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Economic impacts of EU clean air policies assessed in a CGE framework

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A B S T R A C T

This paper assesses the macroeconomic and sectoral impacts of the “Clean Air Policy Package” proposed by the European Commission in December 2013. The analysis incorporates both the expenditures necessary to implement the policy by 2030 and the resulting positive feedback effects on human health and crop production. A decomposition analysis identifies the important drivers of the macroeconomic impacts. We show that while expenditure on pollution abatement is a cost for the abating sectors, it also generates an increased demand for the sectors that produce the goods required for pollution abatement. Moreover, we find that positive feedback effects, particularly those related to health can offset the resource costs associated to the clean air policy and result in positive macroeconomic impacts for the economy of the European Union.

1. Introduction

While over the last couple of decades the European Union (EU) air quality policy has shown important progress in curbing emissions of harmful air pollutants[1], many EU Member States are still falling short of agreed EU air quality standards and World Health Organization (WHO) guidelines. This is associated with high costs for the health of its citizens, the environment and the economy: in 2010, annual premature mortalities amounted to over 400,000 and 62% of the EU ecosystem area was exposed to eutrophication. Total external costs of the health impacts are in the range €330-940bn, depending on the valuation choice applied to the impacts. These external costs are for the most part related to the perceived value of human life, but in part they also include direct costs borne by different economic actors. Such direct economic damages include €15bn from lost workdays, €4bn healthcare costs, €3bn crop yield loss and €1bn damage to buildings (European Commission, 2013a).

The WHO confirms this in several studies. In WHO, 2014 it is found that around 7 million people worldwide died prematurely in 2012 as a result of air pollution exposure, concluding [2] that “this finding more than doubles previous estimates and confirms that air pollution is now the world’s largest single environmental health risk”, and that “reducing air pollution could save millions of lives”. In WHO, 2015 it is found that 600,000 premature deaths in the wider WHO European Region in 2010 where due to air pollution, while the external cost only for the EU in 2010 is calculated around 1400 $bn if a common Value of Statistical Life (VSL) is assumed for all Member States.

With the dual objective to achieve as soon as possible compliance with existing air quality legislation, and to make substantial further progress in the mid-term, the European Commission proposed in 2013 the “Clean Air Policy Package”[3] with a focus on 2020 for the first objective and on 2030 for the second (European Commission, 2013b).

This paper presents the analysis done with a Computable General Equilibrium (CGE) model, GEM-E3, as a contribution to the European Commission’s Impact Assessment of the proposed air

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[†] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission or any other organization.

[1] The first EU air quality directives and emission controls were established in 1980 for SO_2 and suspended particles, in Directive 80/779/EC.

[2] http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

[3] The 2013 proposal reviews of the Thematic Strategy on Air Pollution from 2005 (European Commission, 2005a,b) which established objectives for the protection of health and the environment from the adverse impacts of air pollution.

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pollution reduction policy (European Commission, 2013a), in particular related to the aforementioned 2030 mid-term objective. Macroeconomic and competitiveness impacts of different pollution abatement policy options are assessed by exogenously introducing in the GEM-E3 model the required abatement costs for different sectors, which in turn are obtained from detailed bottom-up models. Further, the analysis also incorporates beneficial feedback effects associated with the air quality improvements. The outcome of the analyses includes macroeconomic variables such as Gross Domestic Product (GDP), sectoral activity, exports and imports, employment and private consumption.

CGE modelling is central in understanding the broader distributional and economic impacts beyond the direct emission abatement costs provided by the bottom-up models. In general terms, expenditure on pollution abatement is a cost for the sectors that need to reduce pollution, resulting in higher production costs that may lead to reduced output and a loss of international competitiveness. Increased demand for abatement technologies is, on the other hand, beneficial for the sectors that produce these technologies. In this context, this paper evaluates the overall balance of these counteracting drivers and identifies the significance of any potential negative impacts.

The main aim of this exercise is thus to assess the broader, both direct and indirect economic impacts of the European air quality policies. We go forward with incorporating in our analysis both policy compliance costs and beneficial feedback effects.

The benefits brought about by cleaner air span a number of end-points covering the environment (through the reduction of acidification, of excess nutrient load – eutrophication – and of foliage damage by ground-level ozone), as well as human health (by reducing both mortality and morbidity) and also the built environment (less corrosion of infrastructure, and erosion and soiling of cultural heritage). While the largest part of these impacts either are very difficult to quantify in economic terms or can be monetized only on the basis of external costs determined by stated or revealed preferences studies, a lesser but significant share of those benefits can be related to reduced direct costs incurred by specific actors in the economy. Related to health, in our analysis we included the reduced healthcare costs of treating air pollution-associated sickness and the increased availability of labour time ensuing from less workdays lost (sick days for people in employment).

With respect to associated costs, our approach focuses on the direct and indirect effects of the abatement-related expenditures on final demand, employment and the competitiveness of the abating sectors. With respect to the beneficial feedback effects of improved air quality, we demonstrate that the improved labour productivity from avoided workdays lost due to morbidity has positive macroeconomic impacts on the European economy, potentially even exceeding the costs of the policy. Moreover, we find that the crop yield benefits due to reduced air pollution moderate the negative impacts of the abatement efforts required by the agricultural sector. In order to identify the relative weight of costs and economic benefits from each feedback effect in the total macroeconomic assessment, we undertake a decomposition analysis isolating the above-mentioned factors one by one, as will be described in the following sections.

2. Models

Detailed integrated policy assessments use different types of models depending on their field of application. Top-down and bottom-up models may be linked for an optimal use of available information. The Impact Assessments of European Commission policy proposals are often supported quantitatively by ‘modelling toolboxes’, consisting of various, highly specialized models. In the context of the Clean Air Policy Package, the model Greenhouse Gas and Air Pollution Interactions and synergies (GAINS) is the central element. This bottom-up air pollution model calculates the abatement costs of 5 key air pollutants (PM2.5, SO_2, NO_x, VOCs, NH_3[4]) for various scenarios. These costs are fed with a one-way linkage (see Section 3) into the top-down GEM-E3 model, and combined with the associated feedback benefits in order to conduct a more complete assessment of the socioeconomic impacts. Below we present a short description of the two abovementioned bottom-up and top-down models which have both been used widely for policy assessments and other research applications.

