in abatement costs. For more flexible targets, the comparison is equivalent to the one performed in case II since the carbon trading price is lower than the CDM price.

3.2 Ancillary benefits from avoided impacts on health

The last step of our analysis is the inclusion of ancillary benefits from reduced impacts on health in mitigation costs. As described in Chapter 1, a wide spectrum of results is present in the literature. Controversial aspects such as the economic valuation of impacts of air pollution on health and environment can lead to very different assessments of ancillary benefits. Given these difficulties, basic assumptions will be made in order to derive general trends. Our aim is not to quantitatively assess all avoided impacts in all Annex-I countries but rather qualitatively analyze evolutions of market equilibriums when new ancillary benefits are introduced. First of all, in accordance with results from the literature review and based on IPCC (2007), we will restrict the scope of ancillary benefits to avoided impacts on health. Difficulties in valuation of environmental resources combined with the economic significance of air pollution impact on human health justify such a restriction. Moreover, as mentioned in IPCC (2007), recent studies have shown that particulate matter emissions account for the biggest part of monetary benefits. We will then only consider PM emissions as the key factor representing avoided health impacts. Finally, for the sake of simplicity and the comprehensibility of results, we assume that one ton of particulate matter emitted into the atmosphere has the same economic impact in any region of the world, regardless of the type and location of sources. This is a simplistic assumption given the wide disparities in population densities, standards of living and emission patterns among Annex I countries. However, it should not prevent us from drawing qualitative conclusions. In practice, a simple benefit (or negative tax) will be attributed to each ton of PM reduced by climate mitigation measures. In order to account for the whole spectrum of ancillary benefits assessed in the literature, we will take three different values for this tax, namely 200€/tPM, 2000€/tPM, and 20000€/tPM. The justification of these arbitrary values lies in the corresponding marginal benefits which approximately amount to 1 €/tCO_2, 10 €/tCO_2, and 100 €/tCO_2 respectively. These values are in accordance with the range of ancillary benefits found in the literature (see Figure 1.3).

A first illustration of the inclusion of ancillary benefits from avoided impacts on health (scenario 3) can be seen on Figure 3.6 for a -20000€/tPM tax. Conclusions are more straightforward than in other scenarios since the amount of ancillary benefits is directly connected to reduced PM emissions. Therefore, countries where correlations between GHG abatement and ancillary PM reduction are the strongest benefit the most from the inclusion of ancillary benefits (Russian Federation, USA, EU, etc.). As expected, costs of mitigation are reduced by including avoided impacts from air pollution on health. With CDM and carbon trading (case III), ancillary benefits tend to lower the demand for CDM credits. For a -20000€/tPM tax, about 300 Mt CO_2 would be reduced at home rather than through CDM projects, in comparison with case II.

A last question of interest is whether the introduction of ancillary benefits in mitigation costs could lead to significant changes in reductions of Annex-

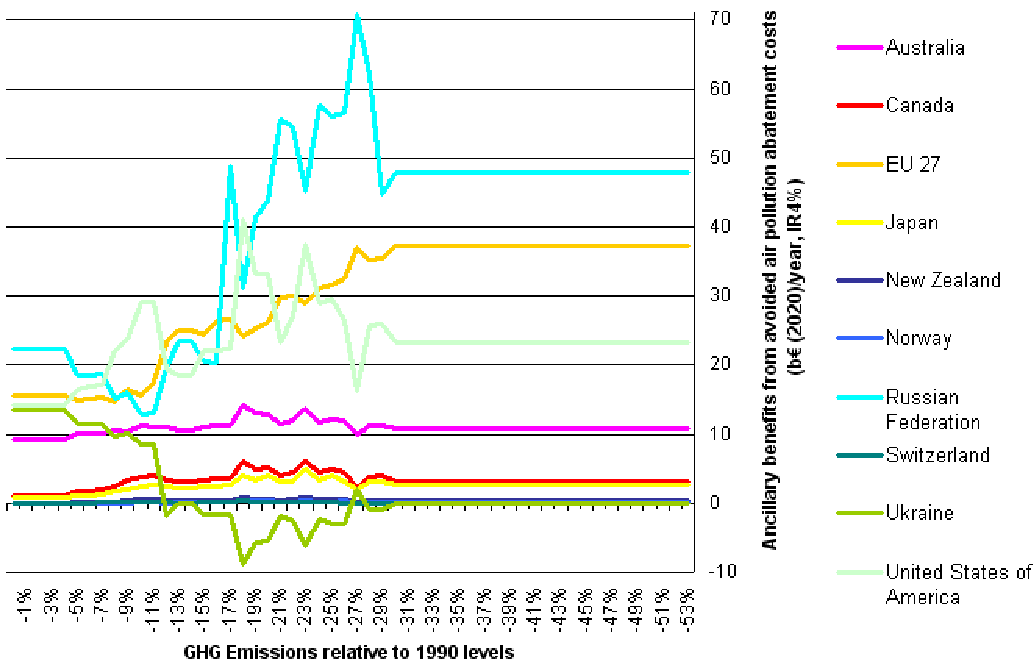


Figure 3.6: Total mitigation costs in 2020 in Annex-I countries in Case II: difference between scenarios 2 and 3 (based on IIASA (2009))

I countries. A first conclusion can be derived from the analysis presented above by comparing domestic GHG reductions for a given GHG abatement under different scenarios. It appears that differences in emission reductions are lower than 1% of total emissions, even in scenario 3 with a -20000 €/tPM tax. The reason is that changes in marginal abatement costs do not seem very high. As mentioned earlier, changes in carbon prices between scenario 1 and the two others are usually lower than 10 €/tCO_2. The analysis of individual marginal abatement costs in all Annex I countries (see Appendix) shows that such a difference in carbon prices can justify changes in respective emission abatement of at most one to two percentage points. Taking the example of a global target of -17%, we mentioned earlier that the carbon market could achieve such a reduction with a price of 45 €/tCO_2 under scenario 2. For the same target, the market price in scenario 1 is equal to 51 €/tCO_2. Using national marginal cost curves from scenarios 1 and 2, one can determine to what extent domestic abatement changes in each country. It appears that they remain equal to -12%, -19% and -4% in Japan, EU and USA respectively and only shift from -37% to -38% in the Russian Federation from scenario 1 to scenario 2. These examples illustrate the fact that changes in carbon prices on the market do not significantly modify the respective mitigation efforts of Annex-I countries in quantitative terms. Another result is that air pollutant emissions are similar in all scenarios. The inclusion of ancillary benefits from reduced air pollution does not significantly change air pollutant emissions in Annex I countries.

