Macro-economic Impacts of Air Pollution Policies in the EU

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Abstract

In this paper we analyse interactions between European air pollution policies and policies for climate change making based on the computable general equilibrium model called WorldScan. WorldScan incorporates both emissions of greenhouse gases (CO_2, N_2O and CH_4) and emissions of air pollutants (SO_2, NO_x, NH_3 and $PM_{2.5}$). WorldScan is extended with equations that enable the simulation of end-of-pipe measures that remove pollutants without affecting the emission-producing activity itself. We simulate air policies in the EU by introducing emission ceilings for air pollutants at the level of member states. The simulations show that mitigation not only consists of implementing emission control technologies, but also efficiency improvements, fuel switching and structural changes. Greenhouse gas emissions decrease, making climate change policies less costly. The decrease in the price on emission of greenhouse gases may be substantial, depending on the ambition level of the air pollution policy and the context of international climate policies.

Keywords: air pollution, climate change, energy, co-benefits, interaction policies

1. Introduction

The economic literature has dealt with the interactions and synergies between mitigation of greenhouse gas (GHG) emissions and reducing air pollution (Burtraw and Toman, 1997; Aunan et al., 2006; Rive, 2010). These studies have in common that they only analyze part of the problem. These studies lack complex interactions because they do not cover all type of gases relevant for air pollution and climate change or they disregard pollution of small sources from freight and personal transport. This paper aims to fill this gap in the literature and sketch the macro-economic impacts of air and climate policies based on a model with complete coverage of the most relevant air pollutants and climate change precursors. The focus will be on recent policy proposals related to air pollution and climate change in Europe, taking into account the complex interactions between these issues.

In 2005, the European Commission launched the Thematic Strategy on Air Pollution (TSAP) (EC, 2005). The ultimate objective is to attain *"levels of air quality that do not give rise to significant negative impacts on, and risks to human health and the environment"*. The TSAP establishes interim objectives for air quality for the period up to 2020. One of the actions announced is a revision of the National Emission Ceilings (NEC) Directive, which requires Member States to meet emission ceilings for the air pollutants sulphur dioxide (SO_2), nitrogen oxides (NO_x), Volatile Organic Compounds (VOC) and ammonia (NH_3) by 2010 and in later years. The revision of the NEC Directive aims to align the national ceilings with the 2020 TSAP objectives and in particular to introduce a ceiling for particulate matter (PM). The revision was postponed to account for the outcome of the negotiations on the EU Climate Change and Energy Package as well as the effects of the economic crisis. Adoption of an up-to-date clean air strategy is envisaged no later than 2013 (EC, 2011).

The EU Climate Change and Energy Package was agreed by the European Parliament and Council in December 2008 and became law in June 2009.[3] The EU considers a 30% emission reduction, provided

[3] This package sets climate and energy targets for 2020, i.e. to reduce EU's GHG emissions with at least 20% below 1990 levels, to attain a 20% share of its energy consumption from renewable resources, and a 20% reduction in

other major emitting countries in the developed and developing worlds commit to do their fair share under a global climate agreement within the United Nations Framework Convention on Climate Change (UNFCCC). Moreover, the EU's Road Map for a Low-Carbon Economy also aims for a more restrictive carbon constraint in the longer term (EC, 2011).

Generally, emissions of air pollutants such as SO_2 and NO_x and GHG are correlated as these emissions are largely driven by the combustion of fossil energy (EEA, 2009). Emission reductions may occur through structural changes in the economy.[4] Whereas for carbon dioxide (CO_2) this is the major way to achieve emission reductions, emissions of other pollutants can also cost-effectively be abated through so-called end-of-pipe (EOP) options, such as flue gas desulphurization techniques and dust filters on stacks of power stations. These are emission control options removing pollutants largely without affecting the emission-producing activity itself as they are an add-on to the production process. Air pollution policies in Europe relied substantially on EOP abatement. Nevertheless, in the past energy prices itself also changed and lead to structural changes, thereby lowering air pollution. But, given the idea that abatement of air pollutants primarily relies on EOP while mitigating carbon dioxide mainly occurs through structural changes, it is no surprise that the EU choose to first decide on the climate policies, and then design the air policy plans. Amman et al. (2007) point at the connection between climate and air policies.[5]

As the abatement potential of relatively cheap EOP abatement options already has been exploited in the past decades, further emission reductions through EOP become more expensive. It may become more efficient to aim for reductions of air pollution through structural changes, e.g. through a switch from

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primary energy use compared with projected levels through improved energy efficiency. Plans for EU's renewable target still have to be elaborated at the national level.

[4] We will use this term throughout this paper. They result from pricing carbon changing the fuel-mix to attain a lower carbon intensity. Further, carbon prices increase energy prices, which in turn may lead to a reallocation of resources towards sectors with a lower energy intensity, and within a sector or household to energy savings to reduce on the energy use per unit of output or income earned.

[5] Mainly this refers to (mitigating) emissions, although there are also interactions between these issues in the long run. E.g., there are temperature changes from SO_x (-) and CO_2(+) and of VOC(-) to O_3(+), see IPCC (2007).

oil to (more expensive but less polluting) natural gas in the transport sector, thereby also avoiding investments in expensive dust-filters in cars and trucks.

This paper analyses cost-effective air pollution policies in the EU based on NEC. It shows that stringent air policy generates a structural change, and hence will reduce the cost of EU climate policies, both for sectors within the Emission Trading System (ETS), the other Non-ETS sectors, and households (NETS).

We analyze the interactions between climate and air policies with WorldScan, which is a multi-sector, multi-region, global Computable General Equilibrium (CGE) model. We choose for a CGE framework as there is little knowledge on the interactions between climate and air pollution policy in this type of model, as well as its policy implications. The model is set up in such a way that emission reductions can be obtained by both structural changes in the economy as well as by EOP. We argue this type of analysis to produce more realistic mitigation costs than those that rely on solely the direct cost estimates of bottom-up studies. We feel the latter type of analyses underestimate or lack the element of structural change. But also they disregard the additional welfare losses from adding policy interventions in a distorted economy (carbon prices on top of existing energy taxes).

We build upon earlier work. To fully take into account the interactions between climate and air policies, WorldScan (Boeters and Korneef, 2010) was extended to include full coverage of all sources of emissions of non-CO_2 greenhouse gases N_2O and CH_4, and those related to air pollutants SO_2, NO_x, NH_3 and $PM_{2.5}$. For this, data were used from the GAINS model (Wagner and Amann, 2009; Amann et al. 2011). The model here is suitable to simulate multiple emission abatement in a consistent economic modelling framework.

Further, we also add to work by Bollen et al. (2009a), Burtraw et al. (2003), and Rive (2009). Burtraw et al. (2003) also analyse interactions between climate and air policy, but only focus on the electricity sector. Rive (2009) also focuses on EU, but only models one EU region, and neglects emissions and EOP abatement of non-CO_2 gases, NH_3 emissions from agriculture, and NO_x emissions from transport services (either ships, freight, public transport and cars). Bollen et al. (2009a) is the most complete analysis, as it also accounts for the value of air pollution and puts both policy issues in the context of an intertemporal cost-benefit analysis, but it lacks country-specific details in the EU and in general information on sectors. Summarizing, this paper adds to the literature as it puts multi-dimensional abatement in a CGE context with sectoral/regional deepening that also allows to analyze actual policy plans in Europe related to both air pollution and climate change.

Although with the type of model we use we cannot simulate precisely the changes of the productions processes at the micro-level that could also be relevant for macro-emission abatement. We nevertheless closely calibrate substance-and-time-specific emission coefficients and Marginal Abatement Cost curves (MAC's) of bottom-up studies such as the GAINS model (Amman et al., 2009). Applying these, we can use our stylized production functions at the sectoral level (including EOP) to simulate the appropriate price signal for structural changes in economies from combinations of air and climate policies.

Section 2 describes the renewed version WorldScan used for our analyses. This section particularly focuses on the extensions of the model with respect to emissions of non-CO_2 greenhouse gases and air pollutants. Section 3 presents the policy cases considered. The results of the simulations are presented in section 4. Finally, in section 5 the main findings are discussed.

2. WorldScan

The macro-economic consequences of specific climate or air policy scenarios are assessed using the global applied general equilibrium model WorldScan, see Bollen et al. (2004), Lejour et al. (2006), Wobst et al. (2007); Manders et al. (2008), Hayden et al. (2010), and Bollen et al. (2011). WorldScan data for the base year 2004 are to a large extent taken from the GTAP-7 database (Badri et al. 2008), which provides integrated data on bilateral trade flows and input-output accounts for 57 sectors and 113 countries and regions. Here we give only a brief sketch of the aggregation level with respect to regions, sectors and the main characteristics of the bottom-up representation of the electricity sector. We conclude with a description of the representation of bottom-up EOP mitigation technologies in the model, which allows simulating cost-effective reduction of emissions of CO_2 from non-energy sources and of CH_4, and N_2O from both energy and process-related sources. This extension allows WorldScan to also simulate what-flexibility with respect to the mitigation of Kyoto-gases. But EOP options are implemented for all air pollutants, which is relevant for any TSAP.

The renewed version of the model enables to simulate the macro-economic impacts of climate and air policies. In this respect, the main instruments are taxes on pollution and income transfers from acting on IET, permit trading in ETS and NETS markets, CDM, subsidies to promote renewable energy, and efficient prices of air pollution.

2.1 Overview

The aggregation of regions and sectors can be flexibly adjusted in WorldScan. We use a version with 23 regions and 18 sectors, listed in Tables 1. Regional disaggregation is relatively fine within Europe, but coarse outside. The main reason is that the emission ceilings for air pollutants are region/country specific because of differences in impact of air pollution on human health and ecosystems. Moreover, cost and potential of control options may differ significantly between regions and/or countries.