2.1. The GAINS model

The GAINS model is a bottom-up integrated assessment model of air pollution. It covers the whole cause-effect chain of air pollution and allows stakeholders to identify cost-effective portfolios of control measures that achieve a set of given environmental objectives (Amann et al., 2011). The GAINS model and its predecessor RAINS has been used previously in a variety of policy applications, in particular in motivating and specifying the emission ceilings of the Gothenburg Protocol of the Convention on Long-Range Transboundary Air Pollution in 1999 and its revision in 2011.

GAINS estimates and projects emissions of all major air pollutants, such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), fine particulate matter (PM2.5), ammonia (NH_3) and volatile organic compounds (VOCs), as well as of the Kyoto greenhouse gases. The application of control technologies can reduce the emissions of pollutants, and the GAINS model database contains efficiency and cost characteristics of several thousands of such control technologies, as well as information on their use under current policies.

For the purposes of the Clean Air Policy Package, GAINS provided emission projections for each member state and each pollutant (Amann et al., 2012a, 2012b, 2012c, Borken-Kleefeld and Ntziachristos, 2012) that reflect not only national and EU energy and agricultural policies, but also policies for air pollution control as they are currently implemented or firmly planned. On the basis of this Reference scenario GAINS estimates the impacts of pollution on human health and ecosystems (Amann et al., 2012d, Kiesewetter et al., 2013). The model was then used to establish the scope for further reductions beyond the current legislation. GAINS provided relevant portfolios of cost-effective measures for each member state that, taken together, provide the environmental objectives at lowest cost (Amann et al., 2012e, 2013).

2.2. The GEM-E3 model

GEM-E3[5] is a multi-sector, multi-region computable recursive-dynamic general equilibrium of the world economy. The GEM-E3 version used for this exercise is calibrated on year 2004 based on the Global Trade Analysis Project (GTAP 8) database and represents the EU-28 together with 10 major world economies individually linked through endogenous bilateral trade. The GTAP data is aggregated to 21 sectors (of which 4 energy resource sectors,

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[4] This analysis does not include measures to reduce methane emissions. Although the Commission proposal includes methane ceilings, those are established on the basis of reductions that would be achievable by taking only measures with positive return on investment (e.g. biogas plants where they are economically viable). As a consequence, the proposed measures to reduce methane may be expected to positively contribute to the overall macroeconomic impact of the Clean Air Package.

[5] Detailed information about the model can be found on www.gem-e3.net or Capros et al. (2013).

5 energy-intensive sectors and 3 separate transport sectors), and complemented with 10 power technologies.

GEM-E3 offers consistent evaluations of the distributional effects of policies for the various economic sectors and agents across the countries. The economic agents optimise their objective functions (utility for households and profits for firms) and determine separately the supply or demand of capital, energy, labour and other goods. Market price adjustments guarantee a global equilibrium across all sectors and countries endogenously and simultaneously to the year that the policy under analysis is implemented as a policy shock to the model. The model calculates macro-economic variables as GDP (with its components like consumption, investment, exports and imports), employment and sectoral production.

Households receive income from their ownership of production factors, of which labour is the most important, from other institutions and transfers from the rest of the world. Household expenditure is allocated between consumption, tax payment and savings. The consumption categories are split in nondurable consumption categories (food, culture etc.) and services from durable goods (cars, heating systems and electric appliances) and the respective consumption of linked products (e.g. fuels). The production of the firms is modelled with a nested Constant Elasticity of Substitution (CES) neo-classical production function, using capital, labour, energy and intermediate goods with considerable sectoral detail and using a differentiated nesting for certain sectors. The model is recursive-dynamic, driven by the accumulation of capital and investment. Labour is immobile across national borders and GEM-E3 model features involuntary unemployment based on the efficiency wages approach implying the negative correlation between wages and unemployment. Technological progress is explicitly represented in the production functions. Total demand of goods is allocated between domestic goods and imported goods, using the Armington specification.

3. Methodology

CGE models have increasingly been used to estimate the macroeconomic and welfare impacts of environmental, climate and energy policies. Particularly with regards to air pollution, recent studies describe the link between human health impacts and (avoided) air pollution. Relevant studies like Matus et al. (2008), Matus et al. (2012) and Nam et al. (2010) assess the impacts of health damages from air pollution by introducing in the Social Accounting Matrix (SAM) a household production sector of “pollution health services”. In order to incorporate the effects of morbidity on the total economy the demand for this service sector endogenously increases according to the level of pollution. Additionally, the abovementioned studies include a change in labour supply in order to depict the effects of mortality due to air pollution and, depending on the approach, may also include a change in the total-time endowment (working hours and leisure) in order to depict morbidity effects on workers and leisure. It should be noted that the approach used in the studies above as well as in our current analysis do not reflect the non-market value that people put on mortality and morbidity (incorporated in the Willingness-to-Pay method, either by the “revealed preference” or the “stated preference” method) but follow the Human Capital approach which can be captured by the real economy in a CGE framework. However, as explained in Parry et al. (2014), the Human Capital approach excludes important non-traded monetized and welfare benefits, thus this CGE approach does not capture the entirety of health-related benefits of avoided air pollution. An assessment of total welfare losses, as conducted in Ciscar et al. (2014) in the context of climate damages, could also provide an insight on the total health-related benefits of the proposed policies.

The papers above use the Massachusetts’s Institute of Technology (MIT) Emissions Prediction and Policy Analysis - Health Effects (EPPA-HE[6]) model, developed for the USA, China and Europe respectively, which calculates health status according to emission levels and associated costs in terms of service input, lost labour and leisure. Their focus is to endogenously assess, with a sophisticated detail, the health related impacts of air pollution by making these impacts endogenous and by making use of the CGE simultaneous price adjustment of all sectors and regions, thus moving ahead from a damage-function approach. They do not, however, assess the socioeconomic impacts of the abatement expenditures nor do they incorporate other positive (benefits) or negative (losses) impacts of air pollution policies and lack a sectoral analysis that could provide insights regarding the competitiveness impacts on different industries. However, the latest United States (US) Environmental Protection Agency (EPA) report on the “Benefits and Costs of the Clean Air Act from 1990 to 2020” (EPA, 2011) incorporates both the compliance costs and certain benefits of air policy regulation (in particular, only health benefits from mortality and morbidity are quantified in the general equilibrium framework) in order to provide more robust policy suggestions, while most recently, Saari et al. (2014) assess the health-related air pollution co-benefits of climate policies by following the approach of Matus et al. (2008) and by developing a soft-link between a CGE model and air quality and health impacts models.