Conclusions

The growing amount of literature dealing with ancillary benefits in air quality from measures aiming at reducing GHG emissions reveals an increasing importance for climate policies. While methodologies and results often differ, all studies conclude on the potential importance of these benefits to balance overall mitigation costs. Using the GAINS model and its special application to climate negotiations among Annex I countries, we have shown that the inclusion of avoided abatement costs of air pollutants and the avoided impacts on health can significantly change the economic incentives of parties to the UNFCCC in taking GHG mitigation measures. With ancillary benefits considered, most countries would see a reduction in their mitigation costs due to a decrease in air pollution control costs and/or in impacts on health. Some exceptions exist for regions which significantly supply the carbon market with permits. The inclusion of ancillary benefits in the assessment of GHG mitigation costs tends to reduce the demand for carbon trading. Basic calculations using the GAINS model allowed to determine that resulting welfare losses for suppliers to the market are not entirely compensated by lower abatement costs. The possibility to use Clean Development Mechanism credits changes this effect since carbon prices no longer vary, and are equal to CDM prices. Another interesting consequence of the inclusion of ancillary benefits is that the volume of CDM credits decreases. Annex I countries have an incentive to reduce more emissions at home. By considering only avoided abatement costs, a reduction of 10% of the volume of CDM credits can be observed under certain conditions (high abatement targets and low CDM prices). Finally, it is important to mention the fact that decreases in carbon prices due to ancillary benefits do not seem to change significantly the repartition of quantitative abatement efforts. A more precise assessment of avoided air pollution abatement costs accounting for more pollutants and a comprehensive study of specific impacts on health and environment from reduced air pollutant emissions in all countries should be performed to confirm the validity of the preliminary conclusions drawn in the present thesis.

Appendix

GHG target relative to 1990 levels (%)	Marginal GHG abatement costs in 2020 Original data from the GAINS model (scenario 2) €(2000)/t $_{CO2}$ (4% interest rate)										Marginal GHG abatement costs in 2020 Scenario 1 €(2000)/t $_{CO2}$ (4% interest rate)									
	Aus.	Ca.	EU	Jap.	NZ	Nor.	RF	Sw.	Uk.	US	Aus.	Ca.	EU	Jap.	NZ	Nor.	RF	Sw.	Uk.	US
40	10										11,9									
39	10										11,9									
38	10										10,3									
37	10				-200						11,8				-200					
36	10				-40						15,4				-40					
35	10				-40						15,6				-40					
34	10	-110			-20						10,6	-109			-20					
33	10	-90			-20						10,6	-89			-20					
32	10	-80			-20						10,5	-79			-20					
31	10	-60			-10						11	-59			-10					
30	10	-60			5						10,9	-59			5					
29	10	-50			5						10,9	-49			5					
28	15	-50			5						15	-49			5,3					
27	15	-40			5						15	-39			5,33					
26	25	-20			5						25	-18			5,23					
25	25	-20			5						25	-18			5,23					
24	25	0			5						25	0,02			5,12					
23	25	5			5						25	5,03			5,42					
22	25	5			10						29,6	5			10,8					
21	30	5			10						34,6	5			10,8					
20	30	5			10						30,6	5			10,5					
19	30	5			10						30,2	5			10,5					
18	30	5			10						34,9	5			10,3					
17	30	5			10	-130					34,9	5			10,3	-130				
16	30	5			10	0				-160	31,1	5			13,6	0				-160
15	30	5			25	5				-100	32,1	5,04			29,6	5				-100
14	30	5			25	25		-200		-80	32,8	7,32			25	25		-200		-80
13	30	5			25	25		-180		-70	33,3	7,71			25	25		-180		-70
12	30	10			25	30		-100		-60	47,1	11,4			32	30,1		-99		-60
11	40	10			30	30		-70		-50	53,8	10,8			40,3	30,3		-67		-50
10	60	10			50	30		-60		-30	73,7	11,1			51,5	30		-60		-29
9	60	10			60	30		-30		5	78,8	11,1			61,5	30		-30		5,8
8	70	10			60	30		0		5	70,5	10,8			60	30		7,51		7,9
7	90	10			100	30		0		5	90	10,9			100	30		8,22		8,1
6	100	15			100	45		0		15	100	17,4			101	45		0		18
5	130	15			100	70		5		25	130	17,6			102	70		5		29
4	130	15			100	70		10		30	130	15,3			100	71		15,8		31
3	130	15		-170	120	80		50		30	130	15,3		-169	120	81,3		55,9		31
2	130	25		-30	150	110		80		30	135	25,3		-28	151	109		86,7		30
1	130	25	-180	-20	338	175		80		30	135	25,3	-180	-18	339	174		88,1		30
0	130	35	-140	-10	340	225		80		30	135	39,7	-140	-8,9	340	225		80		30
-1	140	40	-100	0	340	1920		80		30	146	45,9	-100	1,06	340	1920		80		30
-2	225	80	-80	5	340			100		30	225	84,9	-80	5,34	340			106		30
-3	250	100	-60	15	1238			100		35	250	106	-60	15,3	1238			106		35
-4	250	110	-50	20				100		40	251	116	-50	20,4				103		40
-5	300	130	-20	20				100		50	301	135	-19	20,4				104		50
-6	400	250	-10	20				110		60	400	251	-9,7	20,8				119		60
-7	1450	270	0	25				110		80	1450	272	0,32	25,9				119		80
-8		303	5	25				110		100		301	5,22	26,5				119		100
-9		953	5	25				110		100		951	5,26	26,6				119		100
-10			5	30				110		110			6,18	33,1				122		111

