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Impact Assessment of European Clean Air policies in a CGE framework

Authors:
Zoi Vrontisi, Jan Abrell, Frederik Neuwahl,
Bert Saveyn, Fabian Wagner

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European Commission
Joint Research Centre
Institute for Prospective Technological Studies

Contact information
Bert Saveyn
Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)
E-mail: jrc-ipts-secretariat@ec.europa.eu
Tel.: +34 954 488 318
Fax: +34 954 488 300

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1 Abstract

In March 2014 the UN World Health Organization (World Health Organization, 2014), released a study reporting that in 2012 one in eight of global deaths were a result of air pollution exposure. As part of a long-term effort, in late 2013, the European Commission (EC) adopted the "The Clean Air Policy Package", where it proposes new air pollution reduction objectives for the period up to 2030, as well as instruments to deliver those objectives. This paper explains in detail the modelling conducted with a Computable General Equilibrium model, GEM-E3, for the EC Impact Assessment of this recent EU policy proposal along with an additional analysis of the benefits deriving from the proposed policies. We show that the expenditure on pollution abatement represents a cost for the abating sectors but also that the expenditure in abatement technologies is an economic opportunity for the sectors that produce these technologies. Moreover, we find that the inclusion of benefits in our analysis, especially those related to health, can offset the resource costs and yield overall marginally positive macro-economic impacts on the European economy.

2 Introduction

In March 2014 the UN World Health Organization (World Health Organization, 2014), released a study reporting that in 2012 around 7 million people died –one in eight of global deaths- as a result of air pollution exposure. WHO states[1] 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".

While over the last couple of decades the EU air quality policy (European Commission 2005a, 2005b) has shown important progress in curbing emissions of harmful pollutants such as fine particulate matter, sulphur dioxide, lead, nitrogen oxides, carbon monoxide and benzene, ambient concentrations of several pollutants are still beyond levels that could be considered safe. Fine particles and ozone, in particular, still present significant health risks and the air quality guidelines of the WHO are generally not being met. Many EU Member States are still falling short of agreed EU air quality standards, with high costs for the healthcare system and for the economy at large. For the long term, the EU's Environment Action programme set the objective to achieve levels of air quality that no longer give rise to significant negative impacts on and risks to human health and the environment.

With the dual objective to achieve as soon as possible compliance with existing air quality legislation, and to make substantial further progress towards the EU's long-term objective, the European Commission (EC) adopted on 19/12/2013, the "The Clean Air Policy Package"[2] (European Commission, 2013). The strategic framework of the Package is set out in the communication 'A Clean Air Programme for Europe'. Among other components, the package also includes two legislative proposals: one introduces EU-wide emission limits for medium combustion plants[3], the other revises the National Emission Ceilings Directive by setting stricter national emission ceilings in 2030 for the four currently regulated pollutants (SO2, NOx, VOCs and NH3) and by adding ceilings for primary PM2.5 and methane (CH4).

Before the European Commission can propose a new initiative, it mandatorily has to conduct an Impact Assessment, evaluating the potential economic, social and environmental impacts[4]. This impact assessment of the "Clean Air Policy Package" includes an ex-ante analysis of an update of the EU's strategy on air pollution and the development of accompanying legal proposals and non-regulatory actions. The impact analysis is done with a model-toolbox that utilizes the methodological benefits of bottom-up and top-down models in an effort to capture the impacts of the proposed policy on different aspects of the environment and society and on a different sectoral and regional disaggregation.

This paper presents the analysis done with a Computable General Equilibrium model, GEM-E3, for the related Impact Assessment and aims to illustrate how quantitative modelling

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

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

[3] Medium Combustion Plants (MCP) are those with rated thermal input comprised between 1 and 50 MW. Larger plants are regulated by the Industrial Emissions Directive (formerly Large Combustion Plants Directive); smaller plants are generally within the scope of the Ecodesign Directive

[4] http://ec.europa.eu/smart-regulation/impact/index_en.htm

can directly contribute to real world policy decisions. The GEM-E3 model is used to assess the macro-economic and competitiveness effects of different abatement policy options by utilizing sectoral results from detailed bottom-up models. The effects analysed include GDP, sectoral activity, exports and imports, employment, private consumption and welfare.

A policy analysis using a computable general equilibrium is central to understanding the broader social and economic impacts beyond the emission abatement costs delivered by the bottom-up models. These include, among others, the indirect effects of purchasing the abatement technologies, final demand and employment as well as on the competitiveness of the various sectors. In general terms, expenditure on pollution abatement is a cost for the sectors that need to reduce pollution, resulting in higher production costs for the complying sectors that could lead to reduced domestic consumption and a loss of international competitiveness. However, the installation of abatement technologies is also an economic opportunity for the sectors that produce these technologies. In this context, the Commission's core objective was to evaluate the overall balance of these counteracting drivers and identify whether or not any of the potential negative impacts would be significant.