This analysis is different and contributes to the literature in the following ways: Firstly, the abatement expenditures explicitly increase the demand for abatement technologies. Hence, the analysis assesses both the impacts in the abating industries that purchase the technologies and in the industries that produce these technologies. Secondly, the results are also presented on a sectoral level in order to depict the different impacts of the assessed policies in each sector of the economy. Lastly, the assessment includes some of the main feedback benefits from lower levels of air pollution, namely reduced workdays lost due to morbidity, reduced healthcare expenditure and increased crop yield, expanding the scope of analysis beyond what is presented in the papers above.

3.1. Abatement costs

Overall, in a CGE framework the economic assessment of air pollution abatement policies can be made by using different methodologies. A first approach is the explicit incorporation of emissions and marginal abatement cost functions in the model. An exogenous constraint on emissions generates a shadow cost (dual variable) which directly affects the decisions of economic agents as this internalised cost is incorporated in the production cost of the emitting sectors. Equally, introducing a tax changes the behaviour of the economic agents such that the emission levels reduce. With this approach, emissions can be reduced in three ways: (a) end-of-pipe abatement technologies, the cost and emission reduction potential of which is determined by detailed bottom-up marginal abatement cost functions, (b) by substitution of fuels or substitution of energy use by other production factors that can reduce energy-related emissions, and (c) by a decline in production as a result of the increased cost of production. The modelling work done with the GEM-E3 model for the 2030 Framework for Climate and Energy policies (European Commission, 2014) has followed this approach. The same methodology has been used by Mayeres and Van Regemorter (2008) for local air pollutants, where they make the health feedback of air pollution endogenous by including health in the household utility function. The higher pollution levels

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[6] Paltsev et al. (2005).

increase demand for health services and thus the available disposable income, the household time endowment and labour productivity are reduced.

However, the analysis for air quality policies presented in this paper has followed a different approach. We do not explicitly model air emissions nor implement exogenous emissions constraints or pollution taxation as a policy measure. Here, a one-way linkage with the bottom-up model, GAINS provides the sectoral and domestic abatement expenditures as an input for GEM-E3 model. Thereby, instead of approximating the abatement costs of the bottom-up measures with estimated marginal abatement curves, this approach benefits from directly using the exact expenditures as calculated by the detailed GAINS model and ensures the full use of the bottom-up information. However, with this approach it is more difficult to analyse in a CGE environment the interaction between different policy areas, such as e.g. the co-benefits expected from a simultaneous implementation of air quality and climate mitigation policies.

The one-way linkage is implemented as follows: the abatement expenditures per sector and pollutant from GAINS are incorporated in GEM-E3 as “compulsory production expenditures” of the abating sectors. This abatement cost is added to the unit cost of production of the abating sectors, hence affecting the production levels of these sectors as their price increase reduces the domestic and foreign demand for their goods. At the same time, abatement expenditures for households are introduced as compulsory “abatement” consumption, similar to the notion of subsistence consumption, which does not increase welfare but still reduces disposable income available for other categories of consumption. This can lead to an overall reduction of the consumption and utility level, since the amount of income that is now optimally allocated to the consumption categories is lower. Abatement expenditures do not account for additional investments so as not to create additional capital stock available for the whole economy or increase the GDP but are incorporated with an approach similar to intermediate demand of goods necessary for production.

At the same time the abatement expenditures of firms and households create demand for abatement technologies thus increasing the demand for goods produced by the sectors providing environmental technologies. The demand for abatement technologies is allocated to the various technology producing sectors and the associated services using pollutant-specific abatement matrices. These matrices have been designed in collaboration with experts of the European IPPC Bureau[7] and indicate which sectors will benefit from the increased demand of abatement technologies and services.

3.2. Positive feedback effects

This assessment includes three of the main direct economic benefits from lower levels of air pollution, namely reduced workdays lost, reduced healthcare expenditure and increased crop yield[8].

Reduced loss of workdays has been incorporated in the model through an increase of the total time endowment, including the time available by the households to work[9]. The increase of total time endowment is calculated by multiplying the increase of total active population, provided by the related work of Holland (2014), by the total available hours per person per year as those are assumed in GEM-E3 model.

Reduced healthcare expenditure is modelled through a reduction of the households compulsory subsistence consumption of health and medical services. This approach does not affect the welfare of the households directly since obliged subsistence consumption is not assumed to increase or decrease the level of welfare. However, this results in a higher disposable income that households can spend on other types of consumption that improve the household’s utility. The analysis also takes into consideration that healthcare expenditures in Europe are not entirely paid by households but are partly also included in the government expenditure. The avoided government spending in health is used to lower the social security contributions (i.e. lowering the costs of labour), while maintaining the government surplus/deficit constant as a share of GDP compared with that of the Reference scenario. This approach is identical to one followed with the GEM-E3 model in the PESETA II assessment of the costs of climate change (Ciscar et al., 2014). The input data of reduced healthcare expenditure is provided by Holland (2014).

In order to introduce in the GEM-E3 model the increased crop yields, the total (factor) productivity of the agricultural sector is increased such that the higher production levels correspond to the figures in Holland (2014) with the same factor inputs.

3.3. Decomposition analysis

In order to fully understand the contribution of abatement costs and of each positive feedback effect incorporated in this analysis, this paper undertakes a decomposition analysis. This analysis is conducted by introducing to the GEM-E3 model only one feature of the air quality policy in each decomposition scenario. Namely, as is shown in Table 1, the decomposition scenarios are constructed by only introducing abatement costs for the B7 scenario, by only introducing the positive feedback effect of reduced loss of workdays in the B7_Health scenario, by only introducing the positive feedback effect of reduced healthcare expenditure in the B7_Healthcare scenario, by only introducing the positive feedback effect of increased crop yields in the B7_Crops scenario and finally by introducing all the above elements in the B7_All scenario. Drivers of overall macroeconomic costs of the proposed policy can thus be better identified by analysing the abovementioned scenarios.

4. Reference scenario

A CGE analysis typically compares counterfactual scenarios with a Reference scenario in order to assess the change in certain key variables. A Reference scenario describes how the global economy could –realistically- look like in the next couple of decades. This involves clear assumptions on the main drivers of economic growth, such as active population and technical progress, as well as the structure of the economy, such as the long-lasting effects of already adopted policies, as well as trends in the sectoral composition or oil price evolution. For inter-model consistency all models that are linked or used jointly in the policy assessment need to be harmonized to this common Reference scenario.