-11	5	30		110		110	6,43	34		125		111
-12	10	35		110		120	10	37,2		122		121
-13	15	70		110		130	15	72,9		126		130
-14	15	80		120		150	17	80		129		150
-15	20	110	-100	130		175	22,2	110	-100	139		175
-16	25	110	-50	140		250	26,8	112	-50	171		252
-17	35	140	-30	200		307	37	143	-30	231		309
-18	35	200	-20	200		293	36,4	200	-20	216		300
-19	45	200	-10	250		945	46,5	200	-9,8	266		956
-20	70	200	-10	250			73,3	200	-9,4	250		
-21	70	250	-10	250			74,3	250	-9,3	250		
-22	80	350	-10	250			84	350	-10	266		
-23	90	2437	-10	2845			94,4	2437	-10	2861		
-24	100		-10				104		-10			
-25	110		-10				115		-10			
-26	140		0				145		0,8			
-27	175		0				181		0,9			
-28	200		0				205		0,2			
-29	250		5				255		5,2			
-30	231		5				254		5			
-31	305		10				1200		10			
-32	1796		10				3408		10			
-33			30				1614		30			
-34			40						40			
-35			40						40			
-36			45						50			
-37			45						51			
-38			45						59			
-39			60						77			
-40			70						70			
-41			100						100			
-42			110						129			
-43			130						130			
-44			130						130			
-45			140						140			
-46			175						175			
-47			523						523			
-48												
-49												
-50												
-51												
-52												
-53					-30						-30	
-54					-10						-10	
-55					-10						-10	
-56					-10						-5	
-57					0						5,5	
-58					0						7	
-59					5						12	
-60					5						6,3	
-61					5						6,3	
-62					15						17	
-63					15						18	
-64					15						15	

GHG target relative to 1990 levels (%)	Marginal GHG abatement costs in 2020 Scenario 3 (-200 €/t_{PM}) €(2000)/t_{CO2} (4% interest rate)										Marginal GHG abatement costs in 2020 Scenario 3 (-20000 €/t_{PM}) €(2000)/t_{CO2} (4% interest rate)									
	Aus.	Ca.	EU	Jap.	NZ	Nor.	RF	Sw.	Uk.	US	Aus.	Ca.	EU	Jap.	NZ	Nor.	RF	Sw.	Uk.	US
40	8,39										-151									
39	8,39										-151									
38	8,39										-151									
37	8,55				-200						-135				-200					
36	8,55				-40						-135				-40					
35	8,55				-40						-135				-40					
34	10	-110			-20						10	-110			-20					
33	10	-90			-20						10	-90			-20					
32	10	-80			-20						10	-80			-20					
31	9,84	-60			-10						-6,4	-60			-10					
30	9,84	-60			5						-6,4	-60			5					
29	9,84	-50			5						-6,4	-50			5					
28	15	-50			3,92						15	-62			-103					
27	15	-40			3,92						15	-52			-103					
26	25	-20			3,92						25	-32			-103					
25	25	-21			3,93						25	-88			-102					
24	25	-0,7			3,93						25	-68			-102					
23	25	4,32			3,93						25	-63			-102					
22	24,8	5			10						1,6	5			10					
21	29,8	5			10						6,6	5			10					
20	29,8	5			10						6,6	5			10					
19	29,9	5			10						23	5			10					
18	29,9	5			10						23	5			10					
17	29,9	5			10	-130					23	5			10	-130				
16	29,9	5			10	0				-160	23	5			10	0				-161
15	29,6	4,54			25	5				-100	-12	-41			25	5				-127
14	29,6	4,54			25	25		-200		-80	-12	-41			25	25		-200		-107
13	29,6	4,54			25	25		-180		-70	-12	-41			25	25		-180		-97
12	29,6	9,54			25	30		-100		-60	-12	-36			25	30		-100		-87
11	39,9	9,96			30	29,5		-70		-50	34,7	5,57			30	-22		-70		-81
10	59,9	9,96			50	29,5		-60		-30	54,7	5,57			50	-22		-60		-61
9	59,9	9,96			60	29,5		-30		4,7	54,7	5,57			60	-22		-30		-26
8	69,9	9,96			60	29,5		0		4,7	64,7	5,57			60	-22		0		-26
7	90	9,91			100	29,5		0		5	90	1,15			100	-17		0		5
6	100	14,9			100	44,5		0		15	100	6,15			100	-2,3		0		15
5	130	14,9			100	69,5		5		25	130	6,15			100	22,7		5		25
4	130	14,9			100	69,5		10		30	130	6,15			100	22,7		10		30
3	130	14,9		-170	120	80		50		30	130	6,15		-173	120	80		50		14
2	130	24,9		-30	150	110		80		30	130	16,1		-33	150	110		80		14
1	130	24,9	-180	-20	338	175		80		30	130	16,1	-180	-23	338	175		80		14
0	130	34,9	-140	-10	340	225		80		30	130	26,1	-140	-13	340	225		80		14
-1	140	39,8	-100	-0,2	340	1920		80		30	140	21,2	-109	-23	340	1920		80		30
-2	225	79,8	-80	4,77	340			100		30	225	61,2	-89	-18	340			100		30
-3	250	99,8	-60	14,8	1238			100		35	250	81,2	-69	-7,9	1238			100		35
-4	250	110	-50	19,8				100		40	250	91,2	-59	-2,9				100		40
-5	300	130	-20	19,8				100		50	300	139	-48	4,93				100		50
-6	400	250	-10	19,8				110		60	400	259	-38	4,93				110		60
-7	1450	270	-0,3	24,8				110		80	1450	279	-28	9,93				110		80
-8		303	4,72	24,8				110		100		312	-23	9,93				110		100
-9		953	4,62	25				110		100		963	-33	23,3				110		85
-10			4,62	30				110		110		9,96	-33	28,3				110		95