Likewise, we focus on a set of sectors accurately representing the heterogeneous characteristics of activities causing emissions of GHGs and air pollutants, whereas non-polluting sectors are captured in a more aggregated manner. A distinction is made between sectors taking part in the EU emission trading system (ETS, consisting of the electricity and the energy intensive sector) and sectors and household activities which do not participate in the emission trading system (NETS).

Further, we distinguish five agricultural sectors, because of distinct characteristics with respect to emissions and abatement of air pollutants and of non-CO_2 GHGs and also to be able to appropriately model the production of biofuels (ethanol and bio-diesel). [6,7]

Coal , Oil, and Gas are the primary energy sectors.[8,9] The Electricity sector is refined with a detailed electricity technology specification developed by Boeters and Koornneef (2010). Renewable energy is not

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[6] Rice cultivation, livestock production and fertilizer use are linked the sector Other agricultural activities, which is hence a major source of emissions of CH_4, N_2O and NH_3.

[7] Biodiesel is produced by the sector Vegetable and oils and fats, and ethanol by Sugar beet in Europe and Sugar cane in Brazil, and Wheat and Corn in the USA.

[8] The sector Oil delivers mainly to Petroleum Coal Products, which in turn delivers fuels for one of the two transport sectors or for consumption of the final good Transport and communication.

characterised by a particular input. Here, technologies are introduced as separate economic activities. Electricity generation technologies are represented by simple, linearly increasing supply functions and calibrated using existing estimates of cost ranges and potentials. The technology split is determined by equalising marginal costs across technologies. WorldScan captures five concrete electricity technologies: (1) fossil electricity with a flat supply curve and coal, gas and oil as imperfectly substitutable inputs, (2) wind (onshore and offshore) and solar energy, (3) biomass, (4) nuclear energy, and (5) conventional hydropower.

<<<Table 1 around here >>>

All relevant anthropogenic emissions of GHG's and main outdoor air pollutants are covered. In case of the former type of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and the latter category consists of sulphur dioxide (SO_2), nitrogen oxides (NO_x), fine particulate matter ($PM_{2.5}$), and ammonia (NH_3).

WorldScan is set up to simulate deviations from a "Business-As Usual" (BAU) path by adding taxes or International Emissions Trading (IET) to it.[10] The emissions of the BAU of air pollutants are calibrated at the lowest region/sector level of WorldScan from an emissions pathway of the GAINS models.[11] All electricity technologies are calibrated to this BAU scenario, and nuclear and hydropower cannot endogenously react in our policy scenarios. As individual electricity technologies are not represented in the input-output tables, the values in the aggregate electricity sector must be split up among them. We do this with three simple assumptions: (1) marginal costs (after taxes and subsidies) are equal across technologies, (2) fossil fuels are used as inputs in fossil electricity generation, but not for the other

[9] A concordance matrix is used to relate aggregate production sectors to well-known aggregated consumption categories. These final good categories originate from Lejour et al. (2006), and include: [1] Food, beverages and tobacco, [2] Clothing and furniture, [3] Gross rent and fuel, [4] Other household outlays, [5] Education and medical care, [6] Transport and communication, [7] Recreation, and [8] Other goods and services consumed.

[10] The BAU is not generated by WorldScan itself, but calibrated to the World Energy Outlook 2009 (IEA, 2009). For more details on the calibration of the BAU, see Annex 1 and Bollen et al. (2011a).

[11] We calibrate emissions coefficients while simultaneously simulating sectoral activities of the BAU.

electricity technologies, (3) all other inputs (capital, labour, intermediate goods and services) are used in proportion to the aggregate shares (as in Boeters and Koornneef, 2010).

2.2 Modelling EOP mitigation technologies

Basic principles of emissions and emission abatement

CO_2 emissions can be easily estimated in a CGE model because CO_2 is emitted in fixed proportions with the burning of fossil fuels. This is not true for emissions of other pollutants, e.g. SO_2 and NO_x. Part of the emissions of these pollutants are not related to fossil fuel combustion, but caused by, e.g., agriculture and waste-disposal. A distinction can be made between emissions that are directly related to a specific input to production (e.g. fossil energy) and those inherent to the production process, independent of the inputs. These so-called process emissions are related to the output level of a sector.

Generally, emission reductions can be achieved by more efficient use of inputs (e.g. fossil fuels), substitution across different inputs (e.g. switch from coal to natural gas), investment in emission control technologies, but also demand reduction and change in the structure of the economy. CGE models have their strength when it comes to demand shifts and changes in the production structure. For CO_2 mitigation these are most relevant, but for other pollutants EOP is more relevant. The abatement potential and cost of control options is included in bottom-up engineering models (Markandya, Halsnaes et al., 2001).

Alternative approaches to include emission control in CGE framework

The literature provides a number of approaches for including this kind of emission control in a CGE model. The general concept is that actors can choose between paying for emissions and investing in pollution control. Pollution control serves as a substitute to the pollutant emissions, which comes at a cost. The approaches differ in the way the abatement costs are incorporated in the model. Hyman et al. (2002) introduce emissions as an input to the production function. The elasticity of substitution between the emissions and the conventional inputs is estimated to match a marginal abatement cost curve that is derived from detailed bottom-up studies, e.g. Hyman et al (2002), and Reilly et al. (2002). Gerlagh et al. (2002) and Dellink et al. (2004) introduce for each pollutant an abatement sector producing mitigation technologies in a region. Emission reductions can be achieved by increasing the input of abatement goods. The elasticity of substitution is estimated to fit the data on abatement cost of measures as available from various data sources of technical pollution control measures. Rive (2010) includes abatement in a CGE model by source-specific technology steps, each step representing groupings of abatement technologies with similar marginal abatement costs. This offers a flexible treatment that can incorporate activity- and pollution-specific marginal abatement cost curves of different shapes from bottom-up studies.

Emissions and emission control in Worldscan

In addition to CO_2, we added to WorldScan the major other GHGs (CH_4 and N_2O). Next, we also added the most relevant air pollutants SO_2, NO_x, NH_3 and $PM_{2.5}$ (Amman et al., 2007). For these emissions, not only fossil fuel combustion is relevant, but also the use of other inputs and the production process in general. Therefore, we model emissions occurring at different stages of the production process. Emissions from combustion of energy are calculated as a fixed proportion of the amount of fossil fuel consumption. Emissions related to the use of chemical fertilizer in agricultural production are similarly calculated, using the intermediary input from the chemical sector to the agricultural sector as a proxy for the amount of fertilizer used, illustrated on the nesting of the production function in Figure 2.1. Emissions that cannot directly be linked to a particular input into the production process are included in the model as process emissions, i.e. linked to the sectoral output (the top nest of the production function).

<<< Figure 2.1 around here>>>

Reductions in input-related emissions can be achieved by reductions in the use of these inputs, e.g. through a substitution away from these inputs or by reducing the level of production. Reductions in process emissions can be achieved by reductions in the level of production. Moreover, as indicated above, emissions can to a certain extent be reduced by investment in emission control. The possibility to invest in emission control is introduced in Worldscan by abatement technologies for each type of emissions (input-related and process) in each sector. We omit here indices for region-sector-activity-substance, and the supply function then reads as:

$$c(a)=\left[\alpha\cdot\left(\bar{a}-a\right)^{-\beta}-\gamma\right]\cdot\sum_i \delta_i p_i \qquad (1)$$

With *c(a)* the marginal cost of abatement as a function of *a*, the level of abatement as a percentage of 'unabated emissions', i.e. emissions as they would occur without emission control. $\bar{a}$ is the maximum level of abatement, α and β are parameters (both > 0) and γ is a constant that determines the initial level of the marginal cost $c(0)$. δ_i are input coefficients and p_i prices of the inputs *i*, indicating the share of the various inputs required to produce abatement in the cost. The parameters δ_i are fixed at the shares of the value inputs of the Capital goods sector. If however, wages rise, then this may also increase the marginal costs of abatement proportional to the labour share of production of the Capital Goods sector. This functional form is used because it offers good flexibility to approximate empirical abatement cost curves.[12] The total cost curve is:

$$C(a)=\bar{e}\cdot\left[\alpha\cdot\frac{\bar{x}^{1-\beta}-\left(\bar{x}-x\right)^{1-\beta}}{1-\beta}-\gamma\cdot x\right]\cdot\sum_i \delta_i p_i \qquad (2)$$

with $\bar{e}$ the level of emissions as they would occur without emission control. These unabated emissions are calibrated to a BAU, derived by a bottom-up model (GAINS in this paper), and emission coefficients are equal to the ratio between emissions of a specific activity and the simulated level of that particular activity. However, in a policy scenario, we fix the emission coefficient, but not the activity, and therefore the unabated emissions level $\bar{e}$ may change. This feeds into equation 2, and therefore a fixed set of abatement options may yield different levels of abatement depending whether $\bar{e}$ changes compared to the base year. The commodity and factor input x_i in abatement is given by

$$x_i=\frac{\partial C}{\partial p_i}=\bar{e}\cdot\left[\alpha\cdot\frac{\bar{x}^{1-\beta}-\left(\bar{x}-x\right)^{1-\beta}}{1-\beta}-\gamma\cdot x\right]\cdot\delta_i \qquad (3)$$

[12] More details on an example of the calibration of MAC's is given in Annex 2.

The optimal abatement level is chosen by equalising the marginal abatement cost and the price of IET on ETS in case of the climate policy and the uniform air pollution price in case of a country-specific air pollution target.

The functional form is flexible to approximate a large range of MAC curves. The values of the parameters $\bar{a}$, α, β, γ and δ_i are estimated from derived set of MAC curves from GAINS, which is based on the set of mitigation options of the ranges spanned by Maximum Feasible Target Reductions (MFTR) in addition to those measures necessary to comply with the Current Legislation in 2020, see Amman et al. (2010).