The main aim of this exercise is thus to assess the broader, both direct and indirect economic impacts of the air quality policies. We go forward with incorporating impacts related both to compliance costs and related benefits. 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. We also demonstrate that the improved labour productivity from avoided morbidity but also avoided healthcare expenditure, to a lesser extent, have positive macro-economic impacts on the European economy, possibly 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. Despite including in our analysis almost all direct economic benefits that are part of the Impact Assessment (European Commission, 2013), we have not included the benefits of the reduced damage to buildings, neither do we assess the possible socioeconomic benefits stemming from the climate change co-benefits of air pollution policies (conceptually similar to the wide scientific research on the ancillary air quality benefits of climate change mitigation policies).

2.1 Models

The Impact Assessments of European Commission policy proposals are often supported quantitatively by 'modelling toolboxes', consisting of various (often highly specialized) model types, which are sometimes connected with a soft link. In the context of the Clean Air Policy Package (European Commission, 2013) the most important model for the analysis of impacts is the air pollution mitigation model GAINS. The latter feeds the GEM-E3 model with different scenarios of abatement costs for 5 key air pollutants (PM2.5, SO2, NOx, VOCs, NH3) in order to conduct a complete assessment of the socioeconomic impacts. This analysis did not include measures to reduce methane emissions[5].

2.1.1 The GAINS model

The GAINS model is an bottom-up integrated assessment model of air pollution; that is, 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 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 (SO2), nitrogen oxides (NOx), fine particulate matter (PM2.5), ammonia (NH3) and volatile organic compounds (VOCs), as well as of the Kyoto greenhouse gases. Air pollutant emissions lead to detrimental effects on human health (e.g. loss in life-expectancy and risk of illness due to exposure of fine particles and ozone) and ecosystems (such as acidification and eutrophication, resulting in loss of biodiversity). 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 Impact Assessment (European Commission, 2013) the European Commission has employed the model for a number of purposes. First, GAINS provided an emission projection for each member state and each pollutant, based on assumptions about future energy consumption, as well as industrial and agricultural activities (Amann et al, 2012a, 2012b, 2012c, Borken-Kleefeld and Ntziachristos, 2012). This baseline emission projection reflects 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 baseline scenario GAINS was then used to estimate 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. This analysis took into account specific application limits for various control

[5] 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 measures to reduce methane may be expected to positively contribute to the overall macroeconomic impact of the Clean Air Package

technologies; such limits may be the consequence of turnover rates of capital stock or may result from practical limitations in the implementation of technologies. The current legislation and maximum feasible reduction scenarios determine the range of plausible and achievable scenarios.

For a set of ambition levels, which in turn were motivated by cost-benefit considerations, GAINS then provided portfolios of cost-effective measures for each member state that, taken together, provide the environmental objectives at lowest cost (Amann et al, 2012e, 2013). Furthermore, throughout the design process the web interface GAINS model and database served as an open access tool for stakeholder consultations.

2.1.2 The GEM-E3 model

GEM-E3 is a multi-sector, multi-region computable recursive-dynamic general equilibrium of the world economy developed in a deterministic framework. The GEM-E3 version[6] (Capros et al, 2013) used for this exercise is calibrated on year 2004 based on the GTAP 8 database and represents the EU 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, 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 model is able to compare the welfare effects of various environmental instruments, such as taxes, various forms of pollution permits and command-and-control policies.

The economic agents optimise their objective functions (utility for households and production cost for firms) and determine separately the supply or demand of capital, energy, labour and other goods. Market prices adjustments guarantee a global equilibrium endogenously and simultaneously to the year that the policy under analysis is implemented as a policy shock to the model.

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. The household maximizes its utility deciding on the optimal supply of labour versus leisure. Household expenditure is allocated between consumption, tax payment and savings. The representative household firstly decides on the allocation of its income between present and future consumption of goods. At a 2nd stage the household allocates its total consumption expenditure between the different consumption categories available. 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).

[6] There are two versions of GEM-E3: GEM-E3 Europe and GEM-E3 World. They differ in their geographical and sectoral coverage, but the model specification is the same. The European version covers 24 EU countries (all EU countries, except for Luxemburg, Malta and Cyprus) and the rest of the world (in a reduced form). It is based on EUROSTAT data. See www.gem-e3.net.

The production of the firms is modelled with a nested 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. The amount of capital is fixed within each period. The investment decisions of the firms in the current period affect the stock of capital in the next period. 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.
The demand for goods by the consumers, firms (for intermediate consumption and investment) and the public sector constitutes the total domestic demand. This total demand is allocated between domestic goods and imported goods, using the Armington specification.

Government behaviour is exogenous. The model distinguishes between 9 categories of receipts, including indirect taxes, environmental taxes, direct taxes, value added taxes, production subsidies, social security contributions, import duties, foreign transfers and government firms. It is possible to consider various systems of revenue recycling.