-11	4,62	30		110		110	9,96	-33	28,3		110		95
-12	9,62	35		110		120	9,96	-28	33,3		110		105
-13	14,8	69,9		110		130		-5,8	60,5		110		129
-14	14,8	79,9		120		150		-5,8	70,5		120		149
-15	19,8	110	-100	130		175		-0,8	101	-105	130		174
-16	24,8	110	-50	140		250		4,23	101	-55	140		249
-17	34,6	140	-31	200		307		-1,9	140	-145	200		302
-18	34,6	200	-21	200		293		-1,9	200	-135	200		289
-19	44,6	200	-11	250		945		8,07	200	-125	250		941
-20	69,6	200	-11	250				33,1	200	-125	250		
-21	69,9	250	-10	250				60,8	250	-23	250		
-22	79,9	350	-10	250				70,8	350	-23	250		
-23	89,9	2437	-10	2845				80,8	2437	-23	2845		
-24	99,9		-10					90,8		-23			
-25	110		-10					96,2		-44			
-26	140		-0,3					126		-34			
-27	175		-0,3					161		-34			
-28	200		-0,3					186		-34			
-29	250		4,66					236		-29			
-30	230		5					219		5			
-31	305		10					294		10			
-32	1796		10					1785		10			
-33			30							30			
-34			40							40			
-35			38,3							-127			
-36			43,3							-122			
-37			43,3							-122			
-38			43,3							-122			
-39			58,3							-107			
-40			69,3							-2,9			
-41			99,3							27			
-42			109							37			
-43			129							57			
-44			129							57			
-45			140							93			
-46			175							128			
-47			523							476			
-48										-47			
-49										-47			
-50													
-51													
-52													
-53					-30							-45	
-54					-10							-25	
-55					-10							-25	
-56					-11							-123	
-57					-1							-113	
-58					-1							-113	
-59					3,9							-108	
-60					4,4							-52	
-61					4,4							-52	
-62					14							-42	
-63					14							-42	
-64					15							15	

GHG target relative to 1990 levels (%)	GHG abatement costs in 2020 Original data from the GAINS model (scenario 2) *b€(2000)/year (4% interest rate)*										GHG abatement costs in 2020 Scenario 1 *b€(2000)/year (4% interest rate)*									
	Aus.	Ca.	EU	Jap.	NZ	Nor.	RF	Sw.	Uk.	US	Aus.	Ca.	EU	Jap.	NZ	Nor.	RF	Sw.	Uk.	US
40																				
39	-0,5										-0,4									
38	-0,46										-0,4									
37	-0,42										-0,3									
36	-0,37										-0,3									
35	-0,33	0									-0,2									
34	-0,29	0									-0,2	0,01								
33	-0,25	-0,7									-0,1	-0,6								
32	-0,21	-1,2									-0,1	-1,2								
31	-0,17	-1,7									-0	-1,6								
30	-0,12	-2									0,02	-2								
29	-0,08	-2,4									0,07	-2,3								
28	-0,04	-2,7									0,11	-2,6								
27	0	-3									0,15	-2,9								
26	-0,83	-3,2									-0,7	-3,2								
25	-0,77	-3,3									-0,6	-3,3								
24	-0,67	-3,4									-0,5	-3,4								
23	-0,56	-3,4									-0,4	-3,4								
22	-0,46	-3,4									-0,3	-3,3								
21	-0,35	-3,4									-0,2	-3,3								
20	-0,25	-3,3									-0,1	-3,3								
19	-0,12	-3,3									0,07	-3,3								
18	0	-3,3									0,2	-3,2								
17	0,12	-3,3				0					0,34	-3,2				0				
16	0,25	-3,2				-0,1				0	0,49	-3,2			0	-0,1				0
15	0,37	-3,2				-0,1				-9,8	0,62	-3,1			0,01	-0,1				-9,8
14	0,5	-3,2				-0,1		0		-16	0,75	-3,1			0,01	-0,1		0		-16
13	0,62	-3,1				-0,1		-0,1		-21	0,89	-3,1			0,01	-0		-0,1		-21
12	0,75	-3,1				-0		-0,2		-25	1,02	-3			0,01	-0		-0,2		-25
11	0,87	-3				-0		-0,3		-29	1,22	-2,9			0,01	-0		-0,3		-29
10	1,04	-3				-0		-0,3		-32	1,44	-2,9			0,02	-0		-0,3		-32
9	1,29	-2,9				0,01		-0,3		-34	1,75	-2,8			0,02	0,01		-0,3		-34
8	1,54	-2,9				0,02		-0,3		-33	2,08	-2,8			0,02	0,02		-0,3		-33
7	1,83	-2,8			0,04	0,04		-0,3		-33	2,37	-2,7		0	0,06	0,04		-0,3		-33
6	2,2	-2,8			0,1	0,05		-0,3		-33	2,75	-2,6		0	0,12	0,05		-0,3		-32
5	2,62	-2,7			0,16	0,08		-0,3		-32	3,16	-2,5		0,01	0,18	0,08		-0,3		-31
4	3,16	-2,6			0,22	0,11		-0,3		-30	3,7	-2,4		0,01	0,25	0,11		-0,3		-29
3	3,7	-2,5		0	0,29	0,15		-0,3		-29	4,24	-2,3		0,02	0,31	0,15		-0,3		-27
2	4,24	-2,4		-2,2	0,36	0,19		-0,3		-27	4,79	-2,2		-2,1	0,38	0,19		-0,3		-26
1	4,78	-2,2	0	-2,5	0,45	0,24		-0,3		-25	5,35	-2,1	0	-2,5	0,48	0,24		-0,2		-24
0	5,32	-2,1	-10	-2,8	0,66	0,33		-0,2		-23	5,91	-1,9	-10	-2,7	0,69	0,33		-0,2		-22
-1	5,87	-1,9	-18	-2,9	0,87	0,44		-0,2		-21	6,47	-1,7	-18	-2,8	0,9	0,44		-0,2		-20
-2	6,45	-1,7	-23	-2,9	1,08	1,4		-0,1		-19	7,08	-1,4	-23	-2,8	1,11	1,4		-0,1		-18
-3	7,38	-1,2	-28	-2,9	1,29	1,4		-0,1		-17	8,02	-0,9	-28	-2,7	1,32	1,4		-0,1		-16
-4	8,42	-0,6	-31	-2,7	2,06	1,4		-0		-15	9,06	-0,3	-31	-2,6	2,09	1,4		0		-14
-5	9,46	0,06	-34	-2,4	2,06	1,4		0,02		-13	10,1	0,39	-34	-2,3	2,09	1,41		0,06		-12
-6	10,7	0,83	-35	-2,2	2,06	1,4		0,08		-9,8	11,4	1,18	-35	-2	2,09	1,41		0,11		-8,6
-7	12,4	2,31	-36	-1,9	2,06	1,4		0,14		-6,1	13	2,67	-36	-1,8	2,09	1,41		0,17		-4,9
-8	18,4	4	-36	-1,6	2,06	1,4		0,19		-1,2	19,1	4	-36	-1,4	2,09	1,41		0,24		-0
-9	18,4	5,7	-35	-1,3	2,06	1,4		0,25		4,9	19,1	6,06	-35	-1,1	2,09	1,41		0,3		6,1
-10	18,4	11,3	-35	-1	2,06	1,4		0,31		11	19,1	11,7	-35	-0,8	2,09	1,41		0,36		12