Using sector-specific abatement supply allows taking into account differences between sectors in the possibilities and costs to reduce emissions. This seems to be of particular interest if environmental policies are differentiating between sectors, such as is the case in the EU where climate policy sets different targets for sectors within the system of emission trade (ETS) and other sectors. Moreover, as emission reductions are expressed relative to ‘unabated’ emission levels, changes in emissions that result from changes in production structure or output levels will proportionally lead to changes in the abatement potential by emission control options.

Rive (2010) limited EOP abatement to a small number of discrete steps and disregarded sources of emissions of e.g. the transport sector. By using equation 1 as our format for a MACC, we can deal with many curves and a wider domain of abatement in sectors and countries without excessive computational problems. Hence, we are in a better position to put real numbers to the economy-wide allocation of resources between EOP and structural changes - i.e. to consider air pollution that covers all anthropogenic emission sources, not just those of some major electric power stations. Nevertheless, we realize that the equations above are an approximation, but we think we gain in realism of the analysis by also mimicking the EOP costs of very expensive options (the MFTR potential and a little beyond that range) and the possible extension (flexibility) and more air pollutants in the analysis (here we also add non-CO_2 gases and NH_3).

3 Policy cases

Using WorldScan we assess the impacts of several policy variants up to the year 2020, in particular on emissions and prices of emissions on ETS and NETS markets, on cost-effective air pollutant prices that meet a pre-specified set of NEC's, and on competitiveness and welfare. In this paper, welfare is the Hicksian Equivalent Variation (HEV) to compensate for any losses of utility measured as % of National Income. Any damage valuation of the environmental state or benefits from improved environmental quality of policy interventions is not included in this indicator.

<<<Table 2 around here>>>

The air pollution policies are variants of the TSAP, which are presented for EU-27 in Table 2. We choose three variants of Amman et al. (2007) in increasing order of stringency compared to the BAU: European Commission (EC), European Parliament (EP), or Cost-Benefit Analysis (CBA).[13] They serve to achieve multiple goals of mitigating mortality from the chronic exposure to particulate matter and ozone, and the more traditional environmental problems of acidification and eutrophication (see EC, 2011). The targets are formulated in improvements of the year 2000. The last row of Table 2 refers to an emissions index of Particulate Matter Surrogate (PMs).[14] This indicator reflects the emissions of air pollutants SO_x, NO_x, NH_3 and $PM_{2.5}$ relevant for the built-up of outdoor concentration of fine particulate matter. We choose to present this single indicator, because it summarizes the emissions of air pollution and determines about 80% of the value estimate of air pollution in Europe, see Holland et al (2007). Although

[13] The variants EC, EP, and CBA are taken from Wagner et al. (2010), Amman et al. (2008), and Amman et al. (2005) respectively. The CBA variant equalizes the difference of direct costs from GAINS and benefits of stringent air policy at the margin, as reported in Holland et al. (2005). Upon request, we can provide these numbers, but is beyond the scope of the analysis as presented in this paper.

[14] PMS is weighted sum of air pollutants with weights 0.54, 0.88, 2.0, and 0.64 for SO_x, NO_x, $PM_{2.5}$, and NH_3 respectively. The weights are based on de Leeuw (2000).

we only present here the emission targets for EU27, it should be noted that country-and substance-specific are below this aggregate index (more details in section 4.1).

Mortality from ozone is relevant for air pollution, but is a global externality and hence will be less affected by EU mitigation plans.[15] Table 2 also shows that acidification of ecosystems in Europe will improve considerably when implementing EC, but be aware that around 55% reduction is already foreseen in the existing reduction plans (Current Legislation Emissions scenario in Amman et al., 2004). Other options than mitigation of emissions will be necessary to further lower the acidification in Europe. Eutrophication is more than acidification driven by the deposition of nitrogen, and as NH_3 mitigation is relatively expensive than SO_2 mitigation, the eutrophication improvements (% ecosystem area exceeded) are lower.

Although we realize that in EU's Climate and Energy package is already promoted to legislation, we start with the analytical "clean" option of only air pollution variants based on EU-countries pursuing multiple national ceilings for air pollutants without having to reduce any GHG's. We show here the impacts of the most stringent set of proposed NEC's, i.e. CBA and the more relaxed variant of EP.

Further, the next three cases introduce the ambitious climate change related pledges made by countries up to the Copenhagen Climate Change Conference in December 2009, i.e. the third AMBITIOUS PLEDGES (without air policies) scenario, the fourth AMBITIOUS PLEDGES + CBA variant, and the fifth policy case relaxes on the ambitions of the air policy: AMBITIOUS PLEDGES + EP.[16]

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[15] Although part of the TSAP, we disregard VOC emission reduction plans relevant for ozone formation, because it hardly affects the analysis. Ozone formation is driven by global changes concentrations of tropospheric CO, from emissions of CH_4, CO_2, and then at the regional at the stratosphere affected by emissions of NO_x and VOC, see also Bollen et al. (2009b).

[16] Annex I countries ambitiously adopt relatively low caps on GHG-emissions and allow free permit trade amongst each other. Further, in this scenario China and India impose relative targets for CO2 emission-intensities of 45% and 25% below 2005 intensities. The EU imposes a 30% GHG emission target, and a 20% share of renewable energy in final energy use.

Next, we analyze the less stringent climate policy of the EU solely implementing its' Energy and Climate Package with the renewable target (EU PLEDGE) and without this target (EU GHG).[17] These climate policies are combined with the two earlier air targets, but also extended with EC. Thus, eight cases are designed: EU PLEDGE + CBA, EU PLEDGE + EP, EU PLEDGE + EC, and EU PLEDGE and likewise without EU's renewable target: EU GHG + CBA, EU GHG + EP, and EU GHG + EC, EU GHG.

The AMBITIOUS PLEDGES scenario assumes a completely different institutional setting of climate policies of the EU PLEDGE, i.e. all Annex 1 countries establish an international IET system leading to a single uniform carbon price throughout Annex 1. For analytical purposes, we introduce the EU25% scenario that assumes EU's GHG reduction to be equal to 25% (instead of 20% of EU PLEDGE).

4 Results

Section 4.1 will analyze marginal costs of abatement of stringent air policies (CBA) for different air pollutants and welfare impacts for countries. Then, we will relax the stringency of the air targets, and show how cost-effective structural changes in the economies of the EU-27 induced by air targets reduce the GHG emissions, and how this compares with Europe's GHG emission reductions of the EU PLEDGE and AMBITIOUS PLEDGES. Next, in section 4.2 we will explicitly introduce climate policies, thus enabling to analyze the interaction between air pollution and climate policies. We will show how prices in ETS and NETS markets in Europe and welfare are affected through combinations of ambitious and less ambitious targets for climate policy (30 and 20% targets for GHG and with or without a renewable target for final energy) and air policy (based on CBA, or proposals by the European Parliament or the European Commission). Finally, section 4.3 will bring together the results of all policy variants.

[17] The EU PLEDGE excludes the use of CDM, but assumes permit trade with one uniform carbon price in ETS and one in NETS markets in the EU. Again, the EU imposes a targeted 20% share of renewable energy in final energy use.

4.1 Co-benefits of stringent air targets significant

This section presents the impacts in 2020 of imposing national ceilings in different EU countries based on CBA. We illustrate here the extent to which air policies alone may provoke structural changes in economies in the EU. We realize that the EU designed its Climate and Energy Package for 2020, but nevertheless this case serves as a useful guidance for the results of the other cases presented in this paper. Figure 2 presents the marginal costs of abatement of SO_2, NO_x, $PM_{2.5}$, and NH_3, and welfare losses measured as % of national income.

<<<Figure 2 around here>>>

It can be seen that welfare losses will be the largest in the new Member States of the EU (Poland: 3%; rest of EU-27: 2%). The main reason is that emissions per unit of GDP in these countries will be a factor of four higher in these countries compared to average of the EU27.[18] Hence, the relatively low marginal costs of abatement (non-zero for al substances) necessary to meet the national ceilings will generate large distortions in these economies. The next group of countries with more moderate welfare losses are Italy (1%) and Spain (0.8%). The losses in these countries are mainly driven from the high marginal costs of abatement compared to the other countries. Germany also has high marginal costs for SO_2, but their welfare losses are less than in Italy and Spain. In Germany the air policy mainly affects the electricity sector, whereas in Italy and Spain more gasses are taxed and higher costs associated with transport services. The latter factor will push the welfare losses because of interactions of the air policy with existing oil taxes in the baseline. For comparison, the numerical importance of this argument is provided by Klepper and Peterson (2006).

<<<Figure 3 around here>>>

[18] For all countries we weight emissions of the different substances according to the Leeuw (2000) to represent emissions relevant for mortality from the chronic exposure to $PM_{2.5}$, and divide this aggregate emission index with the BBP.

Figure 3 presents for all EU countries in WorldScan the changes in emissions of GHG's and air pollutants of the air policy to match the ceilings of the CBA variant. Further there are circles that represent the emissions reductions implied by the targets of the EU Energy and Climate Package (20%) and Ambitious Pledges (30%). The results are presented for the same countries as in Figure 2.

It can be seen that stringent air goals have a large indirect impact; it leads to reductions of the GHG emissions. The air policy targets to reduce 20% of the emissions of NO_x, $PM_{2.5}$, and NH_3, and 45% of SO_2, leads to a 25% GHG emission reduction alone! The reason why SO_2 emissions reductions are much larger than for the other substances is that they contribute more significantly to health than the other substances. The emission reductions for NH_3 are significant as well, because ammonia per kg contributes more significantly to health damages than NO_x, and hence EOP options in agriculture are effective as well (de Leeuw, 2000; Holland et al., 2005). Stringent air policies generate a climate change co-benefit larger than the climate targets of the Energy and Climate Package can achieve. For each substance it can be seen that the share contribution of EOP to abatement is limited, keeping in mind that the maximum feasible reduction is at most a factor of two higher than the simulated outcome. The SO_2 emission reductions are generated by 66% from restructuring of the economy. Rive (2010) comes with a 30-50% estimate. The reason why we produce more structural changes is that we include more abatement policies in our BAU, which implies that the low-hanging fruit is excluded in our policy simulations.[19] Next to that, the SO_2 emissions reduction effort in this aper is about a factor three higher. Consequently, it may not be a surprise that there are significant GHG emissions reductions as a co-benefit from these policies.