For this exercise the GEM-E3 model was calibrated consistently to the ‘Reference Scenario 2013’ for the EU28 (European Commission, 2013c). For the countries outside the EU, the economic projection is based on the ‘World Economic Outlook’ (IMF, 2012) on the short term, and the ‘Energy and Climate Outlook 2012’ (MIT, 2012) for the period 2020–2050. The population and active population figures follow the latest United Nations (UN) and International Labour Organization (ILO) projections. It is assumed that all current policies and adopted policies for the future are taking place. In particular, source controls established in current

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[7] eippcb.jrc.ec.europa.eu.

[8] The levels related to air pollution of reduced morbidity related to air pollution, reduced healthcare expenditure, and increased crop yield are all based on Holland (2014).

[9] The study does not look to the non-market effects of avoided morbidity, such as more leisure time or improved well-being.

Table 1
Description of Policy Scenarios.

Scenario name	Description	Year of analysis
Reference	0% additional Air Quality policies	2025, 2030
B1	25% Gap Closure, only abatement expenditures incorporated	2025
B2	50% Gap Closure, only abatement expenditures incorporated	2025
B3	75% Gap Closure, only abatement expenditures incorporated	2025
B7	67% Gap Closure, only abatement expenditures incorporated	2030
B7_Health	67% Gap Closure, only avoided morbidity incorporated	2030
B7_Crops	67% Gap Closure, only crop yield benefits incorporated	2030
B7_Healthcare	67% Gap Closure, only avoided healthcare expenditures incorporated	2030
B7_All	67% Gap Closure, abatement expenditures and health, crop and healthcare benefits incorporated	2030

legislation, along with legislation related to the “2020 Climate and Energy Package”, as for example the renewable, EU Emissions Treading System (ETS) and non-ETS targets, are incorporated in the specification of the Reference scenario. Energy-related projections, such as electricity supply shares and fuel prices have been calibrated to the PRIMES and POLES[10] model reference scenarios, for EU and non-EU regions, respectively. The price of natural gas decouples from oil and due to increasing exploitation capacities of conventional and unconventional reserves, shows a lower rate of increase compared to oil price. Energy intensity is assumed to decrease rapidly for the European economy in line with the European objectives of energy security and climate change mitigation.

5. Policy scenarios

This paper analyses the four policy scenarios that were included in the Impact Assessment of the “Clean Air Policy Package” (European Commission, 2013a), as well as the final compromise proposal that was adopted by the European Commission. Further, this paper undertakes a decomposition analysis of the latter scenario as described in Section 3.

The different scenarios summarised in Table 1 refer to different levels of the “Gap Closure” percentage, namely the percentage by which the new pollution targets would close the gap between the Reference (0% additional policy) and the result of applying all technically available abatement measures[11] (100%). Here, the Gap Closure refers to health impacts due to PM2.5.

The costs of the additional air pollution reduction measures were assessed by the GAINS model, and for reasons of simplicity and harmonization we maintain the scenario names of the TSAP #11 report (Amann et al., 2014). Scenarios B1, B2 and B3 are those presented in the EC Impact Assessment (European Commission, 2013a) while scenario B7 is the final compromise proposal of the European Commission, as described below. Scenario B1 refers to a 25% Gap Closure, Scenario B2 to a 50% Gap Closure, and Scenario B3 to a 75% Gap Closure in 2025, while Scenario B7 refers to 70% Gap Closure in 2025 and a respective 67% Gap Closure for 2030[12].

The EC Impact Assessment initially supported a 75% gap closure in 2025, on the grounds that this was the level where marginal abatement costs would equal the marginal monetized health benefits when using the lower end of the range for the valuation of human life. In this sense the 75% gap closure was argued to be a conservative estimate of the socially optimal level for the new policy. In the further deliberations leading to the final Commission proposal, the Commission decided to move from 75% to 70% as this would preserve most of the policy benefits but substantially reduce costs for the sectors most affected, Agriculture and Oil refineries. The Commission also decided to move the target year from 2025 to 2030, as aligning with the timing of the new climate policy may provide for improved implementation synergies between these two polices. 67% gap-closure in 2030 was found to be equivalent to 70% in 2025 in terms of marginal abatement costs, as a consequence of the shifts of the abatement cost curves following structural changes expected to occur in the five intervening years.

In Table 1, all scenarios of this paper are described. For scenarios B1-B3 we only analyse the impacts of compliance expenditures. The analysis of the B7 scenario not only includes the compliance costs, but also a selection of beneficial feedback effects (loss of workdays, healthcare expenditures and crop yield) and the respective decomposition analysis scenarios.

5.1. Cost/benefit scenario inputs

Table 2 lists the abatement effort per year required by GEM-E3 sector for each of the policy scenarios as an increase of expenditure compared to the Reference scenario. Only the additional costs associated with the emission reduction effort beyond the Reference scenario are presented. This study analyses the net expenditures for each scenario that result after deducting the costs attributed to the Reference scenario. In addition, “no regret costs” provided by the GAINS analysis (i.e. negative costs) have been removed for the purpose of the CGE analysis. As can be seen in Table 2, the Reference scenario includes already the costs of the currently imposed legislation on air pollution which focuses on transport and electricity supply sectors. This is both due to the cost-effective measures available for the abovementioned sectors but also due to the more centralised production of the above (e.g. production of transport equipment, power plants), resulting in a more straightforward implementation of end-of-pipe measures. On the contrary, for the policy scenarios the GAINS model indicates that the most cost-effective sectors to undertake further emission reductions are households and agriculture followed by the energy-intensive industries. As explained in the Impact Assessment (European Commission, 2013a), the varying distributions for policy options reflects the limited further potential in sectors that have been regulated in the past (e.g. transport and power supply sectors), and the larger remaining potential in those that have not.

Examples of sectoral cost-effective technical measures for each policy scenario include[13], among others, substitution of urea fertilizer, reduced open burning of agricultural residuals, covered

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[10] The latest POLES Reference scenario is consistent with the 2012 International Energy Association (IEA) World Energy Outlook New Policies Scenario.

[11] In European Commission (2013a) this is described as the "Maximum Technically Feasible Reduction".

[12] In the Impact Assessment (European Commission, 2013a) the focus-year of the discussion for scenarios B1-B3 is 2025, while it is 2030 for B7, the final compromise proposal. The year 2030 has been proposed by the Commission as the binding reduction commitment year in order to "fully harvest the co-benefits from the climate policy target for 2030″ (Amann et al., 2014). In order to harmonise our analysis with the Impact Assessment and the final agreement of the European Commission, the focus-year of this paper for scenarios B1-B3 is 2025 while for B7 it is 2030.