-11	18,4	11,3	-35	-0,6	2,06	1,4		0,37		18	19,1	11,7	-35	-0,3	2,09	1,41		0,43		19
-12	18,4	11,3	-35	-0,2	2,06	1,4		0,43		25	19,1	11,7	-34	0,09	2,09	1,41		0,5		26
-13	18,4	11,3	-34	0,25	2,06	1,4		0,48		32	19,1	11,7	-34	0,56	2,09	1,41		0,56		33
-14	18,4	11,3	-33	1,14	2,06	1,4		0,54		40	19,1	11,7	-33	1,49	2,09	1,41		0,63		41
-15	18,4	11,3	-32	2,16	2,06	1,4		0,61		49	19,1	11,7	-32	2,51	2,09	1,41		0,69		50
-16	18,4	11,3	-31	3,56	2,06	1,4	-3,3	0,68		60	19,1	11,7	-31	3,91	2,09	1,41	-3,3	0,77		61
-17	18,4	11,3	-30	4,96	2,06	1,4	-5	0,75		75	19,1	11,7	-29	5,34	2,09	1,41	-5	0,86		77
-18	18,4	11,3	-28	6,74	2,06	1,4	-6	0,86		94	19,1	11,7	-27	7,15	2,09	1,41	-6	0,98		96
-19	18,4	11,3	-26	9,29	2,06	1,4	-6,7	0,96		112	19,1	11,7	-25	9,69	2,09	1,41	-6,6	1,1		114
-20	18,4	11,3	-23	11,8	2,06	1,4	-7	1,09		170	19,1	11,7	-22	12,2	2,09	1,41	-7	1,24		173
-21	18,4	11,3	-19	14,4	2,06	1,4	-7,3	1,23		170	19,1	11,7	-18	14,8	2,09	1,41	-7,3	1,37		173
-22	18,4	11,3	-16	17,6	2,06	1,4	-7,6	1,36		170	19,1	11,7	-14	18	2,09	1,41	-7,6	1,5		174
-23	18,4	11,3	-11	22	2,06	1,4	-8	1,49		170	19,1	11,7	-9,6	22,4	2,09	1,41	-7,9	1,64		176
-24	18,4	11,3	-6,1	53	2,06	1,4	-8,3	3		170	19,1	11,7	-4,3	53,4	2,09	1,41	-8,2	3,16		178
-25	18,4	11,3	-0,6	53	2,06	1,4	-8,6	3		170	19,1	11,7	1,48	53,4	2,09	1,41	-8,6	3,16		178
-26	18,4	11,3	5,57	53	2,06	1,4	-9	3		170	19,1	11,7	7,87	53,4	2,09	1,41	-8,9	3,16		178
-27	18,4	11,3	13,4	53	2,06	1,4	-9	3		170	19,1	11,7	15,9	53,4	2,09	1,41	-8,9	3,16		178
-28	18,4	11,3	23,1	53	2,06	1,4	-9	3		170	19,1	11,7	26	53,4	2,09	1,41	-8,9	3,16		178
-29	18,4	11,3	34,2	53	2,06	1,4	-9	3		170	19,1	11,7	37,4	53,4	2,09	1,41	-8,9	3,16		178
-30	18,4	11,3	48,2	53	2,06	1,4	-8,8	3		170	19,1	11,7	51,6	53,4	2,09	1,41	-8,7	3,16		178
-31	18,4	11,3	61	53	2,06	1,4	-8,6	3		170	19,1	11,7	65,7	53,4	2,09	1,41	-8,5	3,16		178
-32	18,4	11,3	78	53	2,06	1,4	-8,3	3		170	19,1	11,7	133	53,4	2,09	1,41	-8,2	3,16		178
-33	18,4	11,3	178	53	2,06	1,4	-8	3		170	19,1	11,7	322	53,4	2,09	1,41	-7,8	3,16		178
-34	18,4	11,3	178	53	2,06	1,4	-7	3		170	19,1	11,7	412	53,4	2,09	1,41	-6,8	3,16		178
-35	18,4	11,3	178	53	2,06	1,4	-5,7	3		170	19,1	11,7	412	53,4	2,09	1,41	-5,5	3,16		178
-36	18,4	11,3	178	53	2,06	1,4	-4,3	3		170	19,1	11,7	412	53,4	2,09	1,41	-4,2	3,16		178
-37	18,4	11,3	178	53	2,06	1,4	-2,8	3		170	19,1	11,7	492	53,4	2,09	1,41	-2,5	3,16		178
-38	18,4	11,3	178	53	2,06	1,4	-1,3	3		170	19,1	11,7	572	53,4	2,09	1,41	-0,8	3,16		178