The co-benefits of efficient stringent air policies come from Germany, Poland and the other accession countries, because air pollution abatement in these countries is cheaper. Actually, the co-benefit is larger than the GHG emission reductions pledged by the EU. The other countries can be seen to do less GHG abatement from their air policies (especially the Netherlands) because of the lack of economies of scale related to abatement. Despite that EOP to total abatement is large in Eastern European countries, there

[19] The SO2 emission level of NEC in Rive (2010) is comparable to the level of our BAU. Hence, the NEC10 calls for an extra 15% SO2 emission reduction compared to NEC. In this paper, we follow CBA and EP that lead to a 40-50% emission reduction.

seems to be enough inefficiencies in the economy to generate a substantial structural improvement leading to the simulated co-benefit.

4.2 Also moderate air targets have impacts on climate change policies

The previous section argues that structural changes in the economy will unfold if only air pollution were to take place (and no climate change policies). In this section we will abandon this assumption, and analyze the impacts of air targets on climate change policies. Figure 4 presents the changes of emissions in EU27 related to the GHG's and air pollutants of various policy scenarios. These scenarios are the air policies to meet the ceilings of the CBA and EP, and the combinations with climate policy: i.e. AMBITIOUS PLEDGES with air targets (+EP, +CBA or no air targets). Further, there are circles that represent the emissions reductions implied by the targets of the AMBITIOUS PLEDGES and EU PLEDGE.

<<<Figure 4 around here>>>

The AMBITIOUS PLEDGES scenario yields a 15% GHG emission reduction, i.e. half of the necessary emission reductions will likely be imported from international permit markets against approximately 10 €/tCO_2 eq.). Hence, not surprisingly, CBA provokes a larger climate co-benefit (a 22% GHG emission reduction) than EU's contribution to the climate in AMBITIOUS PLEDGES scenario (18% GHG emission reduction). Note also that EP approximates the GHG emission reduction of the AMBITIOUS PLEDGES case. Adding climate to air policies magnifies GHG emission reductions of the air policy (compare + CBA with CBA and AMBITIOUS PLEDGES + EP with EP). AMBITIOUS PLEDGES + CBA makes EU indifferent whether to import or export permits. The internal marginal costs of CO_2 abatement goes down and comes close to the international permit price.

Finally, whereas stringent air targets have climate change co-benefits in the order of the GHG reductions of the variants of EU PLEDGE and AMBITIOUS PLEDGES, the air quality co-benefits of climate change policies increase only up to 50% of the benefits of the EP variant. In other words, the EU policy making concentrates with climate change policy, that will only reduce half of the potential number of premature deaths from air pollution policies of CBA, it is the other policy perspective of air pollution that will lower the number premature deaths much more effectively, and generates a co-benefit as envisaged by the climate pledges by the EU.

Next, Figure 5 presents the changes in primary energy use in EU27 from the more relaxed climate policy resembled by the EU PLEDGE scenario, combined with air ceilings of either the CBA or EP variant. Primary energy use is split up in oil, gas, coal and all other non-fossil energy carriers (nuclear, wind, sun, and biomass).

<<<Figure 5 around here>>>

The figure reconfirms the main result of this paper that only achieving air targets without any climate policy goals will substantially restructure the economy of the EU27. The cost-effective response is to switch away from fossil fuels and save on energy by 10-15% of total primary energy use (EP and CBA variant), i.e. fossil energy demand reductions exceed the expansion of the use of non-fossil energy carriers. The structural changes of the CBA variant can be seen to be larger than those of the EU Pledge. Also we can see that imposing air targets in line with CBA generates extra reductions in coal (from 5 to 8%) and oil (from 1.5 to 3%), which is driven by the stringency of SO_2 target for ETS and NO_x and $PM_{2.5}$ targets for oil in transport sectors. The increase of non-fossil energy demand only applies when the renewable target is explicitly applied. Otherwise, energy saving seems to be cheaper and dominates the impacts on energy markets, also reconfirming the results of Boeters et al. (2010). Finally, it can be seen that gas is affected more than oil in all variants, whereas oil relatively contributes more to pollution (carbon intensity is approximately 1/3 higher, and for air pollutants this is often much higher). The reason is that generally the current energy taxes on oil are higher, and hence additional taxation may have a lower impact on end-user prices, thus lowering also its' impact on demand.

<<<Figure 6 around here>>>

Figure 6 brings together the impacts on welfare and prices on ETS and NETS markets of air policies in addition to the climate policies (AMBITIOUS PLEDGES and EU PLEDGE with and without renewable target). The left panel of Figure 6 shows the impacts of air policies on welfare, whereas the right shows them on the prices in €/ t CO_2 eq. The stringency of the air targets are plotted on the x-axis of both panels; i.e on the left side we start with no air policies (0%), then the EC variant (at around 60% of the total CBA abatement effort), the EP variant (around 70%), and finally the CBA variant (100%).

We can see that constraining emissions of air pollutants of the EC variant in addition to climate policies has little impact on welfare and carbon prices (only NETS will go down from 8 to 3 €/ t CO_2 eq.). The welfare losses will be 0.1% point lower without the renewable target. The reason is that this target is binding, and comes at the expense of an additional subsidy on sustainable energy carriers (solar, wind, and biomass) amounting up to 20-24% of the user price (either electricity or biofuels).[20] The losses of the AMBITIOUS PLEDGES and EU PLEDGE are approximately the same. On the on hand the carbon price of the AMBITIOUS PLEDGES is lower than the EU PLEDGE, but on the other hand the terms of trade gains reduce and the compliance costs (at fixed reductions) will increase as other countries also impose a climate policy.

Only with more stringent air targets, we can see significant impacts. The welfare losses of the climate policies (0.4-0.5%) are much increased when imposing an air target (another 0.2% point loss at the most in the CBA variant). In those scenarios the air targets are binding, and even replace the carbon-induced distortions. The ETS price will drop from 17 to 11 and 0 €/ t CO_2 eq by moving from no air targets to EP and CBA. ETS as a means of climate policy may become obsolete. This doesn't mean that innovation in sustainable energy comes to a halt - as the renewable subsidy will remain at least 20% of the end-user price, but the distortion becomes different in nature (switching from CO_2 to $PM_{2.5}$ and NO_x).[21] The NETS

[20] Boeters e al. (2010) also estimate the climate costs of the renewable target to be in the range of 0-30% of the total welfare loss. This paper produces a slightly higher cost estimate than their benchmark case because of lower shares of renewable energy in the BAU (10 versus 15%).

[21] See also a detailed example of coal-fired powerplants in New Member States (excluding Poland) in Annex 1.

sectors price response is relatively large to air pollution policies. The main reason is that the transport sector as part of NETS will be confronted with more binding targets than ETS sectors when also confronted with air policies.

Summarizing, air targets will lower carbon prices substantially, and especially when air targets are more binding than EP, then ETS markets may become obsolete. Welfare losses from air policies are lower than those of climate change policies, especially if they are in addition to climate policies.

4.3 Discussion

Here we bring together the results of the main policy variants. Table 3 presents the impacts of the various scenarios on welfare, emissions of PMS in the EU (resembling the aggregate representative air pollutant in this region) and of the global CO_2eq, and the ETS permit price.

<<<Table 3 around here >>>

From the climate policy perspective the EU PLEDGE is the benchmark. The next steps for the year 2020 in EU policy could involve extra climate policies or air policies, or a combination of both. In the case of climate change policies there are two possibilities. Either there will be a 25% cut in GHG emissions in the same institutional setting as the EU PLEDGE scenario. Or, secondly there will be a 30% cut in GHG emissions as in the AMBITIOUS PLEDGES scenario. This scenario also assumes the most stringent targets as pledged by the other Annex 1 countries with full free permit trading amongst these countries. It can be seen from Table 3 that the impact on global GHG emissions in 2020 in any scenario is limited, and hence additional climate initiatives does not generate substantial climate change improvements. The co-benefits are changes in stylized indicator labelled PMS, with extra 2% cut if the EU moves from a 20 to 25% cut in GHG emissions. If however, the EU switches to free permit trading once the carbon coalition expands, then the trade off occurs with extra global GHG emission reduction of 2.3%, while PMS emissions increase with 2%point because where-flexibility enables to reduce less on carbon. The magnitude of the impacts on emissions may be uncertain, but the trade-off is robust if where-flexibility holds. The ETS carbon price drops in the AMBITIOUS PLEDGES scenario to 10 €/ tCO_2, while welfare is unaffected, because lower mitigation costs are offset with lower terms-of-trade gains.

Next, we can see that the EP scenario will reduce the ETS price with 40% and the emissions of PMS with 10% at lower costs (only 0.05% of NI). Back of the envelope calculus shows that the benefits of avoided air pollution damages is equal ... % of NI. The EP air pollution policy seems to be superior over additional climate policies. The EP policy directly aims to bring significant improvements in air quality in Europe directly affecting people’s health, whereas EU25% is almost as expensive but brings little gains. This stylized fact also is confirmed by cost-benefit analysis on climate change and air pollution in Bollen et al. (2009a), and Bollen et al. (2010).

The EU PLEDGE + CBA scenario is a further reduction of PMs emissions and an ambitious step in environmental policy. At the same time, it can be argued that this step needs to be done as to come in line with EU’s already 10 years old ambition of a fully clean air for all European citizens. The EU PLEDGE + CBA scenario entails a further reduction of the global GHG emissions (0.1% CO_2 eq.) with non- binding GHG targets on ETS markets (more coal reductions) and non-ETS sectors (more oil reductions in transport) and a binding renewable energy target. Nevertheless, the renewable subsidy reduces with 10% as more fossil energy reductions enable to reduce also on biomass because the target is formulated as a 20% share and it produces PM emissions. However, the CBA strategy lowers the ETS market price considerably. Companies under ETS have to comply also with binding targets on SO_2, NO_x and $PM_{2.5}$, and hence new coal fired power stations become too expensive compared to the non-fossil alternatives.