[13] A more extensive list of measures can be found in Table 12 of European Commission (2013a).

Table 2
Abatement effort required by GEM-E3 sector, by policy scenario, in M€ per year as an increase of expenditure compared to the Reference scenario (source: GAINS model)[a]

EU-28 Abatement Expenditure (million €2010/yr, increase compared to reference)	Reference (yr 2025)	Reference (yr 2030)	B1 (yr 2025)	B2 (yr 2025)	B3 (yr 2025)	B7 (yr 2030)
Agriculture	7701.4	7942.9	66.2	339.9	1420.8	892.2
Coal	162.3	113.8	0.0	0.0	0.0	0.0
Crude Oil	0.0	0.0	0.6	0.7	1.0	0.9
Oil	786.9	764.4	32.9	103.7	340.8	196.5
Electricity supply	9276.5	6845.8	16.4	76.0	263.7	146.7
Ferrous and non ferrous metals	2666.7	2676.2	11.6	104.3	230.4	219.3
Chemical Products	2007.1	2036.9	12.5	36.3	173.0	121.7
Other energy intensive	1507.2	1572.8	14.4	83.1	387.9	255.7
Consumer Goods Industries	2384.5	2409.4	4.9	15.0	97.4	90.9
Construction	2745.3	2871.3	0.0	0.9	24.6	20.9
Transport equipment	1248.8	1202.3	0.0	0.0	1.3	0.0
Transport	48620.3	56120.8	0.3	3.0	19.2	4.8
Water transport	385.3	404.8	1.0	1.4	101.4	104.7
Market Services	1097.9	965.8	13.3	24.0	54.1	35.3
Non Market Services	0.8	0.8	2.2	2.2	3.2	2.9
Households	8522.5	8150.4	53.5	418.4	1496.5	1223.1
Total	89113.5	94078.3	229.8	1208.8	4615.4	3315.7

[a] Only sectors that carry abatement expenditures are mentioned in Table 2.

Table 3
The positive feedback effects of pollution control for EU-28 for the B7 scenarios in 2030 (based on Holland, 2014).

B7 Scenario	Increase of active population (% per year)	Crop yield benefits (Mil. Euros 2010/yr)	Healthcare expenditure (Mil. Euros 2010/yr)
EU-28	0.038%	247.1	−551.0

storage of manure for the agriculture sector, and improved stoves and pellet boilers for the fuel combustion of the domestic sector, but also stricter PM2.5 and NO_x control for the power generation sector, wet flue-gas desulphurisation and stricter PM2.5 controls for industrial combustion, stricter control for industrial process-related emissions, and tightening of emission standards for light duty vehicles beyond Euro 6.

Table 3 presents the positive feedback benefits, i.e. the avoided morbidities as a rate of increase of the EU-28 active population, the increase in crop production, and avoided healthcare expenditure, which are incorporated in the GEM-E3 model as described in Section 3.

6. Results

6.1. Macroeconomic impacts of abatement costs

Table 4 presents the aggregate macroeconomic impacts of the compliance costs for scenarios B1, B2, B3 and B7 as a % difference compared to the Reference scenario. The reported EU-28 imports and exports exclude intra-EU trade. The magnitude of macroeconomic impacts on the overall economy is in line with the size of the abatement expenditures (as listed in Table 2), and in particular, it can be seen that the impact on GDP is in all scenarios equal to a drop of around 85% of the abatement expenditure. GDP in B1 and B2 scenarios remains almost unchanged; in B3 scenario it slightly decreases by −0.026%, while in B7 scenario, which corresponds to a lower abatement effort than that of B3, GDP shows a decrease of -0.018% compared to the Reference scenario.

Table 4
Macroeconomic impacts of air pollution abatement policies on EU-28, year 2025 for B1-B3 scenarios, year 2030 for B7 (source: GEM-E3 JRC).

% change from Reference	B1	B2	B3	B7
Abatement expenditure (% of GDP)	0.002	0.008	0.032	0.021
Gross Domestic Product	−0.001	−0.007	−0.026	−0.018
Investment	0.000	0.000	−0.001	0.001
Public Consumption	0.000	0.000	0.000	0.000
Private Consumption	−0.002	−0.010	−0.037	−0.025
Exports	−0.001	−0.003	−0.009	−0.009
Imports	0.001	0.006	0.025	0.019
Employment	0.000	0.000	0.002	0.001

In all scenarios, the decrease in GDP is mainly due to a fall in private consumption and a small deterioration of the balance of trade. Household consumption falls as a result of the reduction of the disposable income, part of which is now allocated to the required abatement expenditure by the households, but also as a result of the higher output prices of goods produced by the abating sectors, as it is assumed that these industries pass-through the expenditure for air pollution control technologies. For example, air pollution mitigation results in an increased cost of energy[14], resulting in a reduction in demand for consumption categories like transportation, heating and cooking and other energy-related services.

Results indicate that even without incorporating the associated feedback benefits the impacts on employment are neutral since demand for more labour intensive abatement products counter-balances the losses due to the abatement costs.

6.2. Decomposition analysis of macroeconomic impacts

Scenario B7_All incorporates the compliance expenditure along with feedback benefits, and thus provides an integrated insight with regards to the positive and negative impacts of the proposed policies. In order to understand the contribution of each type of feedback benefit, in Table 5 we present the aggregate macroeconomic impacts of B7_All and a decomposition analysis of the impacts of costs and of each type of benefits as explained in Table 1. There is an (almost) linear cumulative effect of each respective benefit and costs thereby the sum of the GDP impacts, of GDP components and of employment levels of scenarios B7, B7_Health, B7_Crops and B7_Healthcare result (approximately) in the aggregate impacts of scenario B7_All.

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[14] In this study, the technology mix in the electricity sector is assumed not to change across the various scenarios. However, in reality some fuel and technology-switch could be expected.

Table 5
Decomposition analysis of macroeconomic impacts of B7 scenario and decomposition scenarios on EU-28 (source: GEM-E3 JRC).