-39	18,4	11,3	178	53	2,06	1,4	0,17	3		170	19,1	11,7	572	53,4	2,09	1,41	1,1	3,16		178
-40	18,4	11,3	178	53	2,06	1,4	2,16	3		170	19,1	11,7	572	53,4	2,09	1,41	3,7	3,16		178
-41	18,4	11,3	178	53	2,06	1,4	4,49	3		170	19,1	11,7	572	53,4	2,09	1,41	6	3,16		178
-42	18,4	11,3	178	53	2,06	1,4	7,82	3		170	19,1	11,7	572	53,4	2,09	1,41	9,4	3,16		178
-43	18,4	11,3	178	53	2,06	1,4	11,5	3		170	19,1	11,7	572	53,4	2,09	1,41	14	3,16		178
-44	18,4	11,3	178	53	2,06	1,4	15,8	3		170	19,1	11,7	572	53,4	2,09	1,41	18	3,16		178
-45	18,4	11,3	178	53	2,06	1,4	20,1	3		170	19,1	11,7	572	53,4	2,09	1,41	23	3,16		178
-46	18,4	11,3	178	53	2,06	1,4	24,8	3		170	19,1	11,7	572	53,4	2,09	1,41	28	3,16		178
-47	18,4	11,3	178	53	2,06	1,4	30,6	3		170	19,1	11,7	572	53,4	2,09	1,41	33	3,16		178
-48	18,4	11,3	178	53	2,06	1,4	48	3		170	19,1	11,7	572	53,4	2,09	1,41	51	3,16		178
-49	18,4	11,3	178	53	2,06	1,4	48	3		170	19,1	11,7	572	53,4	2,09	1,41	51	3,16		178
-50	18,4	11,3	178	53	2,06	1,4	48	3		170	19,1	11,7	572	53,4	2,09	1,41	51	3,16		178
-51	18,4	11,3	178	53	2,06	1,4	48	3		170	19,1	11,7	572	53,4	2,09	1,41	51	3,16		178
-52	18,4	11,3	178	53	2,06	1,4	48	3		170	19,1	11,7	572	53,4	2,09	1,41	51	3,16		178
-53	18,4	11,3	178	53	2,06	1,4	48	3	0	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	0	178
-54	18,4	11,3	178	53	2,06	1,4	48	3	-0	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	-0	178
-55	18,4	11,3	178	53	2,06	1,4	48	3	-0	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	-0	178
-56	18,4	11,3	178	53	2,06	1,4	48	3	-0	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	-0	178
-57	18,4	11,3	178	53	2,06	1,4	48	3	-1	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	-0	178
-58	18,4	11,3	178	53	2,06	1,4	48	3	-1	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	-0	178
-59	18,4	11,3	178	53	2,06	1,4	48	3	-1	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	-0	178
-60	18,4	11,3	178	53	2,06	1,4	48	3	-1	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	-0	178
-61	18,4	11,3	178	53	2,06	1,4	48	3	-0	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	-0	178
-62	18,4	11,3	178	53	2,06	1,4	48	3	-0	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	-0	178
-63	18,4	11,3	178	53	2,06	1,4	48	3	-0	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	0	178
-64	18,4	11,3	178	53	2,06	1,4	48	3	-0	170	19,1	11,7	572	53,4	2,09	1,41	51	3,16	0,2	178