The negotiations within the EU and UN-ECE on air pollution will start this year and finalized by 2014, and some options for policy can be investigated with the model designed for this paper. With some modifications the model can also be used to optimally allocate emission ceilings across EU countries that maximize the health benefits of avoided premature mortality associated with the chronic exposure to outdoor PM. Although we cannot fully address all the detailed impacts of bottom-models like GAINS, we nevertheless can shed some light on the structural adjustments in energy markets and the EU-economy from climate and air policy variants.

Recall from Table 3 that the ceilings based on CBA reduce 53% of number of Years Of Life Lost (YOLL) in EU27 in the year 2000. The reduction of the number of YOLL in the CBA scenario (compared to the EU PLEDGE scenario) is equal to .. mn YOLL in a period of 10 years. This improvement times the very conservative estimate median value of YOLL (52000 € per YOLL) is equal 0.?% of NI, which is a factor x higher than the compliance costs of 0.25% NI. The CBA in addition to the EU PLEDGE pays back, and further reductions seem feasible. This is also confirmed by Bollen et al. (2009a). Additional climate policy will be less effective than air policies, because the air pollution improvements are much smaller almost nothing, and the climate impact (i.e. on global CO_2 eq. emissions) is insignificantly different from the air policy.

In this paper, we focussed on Europe, but employed the WorldScan model, which has global coverage. The database developed for this paper also calibrates air pollution emission coefficients and EOP abatement options for China and the US, and can also be used to investigate air pollution policies in a these regions in a global international trade context. We would expect especially that air pollution policies in China to impact fossil energy markets and prices, and hence may have an effect on other countries' economies and environmental policies. This topic will certainly have to be addressed in future research.

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Annex 1: Calibrating WEO 2009 as a Business-As-Usual Scenario

The effects of climate policy depend strongly on the underlying baseline. Our policy scenarios are based on the baseline of the 2009 World Energy Outlook (WEO, IEA, 2009). With our baseline we deviate from the WEO-baseline in one respect however. We removed the ETS-caps from the WEO in order to establish a level playing field for our assessments of the mitigation pledges in an international context.

The baseline calibration employs trends for population and GDP by region, energy use by region and energy carrier, and world fossil fuel prices by energy carrier. Population is exogenous, but the other time series are reproduced by adjusting the model parameters. GDP is targeted by total factor productivity (differentiated by sector), energy quantities are targeted by energy efficiency, and fuel prices are targeted by the amount of natural resources available as input to fossil fuel production. In policy variants, total factor productivity, energy efficiency, and natural sources are fixed exogenously, and GDP, energy use, and energy prices are endogenous variables.

According to our baseline, global population will continue to expand. Combined with worldwide economic growth of 2.7% per year global demand for energy will be almost 30% higher in 2020 than in 2004. As described in WEO2009, the effects of the financial and economic crisis are included and have a large impact on medium term economic growth rates. This expansion predominantly takes place in Non-Annex I, thus partially reducing the gap in energy consumption per capita with the industrialized countries. Table 2.1 gives some key overview characteristics of the baseline for the 2004-2020 period. The table indicates that in the baseline energy- and GHG-intensities are declining worldwide and especially in Non-Annex I. In principle our baseline follows the fossil fuel price projections of WEO2009 , e.g. the oil price will reach 100 US$ per barrel in 2020. In Europe, the gas price is expected to lag behind the oil price. Regional coal prices are expected to remain constant at their 2009 level.

Basically, the main difference between the WEO-baseline and our baseline is increased energy consumption in the EU (due to the lifting of ETS-caps) and reduced energy consumption elsewhere (due to somewhat higher fossil fuel prices). Table A.1 in the Annex provides the differences in characteristics of both baselines.

<<Table A.1 around here >>>

PM

1. In Europe no extra renewable energy policies, but already moving 15% by 2020.
2. Air pollution policies in EU, USA, and China
3. We calibrate also the emission-coefficients to derive scenarios for emissions of SO_2, NO_x, $PM_{2.5}$, CH_4, N_2O, and NH_3. Likewise, we also implement cost curves for these pollutants for each sector/region. See Annex 1 for more details
4. Outside Europe

PM

Annex 1: How does EOP work in WorldScan; an example

Environmental policies are implemented in the model by introducing a price on emissions (Lejour et al., 2006). This emission price makes polluting activities more expensive and will provide an incentive to reduce these emissions. For emissions directly related to the use of a specific input, such as fossil fuels, the emission price will in fact cause a rise in the user price of this input. Consequently, this will lead to a fall in the demand for it and hence a reduction in emissions. For emissions related to sectoral output levels, the emission price will cause a rise in the output price of the associated product. Consequently, this will lead to a fall in demand for it and hence in a reduction in emissions. Moreover, if emission control options are available, these will be implemented up to the level where the marginal cost of emission control equals the emission price. The emission price can be introduced exogenously, but it is also possible to set a restriction on emissions in the model. In this case the emission price is endogenously determined in the model at the level needed to reduce emissions to the predetermined emission target.

For illustrative purposes, we will elaborate the effect of a restriction on emissions of greenhouse gases and on SO_2 emissions for a specific sector, viz. coal-fired power plants in the New Member States (excluding Poland). Table A.2 presents some relevant results for this sector. In the baseline, 2020 emissions of greenhouse gases are 109 Mton. The EU PLEDGE scenario leads permit trade in ETS markets leading to a price on GHG emissions of €17/ton CO_2-eq, but likewise the renewable target leads to a renewable price equal to 24% of the user price (not shown in Table A1, but important to keep in mind) . This emission price is translated into a mark-up on the market price of fossil fuels of 71%, i.e. the user price of coal for coal-fired power plants in Italy doubles. Also the price of oil and gas rises, so electricity becomes more expensive and hence the demand for electricity in the New Member States (excluding Poland) declines by 7%. Because CO_2 emissions per energy unit are larger for coal than for oil and gas, the demand for coal will fall more than proportional: 63% (16 Mtoe). As a result of the decline in the use of coal, the associated GHG and emissions will decline by 65%. As a co-benefit of climate policy, SO_2 emissions will also be reduced.

Reductions in emissions of GHGs from coal-fired power plants in the new Member States (excluding Poland) can also to some extent be achieved by end-of-pipe abatement. The abatement cost curve in Figure A.1 shows that at a marginal cost of €31/ton CO_2-eq. the N_2O emissions from coal-fired power plants can be reduced by 74%. N_2O emissions in the climate policy case amount to 2.4 Mton CO_2-eq., so a reduction of 1.8 Mton can be achieved by implementing end-of-pipe control. So, the overall reduction of GHG emissions from coal-fired power plants is 75%, which consists of a 74% reduction as a result of reduced use of coal and an additional 1% reduction as a result of end-of-pipe abatement of SO_2 emissions.

<<<Table A1 around here>>>

Policies for air quality improvements are implemented by introducing, in addition to the GHG emission reduction target, a restriction on emissions of SO_2 in the new Member States (excluding Poland). This will result in an emission price for SO_2 of €13/kg SO_2. Coal being an important source of SO_2 emissions, the price on SO_2 emissions causes the price of coal to increase with 44%. As a result, the demand for coal will fall by another 11% (74-63%) and consequently also the associated emissions of SO_2. As a co-benefit of this air policy also emissions of GHGs will fall by the same percentage.

The SO_2 emission price also induces investment in SO_2 emission control. The abatement potential is limited (about 30% of total SO_2 emissions from coal-fired power plants) because to a large extent emission control already is implemented in the baseline. The abatement cost curve in the right panel of Figure A.1 indicates that at a marginal cost of €86/kg 19% of the SO_2 emissions (i.e. the emissions that remain after the fall in coal use) can be reduced by emission control.

The fall in GHG emissions makes it much easier to meet the GHG emission reduction target. An emission price of €11/ton CO_2-eq. now is sufficient to meet the ETS reduction target (NB since the ETS target concerns not only power plants in the new Member States (excluding Poland), but emissions from all ETS sectors in the EU, this price fall is not uniquely caused by the co-benefit of SO_2 reduction in the coal-fired power plants in the new Member States (excluding Poland); similar co-benefits occur in other sectors and other countries). Since this price is below the initial marginal cost for end-of-pipe abatement of N_2O (see left panel of Figure 3.1), so no end-of-pipe abatement of GHG emissions will take place. Note that with climate and air policies together, the coal-fired power plants will contribute more to the total ETS reduction target (i.e. they will have to purchase less emission permits) than in the case with climate policy only (28 vs. 38 CO_2-eq.).