% change from Reference	B7_All	B7	B7_Health	B7_Crops	B7_Healthcare
Abatement expenditure (% of GDP)	0.021	0.021	0.000	0.000	0.000
Gross Domestic Product	0.007	−0.018	0.023	0.002	0.000
Investment	0.015	0.001	0.014	0.000	0.000
Public Consumption	0.000	0.000	0.000	0.000	0.000
Private Consumption	0.007	−0.025	0.028	0.004	0.000
Exports	0.018	−0.009	0.030	−0.002	−0.001
Imports	0.016	0.019	−0.002	−0.002	0.000
Employment	0.042	0.001	0.041	0.000	0.000

The results of the decomposition analysis indicate that the benefits from avoided workdays lost due to improved air quality are the most significant feedback impact, and offset the negative impacts of abatement expenditures. The reduction of sick leaves in the European economy results in higher productivity levels of the given human capital leading to additional employment, more competitive exports and higher disposable incomes and demand for consumption. The improvement of labour productivity from air quality policies result in a reduction of the unit cost of labour, thus providing a more cost-efficient substitute for energy, the unit cost of which has increased as a result of the abatement policies. In addition, investment demand also increases as prices for investment goods decrease more than the price of capital as compared to the Reference scenario.

With regards to crop yield benefits, the results indicate that their impacts in the overall economy are small. However, as seen in the sectoral analysis in Section 6.3, crop yield benefits are significant for the agricultural sector as they decrease the level of reduced production of the sector. Crop yield benefits are equal to almost 30% of the abatement expenditures of the sector (see Tables 2 and 3) and as described are incorporated in the model as an increase in productivity. The avoided healthcare expenditures have a small impact on the total economy due to the relatively small magnitude in relation to the overall expenditure levels of the households.

6.3. Sectoral results for the final European Commission proposal (B7 scenario)

The abatement expenditures and impacts differ considerably across the various sectors depending on the sector's air pollution emissions, on the cost-efficiency of available mitigation measures and on whether the sector produces an abatement technology or is directly benefiting by the improvement of air quality. This section presents a sectoral analysis of the impacts of certain scenarios.

Fig. 1[15] presents a comparison of sectoral impacts of B7_All and B7 scenario in order to depict the differences across sectors when incorporating the benefits of the implemented policies, whereas Fig. 2 shows the variation of impacts across sectors with cost-optimal sectoral abatement expenditures for scenarios B1, B2, B3.

Some sectors increase their production in all scenarios as the output related to the production, maintenance or operation of abatement technologies outweighs the possible production loss due to their own sectoral abatement efforts (e.g. Chemical products, Electricity supply). An example is electricity, which is both an intermediate input to sectors that produce abatement technologies (e.g. Chemical Industry) but also a means of abatement itself for certain air pollution reduction techniques[16]. The Transport equipment sector also slightly increases its production, even for the "expenditure only" B7 scenario, since it provides the abatement technologies for the water transport sector while there is no decrease in demand from other sectors (the Land and Air Transport sector does not carry a significant abatement effort since for land transport most abatement potential has been exploited within the Reference scenario as shown in Table 2, while add-on pollution reduction devices for aircraft are essentially non-existing). For the same reason, energy-intensive sectors only marginally reduce production (or even slightly increase, as in the case of the Chemical Industry) in the "expenditure only" scenario (B7) despite the significant abatement costs and increased energy cost they bear, since they also deliver intermediate and final pollution abatement goods.

Overall production changes are slightly positive in the B7_All scenario for most sectors due to overall increased demand for goods stemming from the higher labour productivity (less sick leaves) that leads to greater disposable incomes of the households. When the positive feedback benefits are incorporated (B7_All), refineries, agriculture and water transport still show lower activity levels, albeit higher than in the B7 scenario.

Fig. 1 and Fig. 2 also illustrate that the abatement efforts of the various sectors are not proportional to the total abatement ambition of the respective scenarios (25% in B1, 50% in B2, 75% in B3, and 67% in B7). The cost-efficient allocation of the abatement effort by the GAINS model results in different sectors stepping in at different ambition levels. For example, the ferrous and non-ferrous metals sector shows the fourth highest reduction in the B2 scenario but the eighth in B3, indicating that to reach a higher level of air quality other sectors need to be involved. The agricultural sector is the most negatively affected sector[17] in B2, B3 and B7, but not in B1 where the low emission reduction is achieved without the sector's contribution. When the positive feedback on the crop yield is taken into account, in the B7_All scenario the output loss is reduced by more than half.

Figs. 3 and 4 present the impact of the examined air quality policies on European imports and exports as a percentage change from the Reference scenario. The figures only correspond to the extra-European trade in order to see the impact on European competitiveness. The European net trade balance is unchanged in the B7_All scenario while net European imports increase by 0.14% in the B7 scenario. Imports increase mainly in sectors with a high abatement effort, like the agricultural sector. Sectors with an increase in domestic production also see higher imports as part of the intermediates is met by imported goods.

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[15] In Figs. 1–5, the height of the bars indicate the share of each sector in the Reference scenario, thus the surface of the bars indicates the change in absolute numbers of a sector compared to the Reference scenario.

[16] E.g. electrostatic precipitators for PM reduction (Brandley, 2005), non-evaporative cooling system and Venturi scrubber techniques for NH3 abatement (Handley et al., 2001).

[17] The negative impacts in the agricultural sector are possibly overestimated for the following reasons: (1) the shock responses of this sector are modelled as in a full free-market sector, whereas cross-border tariff adjustments (or equivalent measures) are commonplace to mitigate impacts on agricultural production, (2) some of the pollution abatement measures that farmers would have to put in place could be subsidised through the 2nd pillar of the EU's Common Agricultural Policy (Rural Development funding).

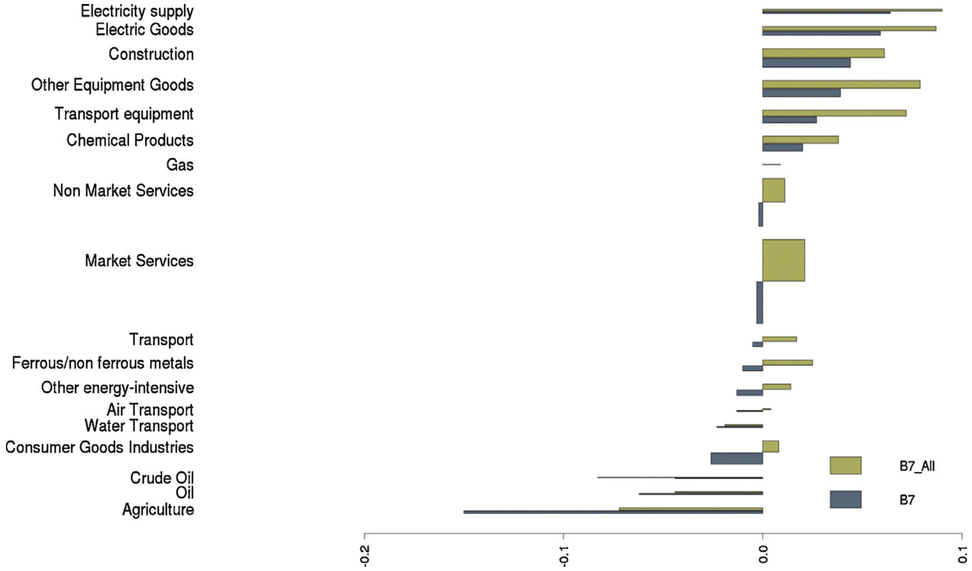

Fig. 1. EU-28 Sector Production as a change from Reference scenario, year 2030 for scenarios B7-B7_All (source: GEM-E3 JRC).