GHG target relative to 1990 levels (%)	GHG abatement costs in 2020 Scenario 3 (-200 €/t_{PM}) b€(2000)/year (4% interest rate)										GHG abatement costs in 2020 Scenario 3 (-20000 €/t_{PM}) b€(2000)/year (4% interest rate)									
	Aus.	Ca.	EU	Jap.	NZ	Nor.	RF	Sw.	Uk.	US	Aus.	Ca.	EU	Jap.	NZ	Nor.	RF	Sw.	Uk.	US
40											-5,6									
39	-0,56										-6,7									
38	-0,53										-7,4									
37	-0,49										-8									
36	-0,46										-8,6									
35	-0,42										-9,1									
34	-0,39	0									-9,7	0								
33	-0,34	-0,7									-9,7	-0,7								
32	-0,3	-1,2									-9,6	-1,2								
31	-0,26	-1,7									-9,6	-1,7								
30	-0,22	-2									-9,6	-2								
29	-0,18	-2,4									-9,6	-2,4								
28	-0,14	-2,7									-9,6	-2,7								
27	-0,1	-3									-9,6	-3								
26	-0,93	-3,2									-10	-3,3								
25	-0,87	-3,3									-10	-3,5								
24	-0,76	-3,4									-10	-4								
23	-0,66	-3,4									-10	-4,4								
22	-0,55	-3,4									-10	-4,8								
21	-0,45	-3,4									-10	-4,8								
20	-0,35	-3,4									-10	-4,8								
19	-0,22	-3,3									-10	-4,7								
18	-0,1	-3,3									-9,9	-4,7								
17	0,03	-3,3			-0	0					-9,8	-4,7			-0,4	0,07				-0,2
16	0,15	-3,2			-0	-0,1				-0	-9,7	-4,6			-0,4	0				-0,3
15	0,27	-3,2			-0	-0,1		-0		-9,8	-9,6	-4,6			-0,4	0		-0		-10
14	0,4	-3,2			-0	-0,1		-0		-16	-9,7	-4,9			-0,4	0,01		-0		-18
13	0,52	-3,2			-0	-0		-0,1		-21	-9,7	-5,1			-0,4	0,02		-0,1		-24
12	0,64	-3,1			-0	-0		-0,2		-25	-9,8	-5,3			-0,4	0,03		-0,2		-30
11	0,77	-3,1			-0	-0		-0,3		-29	-9,8	-5,6			-0,4	0,05		-0,3		-36
10	0,93	-3			-0	-0		-0,3		-32	-9,7	-5,5			-0,4	0,04		-0,3		-41
9	1,18	-3			-0	0,01		-0,3		-34	-9,5	-5,5			-0,4	0,02		-0,4		-44
8	1,43	-2,9			-0	0,02		-0,3		-34	-9,2	-5,5			-0,4	0,01		-0,4		-46
7	1,72	-2,8		-0	0,03	0,04		-0,3		-33	-9	-5,4		-0,1	-0,4	0		-0,4		-48
6	2,1	-2,8		-0	0,1	0,05		-0,3		-33	-8,6	-5,4		-0,1	-0,3	-0		-0,4		-47
5	2,51	-2,7		-0	0,16	0,07		-0,3		-32	-8,2	-5,4		-0,1	-0,2	-0		-0,4		-46
4	3,05	-2,6		-0	0,22	0,11		-0,3		-31	-7,6	-5,4		-0,1	-0,2	0		-0,4		-45
3	3,59	-2,5		-0	0,28	0,14		-0,3		-29	-7,1	-5,3		-0,1	-0,1	0,02		-0,4		-43
2	4,14	-2,4		-2,2	0,36	0,18		-0,3		-27	-6,6	-5,3		-2,3	-0	0,06		-0,3		-42
1	4,68	-2,3	0	-2,5	0,45	0,24		-0,3		-25	-6	-5,2	0	-2,7	0,06	0,11		-0,3		-41
0	5,22	-2,1	-10	-2,8	0,66	0,33		-0,2		-23	-5,5	-5,1	-10	-3	0,27	0,2		-0,3		-40
-1	5,76	-1,9	-18	-2,9	0,87	0,44		-0,2		-21	-4,9	-4,9	-18	-3,2	0,48	0,31		-0,2		-40
-2	6,34	-1,7	-23	-2,9	1,08	1,4		-0,1		-20	-4,4	-4,8	-24	-3,5	0,69	1,27		-0,2		-38
-3	7,28	-1,2	-28	-2,9	1,29	1,4		-0,1		-18	-3,4	-4,4	-29	-3,7	0,91	1,27		-0,1		-36
-4	8,32	-0,6	-31	-2,7	2,06	1,4		-0		-16	-2,4	-4	-33	-3,8	1,67	1,27		-0,1		-34
-5	9,36	0,02	-34	-2,4	2,06	1,4		0,02		-13	-1,3	-3,4	-36	-3,9	1,67	1,27		-0		-31
-6	10,6	0,79	-35	-2,2	2,06	1,4		0,08		-10	-0,1	-2,6	-39	-3,8	1,67	1,27		0,04		-28
-7	12,3	2,28	-36	-1,9	2,06	1,4		0,13		-6,3	1,57	-1,1	-41	-3,7	1,67	1,27		0,1		-25
-8	18,3	4	-36	-1,6	2,06	1,4		0,19		-1,4	7,6	1	-42	-3,6	1,67	1,27		0,16		-20
-9	18,3	5,67	-35	-1,3	2,06	1,4		0,25		4,7	7,6	2,43	-44	-3,5	1,67	1,27		0,21		-14
-10	18,3	11,3	-35	-1	2,06	1,4		0,31		11	7,6	8,12	-45	-3,2	1,67	1,27		0,27		-8,3