Annex 3: Mapping from GAINS to GTAP-VII

<<<here Table A.3>>>

Table 1 Overview of regions, sectors and technologies and production inputs in WorldScan

Regions[a)]	*Sectors*[b)]	*Inputs*[b)]
Germany	Cereals (Wheat and Cereal Grains NEC)	*Factors*
France	Oilseeds	Low-skilled labour
United Kingdom	Sugar Crops (Sugar Cane, Sugar Beet)	High-skilled labour
Italy	Other Agriculture	Capital
Spain	Minerals NEC	Land
Netherlands	Oil	Natural resources
Other EU15	Coal	
Poland	Petroleum Coal Products	*Primary energy carriers*
Rest of EU-27	Natural Gas (incl. gas distribution)	Coal
Norway	**Electricity**	Petroleum, coal products
Switzerland	**Energy Intensive (incl. Chemical Products)**	Natural gas
Russia	Vegetable Oils and Fats	Modern biomass
Ukraine	Consumer Food Products	
USA	Other Consumer Goods	*Other intermediates*
Canada	Capital Goods and Durables	Cereals (Wheat & Cereal Grains)
Japan	Road and Rail Transport	Oilseeds
Australia	Other Transport (water and air)	Sugar Crops (Sugar Cane&Beet)
New Zealand	Other Services	Other Agriculture
Brazil		Minerals NEC
Middle East and North Africa	*Electricity Technologies*	Oil
China (incl. Hong Kong)	Conventional fossil (without CCS)	Coal
India	Fossil with CCS	Petroleum Coal Products
Rest of the World	Nuclear	Natural Gas (incl. Distribution)
	Wind	**Electricity**
	Biomass	**Energy Intensive (incl. Chemical Products)**
Substances	Hydropower	Vegetable Oils and Fats
CO_2		Consumer Food Products
CH_4	*Conventional biofuel technologies*	Other Consumer Goods
N_2O	Ethanol	Capital Goods and Durables
	from sugar beet	Road and Rail Transport
SO_2	from sugar cane	Other Transport (water and air)
NO_x	from wheat	Other Services
NH_3	from corn	Biodiesel
$PM_{2.5}$	Biodiesel	Ethanol

a) Non-Annex I regions are denoted in italics
b) ETS-sectors and inputs denoted in bold

Figure 1 Production structure with CO_2, CH_4 and N_2O emissions

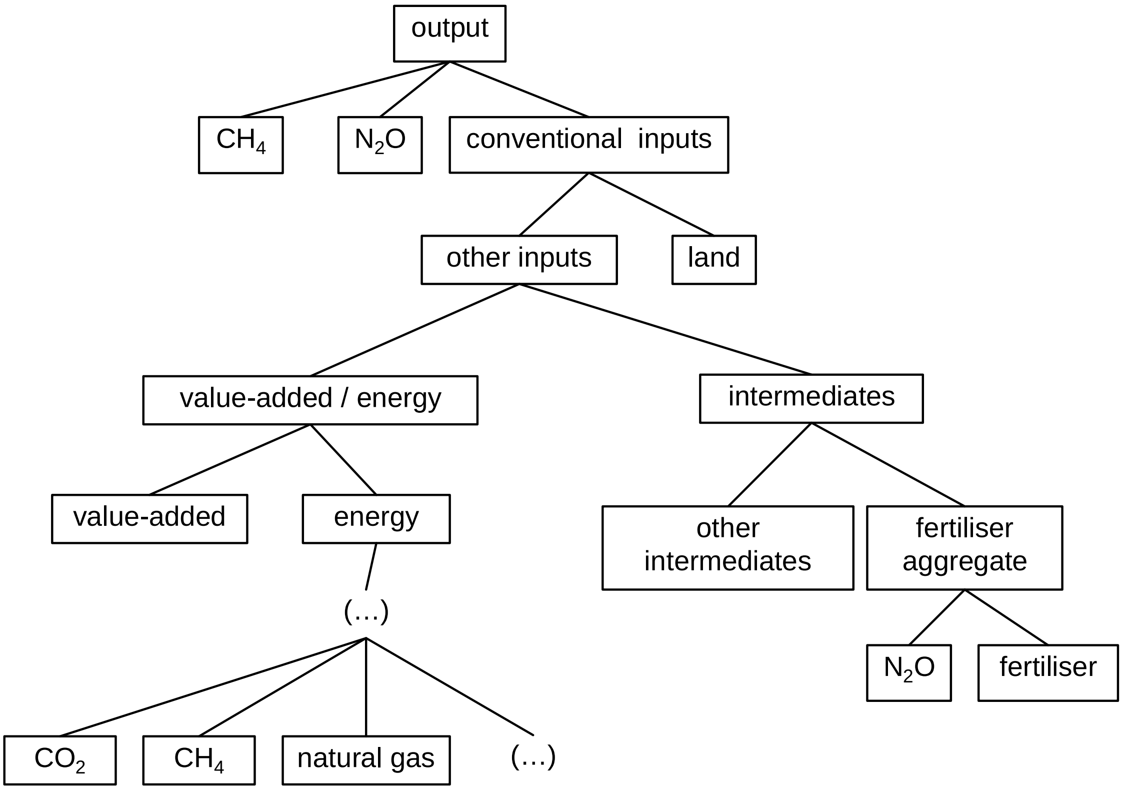
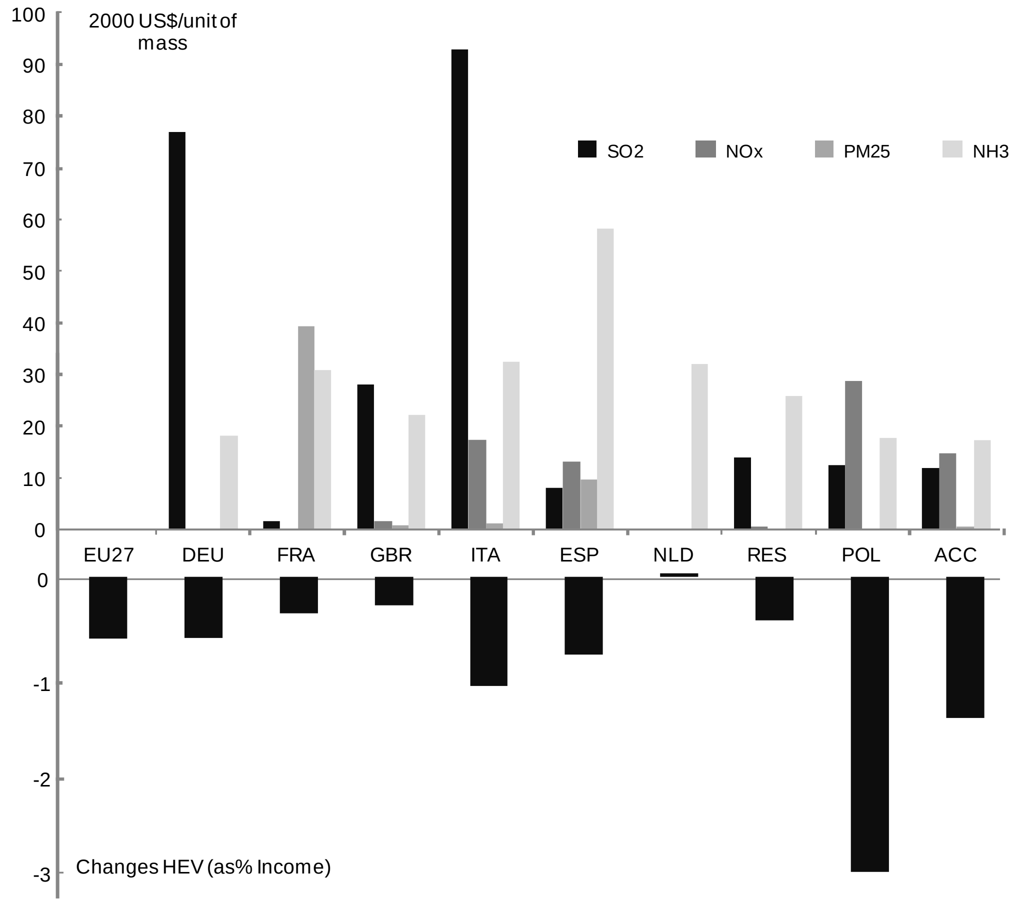


Table 2 Ambition levels for TSAP strategies (% reductions compared to the year 2000)

	EC	EP	CBA
Life Years Lost from particulate matter	47	50	53
Acute mortality from ozone	10	16	24
Acidification - ecosystem forest area exceeded	74	79	79
Eutrophication - ecosystem area exceeded	43	46	53
PMS*	55	58	62

Source: Own calculations based on EC (….); PMS is weighted sum of air pollutants with weights equal to 0.54, 0.88, 2.0, and 0.64 for SO_x, NO_x, $PM_{2.5}$, and NH_3 respectively.