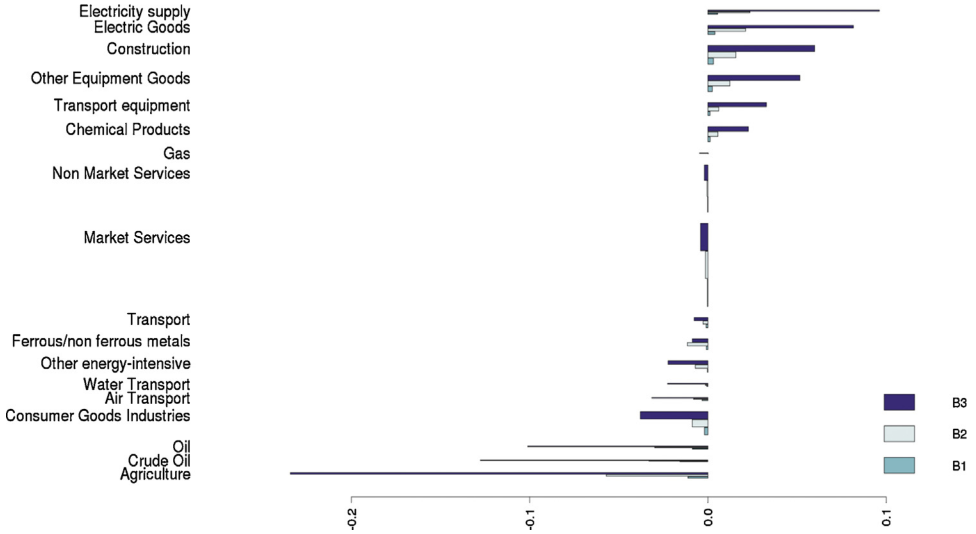

Fig. 2. EU-28 Sector Production as a change from Reference scenario, year 2025 for scenarios B1, B2, B3 (source: GEM-E3 JRC).

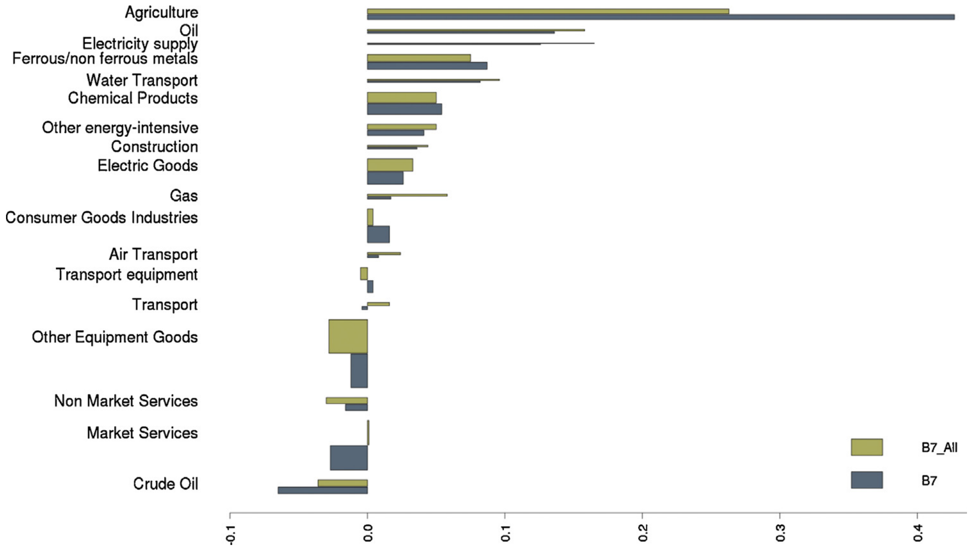

Fig. 3. EU-28 Sector imports as a change from Reference scenario, year 2030 for scenarios B7-B7_All, (source: GEM-E3 JRC).

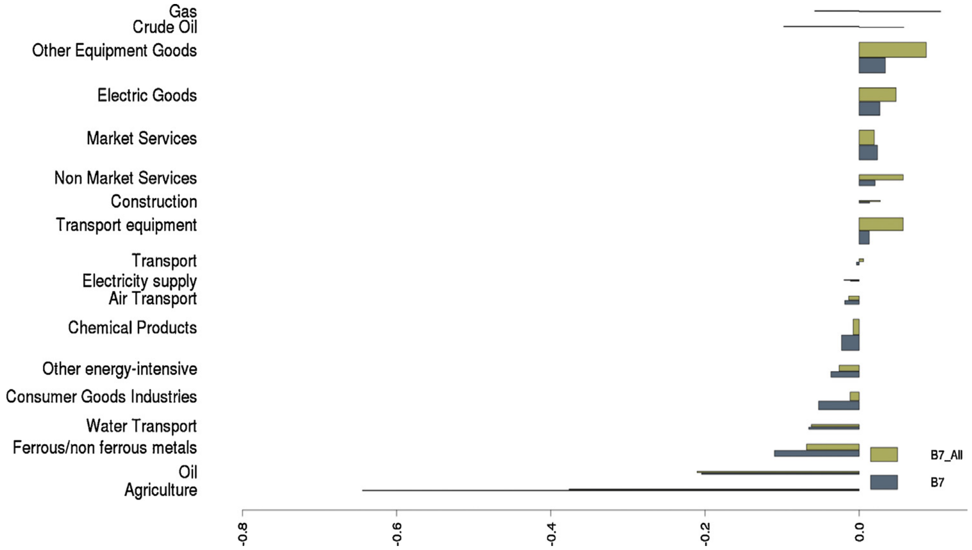

Fig. 4. EU-28 Sector exports as a change from Reference scenario, year 2030 for scenarios B7-B7_All, (source: GEM-E3 JRC).