-11	18,3	11,3	-35	-0,6	2,06	1,4		0,37		18	7,6	8,18	-47	-2,8	1,67	1,27		0,33		-2,5
-12	18,3	11,3	-35	-0,2	2,06	1,4		0,43		24	7,6	8,24	-49	-2,5	1,67	1,27		0,39		3,3
-13	18,3	11,3	-34	0,23	2,06	1,4		0,48		32	7,6	8,3	-51	-2	1,67	1,27		0,45		9,7
-14	18,3	11,3	-33	1,12	2,06	1,4		0,54		40	7,6	8,3	-51	-1,3	1,67	1,27		0,5		18
-15	18,3	11,3	-32	2,14	2,06	1,4		0,61		49	7,6	8,3	-51	-0,4	1,67	1,27		0,57		27
-16	18,3	11,3	-31	3,54	2,06	1,4	-3,3	0,68		60	7,6	8,3	-51	0,9	1,67	1,27	-3,9	0,64		37
-17	18,3	11,3	-30	4,93	2,06	1,4	-5	0,75		75	7,6	8,3	-51	2,18	1,67	1,27	-5,7	0,71		53
-18	18,3	11,3	-28	6,71	2,06	1,4	-6	0,86		94	7,6	8,3	-51	3,96	1,67	1,27	-11	0,82		71
-19	18,3	11,3	-26	9,26	2,06	1,4	-6,7	0,96		112	7,6	8,3	-51	6,5	1,67	1,27	-15	0,92		89
-20	18,3	11,3	-24	11,8	2,06	1,4	-7,1	1,09		170	7,6	8,3	-51	9,05	1,67	1,27	-19	1,06		147
-21	18,3	11,3	-20	14,3	2,06	1,4	-7,5	1,23		170	7,6	8,3	-49	11,6	1,67	1,27	-23	1,19		146
-22	18,3	11,3	-16	17,5	2,06	1,4	-7,8	1,36		170	7,6	8,3	-46	14,8	1,67	1,27	-24	1,32		146
-23	18,3	11,3	-11	22	2,06	1,4	-8,2	1,49		170	7,6	8,3	-42	19,2	1,67	1,27	-25	1,45		146
-24	18,3	11,3	-6,4	53	2,06	1,4	-8,5	3		170	7,6	8,3	-37	50,2	1,67	1,27	-26	2,96		145
-25	18,3	11,3	-0,9	53	2,06	1,4	-8,8	3		170	7,6	8,3	-32	50,2	1,67	1,27	-26	2,96		145
-26	18,3	11,3	5,24	53	2,06	1,4	-9,2	3		170	7,6	8,3	-27	50,2	1,67	1,27	-28	2,96		145
-27	18,3	11,3	13	53	2,06	1,4	-9,2	3		170	7,6	8,3	-20	50,2	1,67	1,27	-29	2,96		145
-28	18,3	11,3	22,8	53	2,06	1,4	-9,2	3		170	7,6	8,3	-11	50,2	1,67	1,27	-30	2,96		145
-29	18,3	11,3	33,9	53	2,06	1,4	-9,2	3		170	7,6	8,3	-0,5	50,2	1,67	1,27	-31	2,96		145
-30	18,3	11,3	47,8	53	2,06	1,4	-9	3		170	7,6	8,3	12,7	50,2	1,67	1,27	-32	2,96		145
-31	18,3	11,3	60,6	53	2,06	1,4	-8,9	3		170	7,6	8,3	24,9	50,2	1,67	1,27	-32	2,96		145
-32	18,3	11,3	77,6	53	2,06	1,4	-8,6	3		170	7,6	8,3	41,3	50,2	1,67	1,27	-32	2,96		145
-33	18,3	11,3	178	53	2,06	1,4	-8,2	3		170	7,6	8,3	141	50,2	1,67	1,27	-32	2,96		145
-34	18,3	11,3	178	53	2,06	1,4	-7,2	3		170	7,6	8,3	140	50,2	1,67	1,27	-31	2,96		145
-35	18,3	11,3	178	53	2,06	1,4	-5,9	3		170	7,6	8,3	139	50,2	1,67	1,27	-29	2,96		145
-36	18,3	11,3	178	53	2,06	1,4	-4,6	3		170	7,6	8,3	139	50,2	1,67	1,27	-33	2,96		145
-37	18,3	11,3	178	53	2,06	1,4	-3,2	3		170	7,6	8,3	139	50,2	1,67	1,27	-38	2,96		145
-38	18,3	11,3	178	53	2,06	1,4	-1,7	3		170	7,6	8,3	138	50,2	1,67	1,27	-42	2,96		145
-39	18,3	11,3	178	53	2,06	1,4	-0,3	3		170	7,6	8,3	138	50,2	1,67	1,27	-46	2,96		145
-40	18,3	11,3	178	53	2,06	1,4	1,65	3		170	7,6	8,3	138	50,2	1,67	1,27	-49	2,96		145
-41	18,3	11,3	178	53	2,06	1,4	3,95	3		170	7,6	8,3	138	50,2	1,67	1,27	-49	2,96		145
-42	18,3	11,3	178	53	2,06	1,4	7,25	3		170	7,6	8,3	138	50,2	1,67	1,27	-48	2,96		145
-43	18,3	11,3	178	53	2,06	1,4	10,9	3		170	7,6	8,3	138	50,2	1,67	1,27	-47	2,96		145
-44	18,3	11,3	178	53	2,06	1,4	15,2	3		170	7,6	8,3	138	50,2	1,67	1,27	-45	2,96		145
-45	18,3	11,3	178	53	2,06	1,4	19,5	3		170	7,6	8,3	138	50,2	1,67	1,27	-43	2,96		145
-46	18,3	11,3	178	53	2,06	1,4	24,1	3		170	7,6	8,3	138	50,2	1,67	1,27	-40	2,96		145
-47	18,3	11,3	178	53	2,06	1,4	29,9	3		170	7,6	8,3	138	50,2	1,67	1,27	-36	2,96		145
-48	18,3	11,3	178	53	2,06	1,4	47,3	3		170	7,6	8,3	138	50,2	1,67	1,27	-20	2,96		145
-49	18,3	11,3	178	53	2,06	1,4	47,3	3		170	7,6	8,3	138	50,2	1,67	1,27	-22	2,96		145
-50	18,3	11,3	178	53	2,06	1,4	47,3	3		170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96		145
-51	18,3	11,3	178	53	2,06	1,4	47,3	3		170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96		145
-52	18,3	11,3	178	53	2,06	1,4	47,3	3		170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96		145
-53	18,3	11,3	178	53	2,06	1,4	47,3	3	-0	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-8	145
-54	18,3	11,3	178	53	2,06	1,4	47,3	3	-0	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-8	145
-55	18,3	11,3	178	53	2,06	1,4	47,3	3	-0	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-8	145
-56	18,3	11,3	178	53	2,06	1,4	47,3	3	-1	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-8	145
-57	18,3	11,3	178	53	2,06	1,4	47,3	3	-1	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-10	145
-58	18,3	11,3	178	53	2,06	1,4	47,3	3	-1	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-11	145
-59	18,3	11,3	178	53	2,06	1,4	47,3	3	-1	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-12	145
-60	18,3	11,3	178	53	2,06	1,4	47,3	3	-1	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-13	145
-61	18,3	11,3	178	53	2,06	1,4	47,3	3	-1	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-13	145
-62	18,3	11,3	178	53	2,06	1,4	47,3	3	-1	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-14	145
-63	18,3	11,3	178	53	2,06	1,4	47,3	3	-0	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-14	145
-64	18,3	11,3	178	53	2,06	1,4	47,3	3	-0	170	7,6	8,3	138	50,2	1,67	1,27	-23	2,96	-14	145

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