Figure 2 Impacts of CBA Ceilings on Emissions price and National Income



Note: SO2 price in / kg SO2

Figure 3 Impacts of CBA Ceilings on Air Pollutant and GHG Emissions

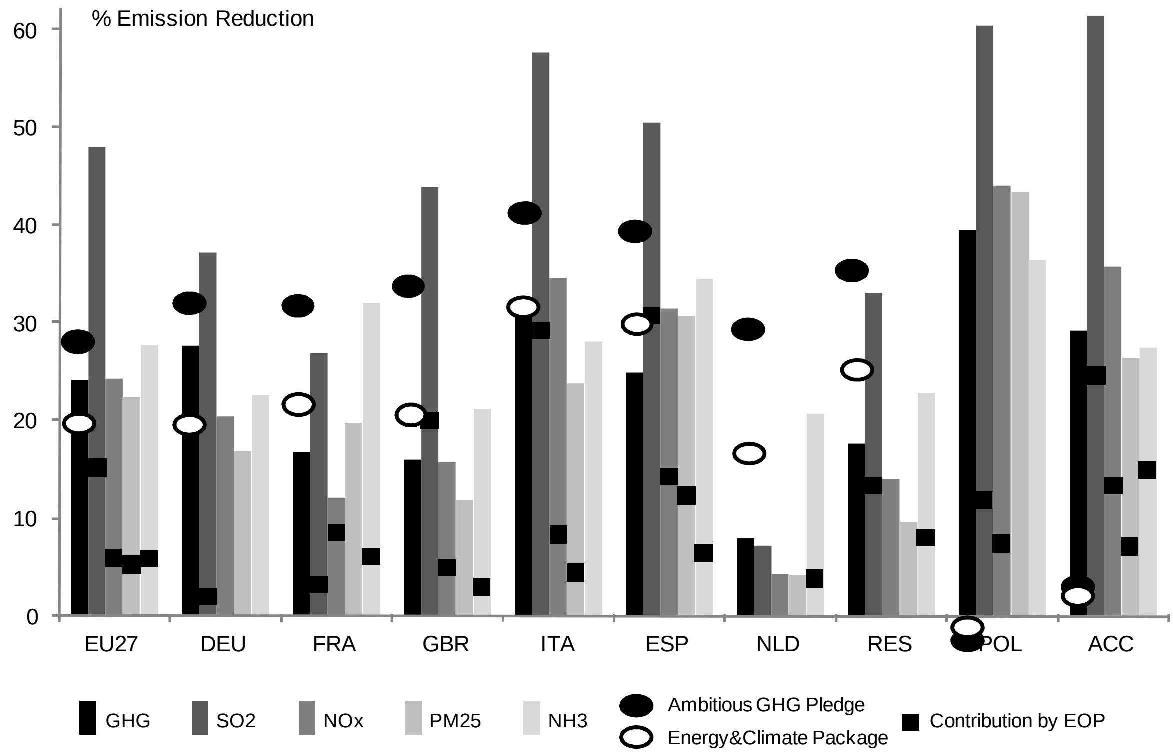


Figure 4 Impacts of different Policy Scenarios on Air and GHG Emissions in EU-27

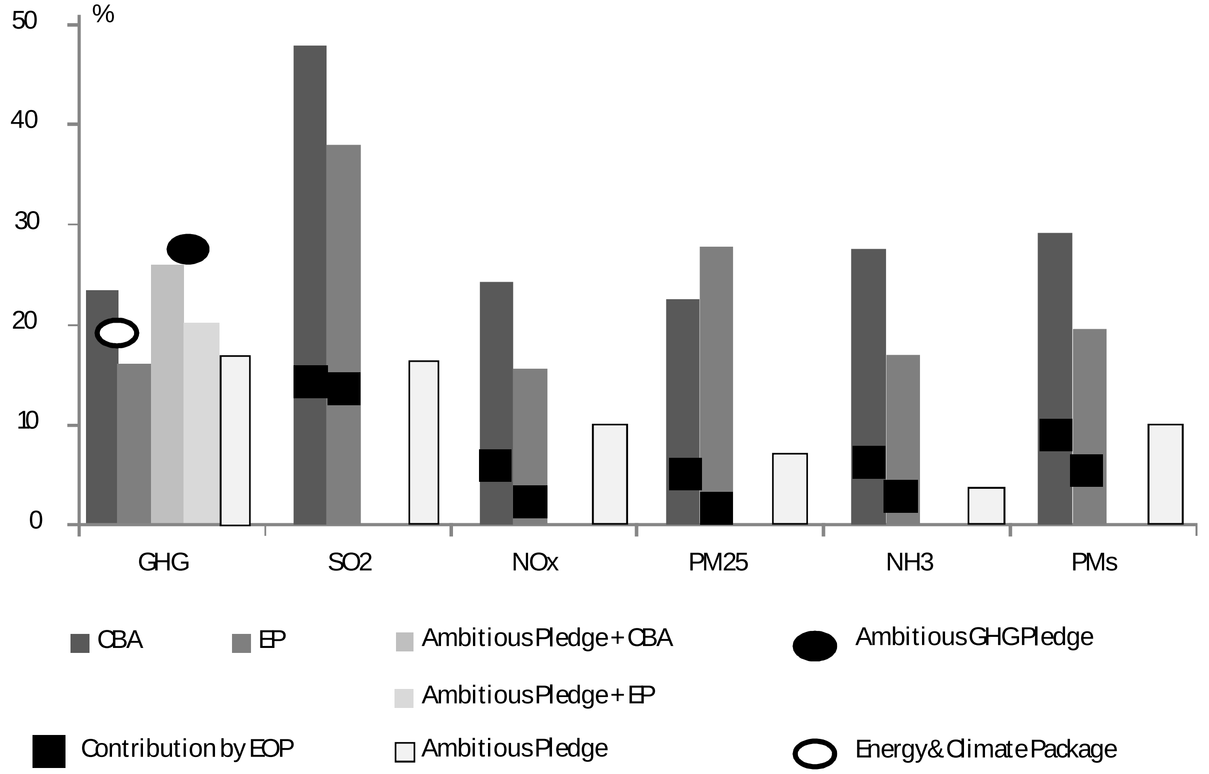


Figure 5 Impacts of different Policy Scenarios on Primary Energy Demand in EU-27

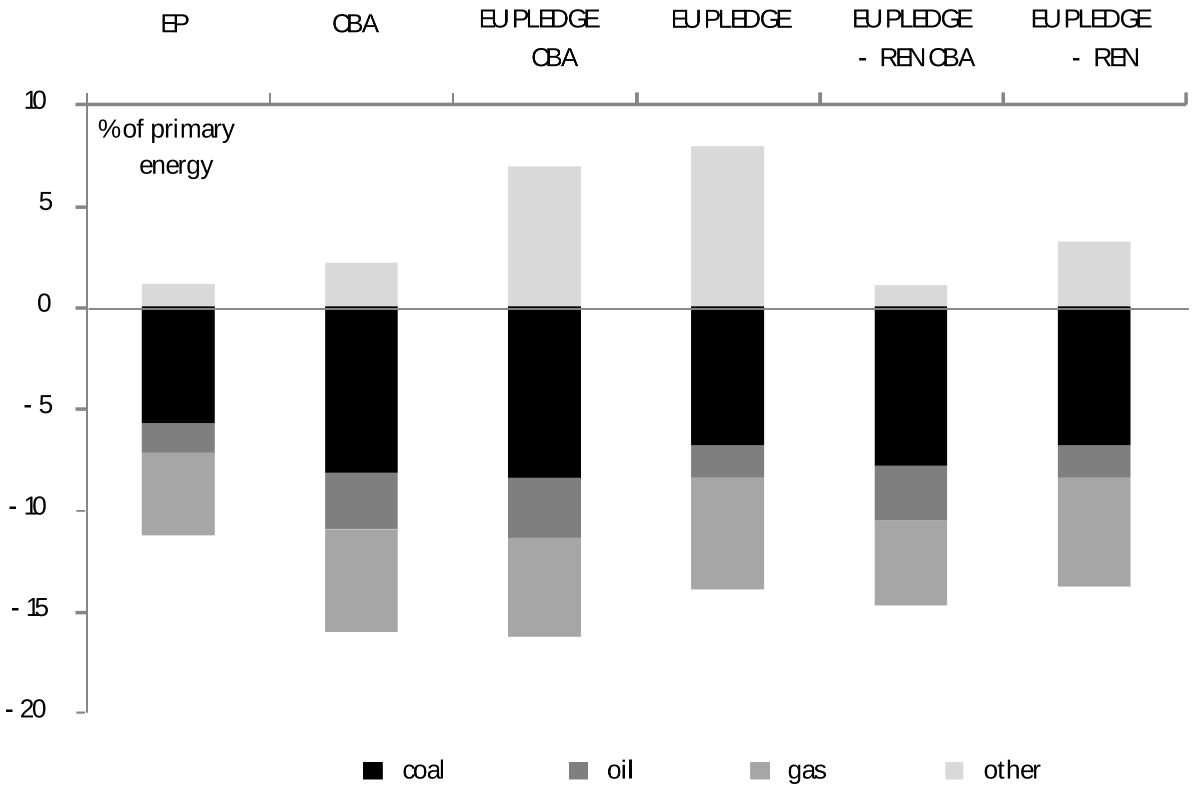
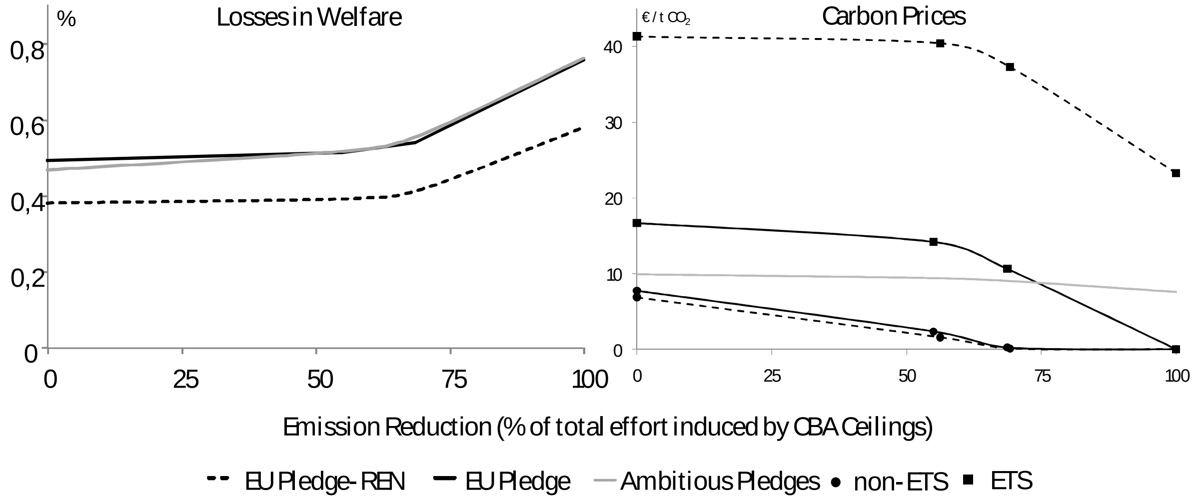


Figure 6 Impacts of Climate & Air Policies on Welfare and Carbon prices in EU-27



Note: 0= no air policies, ≈60%=EC, ≈70% = EP, 100%=CBA

Table 3 Summarizing Climate and Air Policies

	PMS (%)	CO_2 eq. (%)	Welfare (%)	ETS Price (€ / tCO_2 eq.)
Climate Policy				
EU Pledge	-11	-0,9	-0,5	17
additional changes compared to EU Pledge				
+ EU 25%	-3	-0,3	-0,08	8
+ Ambitious Pledge	2	-2,3	0,02	-7
+ EC	-5	0,0	-0,02	-3
+ EP	-10	0,0	-0,05	-6
+ CBA	-20	-0,1	-0,27	-17
Air Policy				
CBA	-29	-0,7	-0,6	-