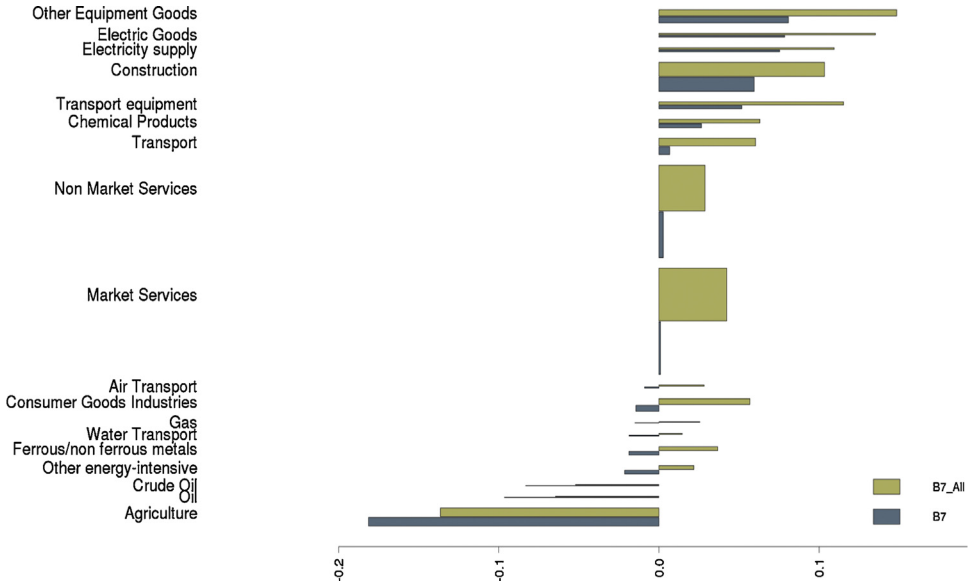

Fig. 5. EU-28 Sector Employment change from Reference scenario, year 2030 for scenarios B7-B7_All, (source: GEM-E3 JRC).

On the other hand, EU exporting sectors, like the Electric Goods, Transport Equipment and Other Equipment industries show a small increase of exports due to the reduction of the unit cost of production in both B7 and B7_All scenarios. This reduction in the unit cost of production is not only due to the positive feedback effects (only in scenario B7_All), but also because sectors with no abatement obligations become slightly more competitive compared to sectors that face abatement expenditures due to the release of production factors (in this case labour and capital).

Gains in employment are very small in the B7 scenario (almost 3000 jobs) reflecting the differences in labour intensity between sectors that install abatement technologies and sectors providing them, as can be seen in Fig. 5. The main sectors providing abatement goods, like construction, transport and other equipment goods are labour-intensive and represent a significant share of EU employment. This finding is consistent with the EPA (2012) report which concludes that according to their literature review of peer-reviewed econometric studies, the net employment effects of environmental policies have been small and not affecting the economy in a significant way. However, when taking into account the positive feedback of the proposed policies benefits (B7_All), a positive employment effect is found (close to 100,000 jobs equivalents in 2030). The increase of the days and hours worked by the existing labour force accounts for 76,000 equivalents[18], whereas this higher labour and crop productivity leads to an additional net job creation of 24,000 equivalents thanks to the improved competitiveness of the EU.

7. Conclusions and further research proposals

The GEM-E3 model has been used to quantify the socioeconomic impacts of the European Commission's proposed "Clean Air Policy Package". This paper analyses the main macroeconomic impacts of the policy proposal as well as its impacts on sectoral production, demand, trade competitiveness and employment. Our

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[18] The 76,000 job equivalents can be interpreted, among others, as a lower rate of absenteeism and sick leave due to air pollution related illness.

work presents the scenarios analysed in the corresponding Impact Assessment as well as the final compromise proposal by the European Commission. Further, this analysis not only includes the impacts of the expenditures related to the policy implementation, but also assesses effects of the positive feedback benefits thanks to avoided environmental costs such as workdays lost, health care expenditures and crop yield losses.

The pollution abatement expenditures obtained from the integrated assessment model, GAINS, and the quantified feedback effects are a direct input to the economic model GEM-E3. This linking between the bottom-up integrated assessment model and top-down economic model allows for a consistent analysis of the air policy scenarios

The analysis with the GEM-E3 model enables an assessment of both direct and indirect economic effects of the air pollution policies. The expenditure on pollution abatement represents a cost for the abating sectors which increase production costs, leading to slightly reduced domestic demand and a small loss of competitiveness for these sectors. The expenditures undertaken by the households reduce their disposable income to the detriment of other consumption categories. On the other hand, an important result of the analysis is that the expenditure in abatement technologies also increases the demand for the sectors that produce air pollution mitigation technologies. Hence, there is additional demand for sectors like equipment, electric goods, chemicals and construction, and thus the domestic production and imports of these products are increased.

The higher employment in sectors that produce abatement technologies compensates for the employment losses in the sector that face abatement expenditures. If the positive feedback benefits are taken into consideration (in particular health-related), employment levels increase. The decomposition analysis demonstrates that the increased labour supply has positive macroeconomic impacts on the European economy, counterbalancing the costs of the policy. By further taking into consideration other benefits such as the reduced healthcare expenditure and increased crop yield, we find that the implementation of the 'Clean Air Policy Package' may have a small positive impact on the European economy and many of its economic sectors.

The decomposition analysis provides further insights, as it shows the relative importance of the abatement expenditures and each feedback benefit in the overall impacts of the proposed policy. The current analysis assesses the effects of reduced working days lost due to morbidity, healthcare costs and increased crop yields; however, further feedback mechanisms could be envisaged. Furthermore, in future analysis, the use of financial instruments to subsidise certain pollution abatement measures (e.g. agro-environmental measures through the EU's Rural Development Programme) could deliver important insights on the implementation and distributional impacts of the policy.

In our analysis we have not examined the possible synergies or antagonistic effects of air pollution and climate change mitigation policies (beyond the EU 20-20-20 polices that are considered in the Reference scenario), which may affect the results significantly. In particular, a common assessment of climate and air quality policies could provide further insight in terms of cost-effectiveness and complementarity of certain measures. Lastly, a further field of analysis could involve the assessment of possible trade benefits in case other regions of the world go forward with ambitious air pollution or climate change policies.

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