Table A.1 Overview characteristics of the BAU, average annual growth (%), 2004-2020

	Population	GDP volume	Energy consumption [a)]	GHG emissions	Energy intensity	GHG intensity [b)]
Annex I	0.3	1.8	0.0	0.1	-1.8	-0.0
EU-27	0.3	1.5	0.6	0.5	-1.0	-0.1
Non-Annex I	1.3	5.4	3.2	3.0	-2.2	-2.9
China (incl. Hong Kong)	0.7	8.2	4.4	3.3	-3.7	-1.1
India	1.3	7.1	4.6	3.2	-2.5	-1.4
World	1.1	2.7	1.6	-1.6	-1.1	-1.7

	SO_2 emissions	NO_X emissions	PM_{25} emissions	NH_3 emissions
Annex I	PM			
EU-27				
Non-Annex I				
China (incl. Hong Kong)				
India				
World				

a) Total of coal, refinery products, natural gas, biofuels, commercial biomass and renewable energy

b) GHG-intensity represents the ratio of GHG-emissions and energy consumption

Source: WorldScan

Figure A2 Sectoral Contributions to Total Emissions in EU-27

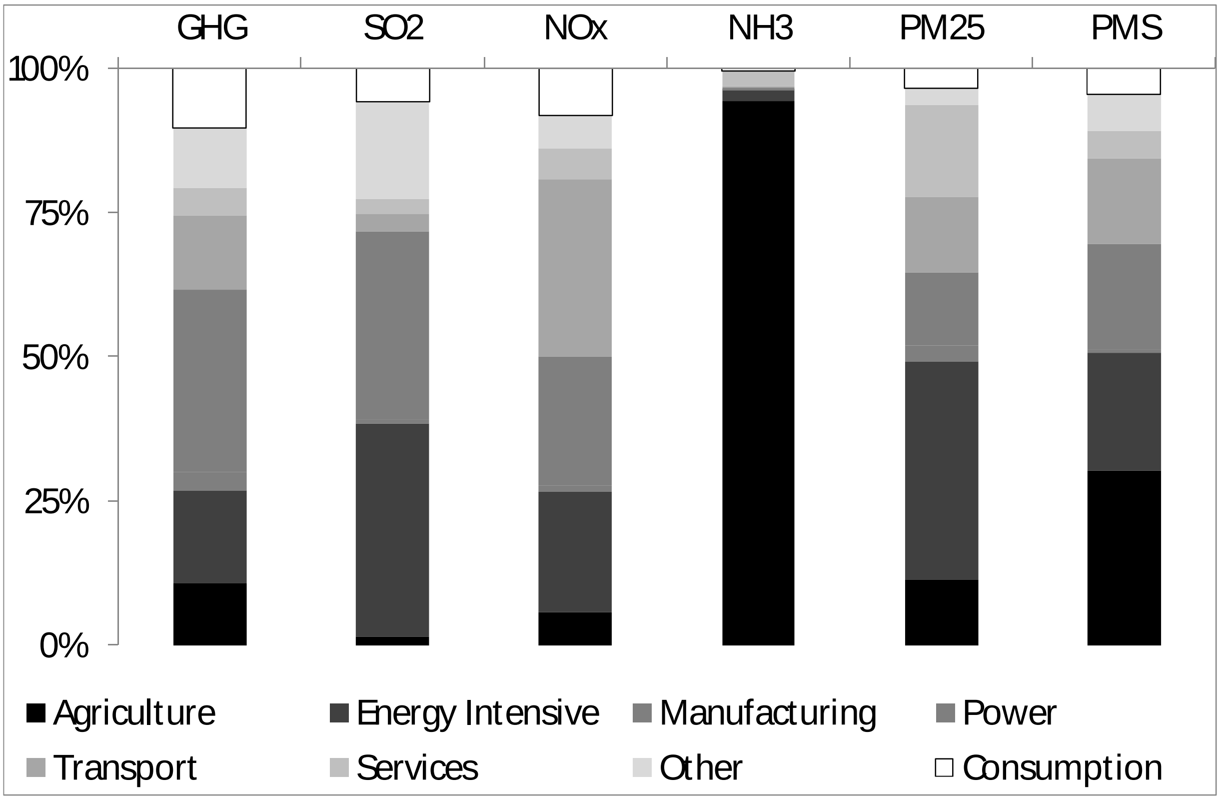


Table A.2 Effects of a restriction on emissions of CO_2 eq. and SO_2 for coal-fired power plants in New Member States (excluding Poland)

		BAU	EU PLEDGE	EU PLEDGE+EP
Coal use	(Mtoe)	26	10 (-43%)	7 (-52%)
Emission price	GHG (€/ton CO_2-eq.)		17	11
	SO_2 (€/kg SO2)		0	13
Mark-up price coal	related to price GHG		71%	47%
	related to price SO_2		-	44%
Emissions	GHG (Mton)	109	38	28
	SO_2 (kton)	173	63	45
Change emissions	GHG		-71 (-65%)	-82 (-75%)
of which	*- end-of-pipe*		-2	-1
	- structure effects		-69	-81
Change emissions	SO_2		-109 (-63%)	-128 (-74%)
Of which	*- end-of-pipe*		0	-1
	- structure effects		-109	-127

Figure A.1 Abatement cost curve CO_2 and SO_2 for coal-fired power plants in Italy

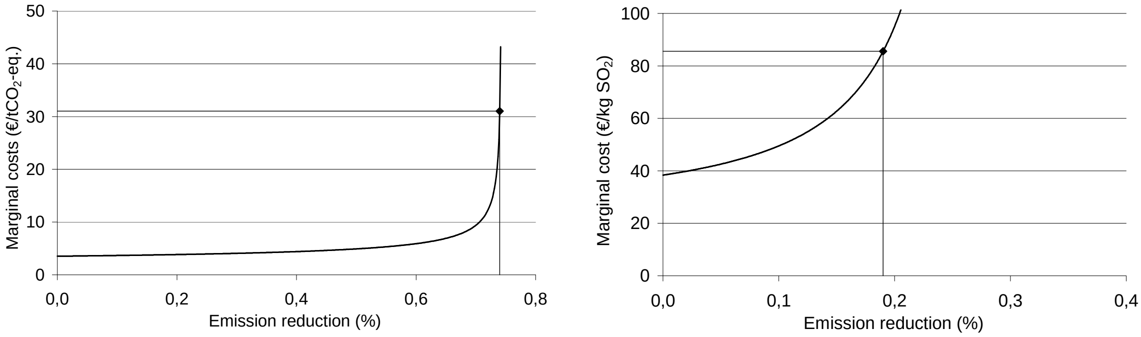


Table A.3 Mapping of GAINS sectors to WorldScan sectors

Worldscan sectors	GAINS sectors
Cereals, Oilseeds, Sugar crops, Other agriculture	Agriculture: Ploughing, tilling, harvesting
	Crops left on field
	Other transport: agriculture and forestry
	Domestic sector - other services, agriculture, forestry, fishing, and non-specified sub-sectors
Cereals	Storage and handling: Agricultural products (crops)
Other agriculture	Rice cultivation
	Agriculture: grassland and soils / organic soils / Livestock / Other
	Manure treatment and manure distributed on soils
	Forestry
	Waste: Agricultural waste burning
	Use of mineral N-fertilizer
Minerals NEC	Mining: Bauxite, copper, iron ore, zinc ore, manganese ore, other
	Storage and handling: Iron ore
Coal, Oil, Natural gas, Petroleum, coal products	Fuel combustion in furnaces used in the energy transformation sector
Oil, Natural gas	Waste: Flaring in gas and oil industry
Natural gas, Petroleum, coal products	Own use of energy sector and losses during production, transmission of final product
Oil	Extraction of crude oil
Natural gas (incl. distribution)	Extraction, proc. and distribution of gaseous fuels
	Transportation of gas
Coal	Mining: Brown coal, Hard coal
	Storage and handling: Coal
Petroleum, coal products	Crude oil & other products - input to Petroleum refineries
	Ind. Process: Briquettes production
	Conversion: Combustion in boilers
Electricity	Power and district heating plants
	Industrial power and CHP plants
Energy intensive sectors (incl chemical products), Consumer fo	Other Industry
	Ind. Process: Carbon black production / Open hearth furnace / Agglomeration plant - pellets / Sn
Energy intensive sectors (incl chemical products)	Iron and Steel Industry
	Chemical Industry
	Non-Ferrous Metals
	Building Materials Industry
	Paper and Pulp Industry
	N - fertilizer production
	Storage and handling: N,P,K fertilizers
	Wastewater from organic chemical (non-food) manufacturing industry
	Nonenergy use of fuels
	Storage and handling: Other industrial products (cement, bauxite, coke)
	Ind. Process: Production of Cement / Lime / Glass / Bricks / Basic oxygen furnace / Cast iron / Coke c
Vegetable oils and fats, Consumer food products	Food (incl. beverages and tobacco) manufacturing industry
Vegetable oils and fats	Fat, edible and non-edible oil extraction
Consumer food products	Meat produced
Other consumer goods	Textile industry
	Wood and wood products industry
Road and rail transport	Road transport - Heavy duty vehicles / Light duty vehicles / Motorcycles / Motorcycles, mopeds and ca
	Other transport: rail / offroad / other off-road
Other Transport (water and air)	Other transport: domestic air traffic - civil aviation / inland waterways / maritime activities
Other services	Domestic sector - commercial and public services
	Waste treatment and disposal
	Waste water treatment (domestic)
	Municipal solid waste
	Waste: Open burning of residential waste
	Gasoline distribution
	Construction activities
	Other transport: mobile sources in construction and industry
Consumption categories	
Gross rent and fuel, Other goods and services consumed	Domestic sector - residential
Transport and communication	Road transport - Light duty vehicles: cars and small buses with 4-stroke engines