3 Methodology

Computable General Equilibrium models have increasingly been used to estimate the macroeconomic and welfare impacts of environmental policies. Particularly with regards to air pollution, recent studies have described 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) have assessed 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 to 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 to depict the effects of mortality from air pollution and depending on the approach, a change in the total-time endowment (working hours and leisure) in order to depict morbidity effects on workers and non-market effects expressed in terms of loss of 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 that "stated preference" method) but follow the Human Capital approach which can be captured by the real economy of 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, which were however included in the overall cost-benefit analysis conducted by the Commission for the Clean Air Package Impact Assessment (Holland, 2014). An assessment of total welfare losses, as conducted in Ciscar et al (2014), can also provide an insight on the total health-related benefits of the proposed policies.

The papers above use the MIT EPPA-HE 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 making use of the CGE simultaneous price adjustment of all sectors and regions and thus moving ahead from the damage-function approach. They do not, however, assess the socioeconomic impacts of the expenditures for mitigation policies and the impacts of other benefits/losses due to air pollution mitigation/increase and they do not focus on a sectoral analysis that can provide insights regarding the competitiveness impacts on different industries. However, in the latest US EPA report on the "Benefits and Costs of the Clean Air Act from 1990 to 2020" (EPA, 2011) we find an incorporation of both 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.

The explicit inclusion of the economic opportunity for environmental technology industries is a significant contribution of our analysis. Furthermore, an advanced contribution is the incorporation in our assessment of the main benefits from the abatement of air pollution, namely reduced morbidity, reduced healthcare expenditure and increased crop yield, expanding the scope of analysis beyond what is presented in the papers presented above.

Overall, 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 it 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 that may reduce energy-related emissions, and c) by a decline in production as a result of the increased cost of production. The modelling work with GEM-E3 has followed this approach for greenhouse gasses in the recent 2030 Framework for Climate and Energy policies (European Commission, 2014) but also for local air pollutants by Mayeres and Van Regemorter (2008), which endogenize the health feedback of air pollution in a CGE framework by including health in the household utility function in a way that higher pollution levels increase demand for health services and thus the available disposable income is reduced as well as the household time endowment and labour productivity.

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 an exogenous constraint or taxation as policy measure. Here, the cost of the policy is calculated through the direct incorporation of the emission abatement expenditures of sectors and households in GEM-E3. These abatement expenditures originate from the output of the bottom-up GAINS model. Thereby, instead of using an estimated function approximating the marginal abatement costs (MAC) of the bottom-up measures, this approach benefits by using the exact expenditures as calculated by the detailed GAINS model and ensures consistency and full harmonization between the two different modelling frameworks that are involved in the Impact Assessment of the European Commission (EC, 2013). Moreover, the single pollutant MAC curves usually incorporated in CGE models are unable to capture the capacity of a simultaneous reduction of multiple pollutants by a single technology thereby their use may potentially result in an overestimation of real costs. However, it should be noted that by using this approach we may exclude any possible changes in abatement expenditure due to the general equilibrium simultaneous price adjustment.

A CGE framework calculates the direct and indirect effects. As direct effects, the abatement expenditures per sector and pollutant from GAINS are incorporated in GEM-E3 as 'obliged production expenditures' for the sectors that have to reduce their air pollution emissions. This abatement cost is added to the unit cost of production of the abating sectors, hence affecting the price equilibrium and the production levels of these sectors. At the same time, the abatement expenditures for households are introduced in the CGE framework as compulsory abatement consumption which does not increase their welfare but still reduces their disposable income for other categories of consumption. This can lead to an overall reduction of the consumption level, since the amount of income that is now optimally allocated to the consumption categories is less. Abatement expenditures do not account for additional investments so as not to create additional capital stock available for the whole economy (in accordance with the assumption that capital is mobile across sectors) 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, both from firms and households create demand for abatement technologies increasing the demand for goods produced by the sectors providing environmental technologies. This additional demand generates an economic opportunity for the manufacturers of abatement technologies. Pollutant-specific abatement matrices with constant coefficients allocate the demand for abatement technologies to the various sectors that supply these technologies, thus increasing demand for production. These matrices have been designed in collaboration with experts of the European IPPC Bureau[7] and are an important driver of our results on the economic impacts of emission abatement policies.

Reduced air pollution-related morbidity has been incorporated in the model through an increase of the total time endowment, namely the time available by the households for labour supply and leisure, which is then allocated according to the household's optimization decision. Increase (or reduction in the case of higher pollution levels) of labour supply depicts the equivalent gained work time due to avoided morbidity, while increase/reduction of leisure depicts the non-market effects of both morbidity. The respective 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 household's obliged consumption of "Health and Medical Services". This approach does not affect the welfare of

[7] This matrix has been designed in collaboration with experts of the European IPPC Bureau (*eippcb.jrc.ec.europa.eu/*).

the households directly since obliged consumption is not assumed to increase or decrease the level of welfare. However, it affects it indirectly due to the now higher disposable income of the household that can be allocated in different consumption categories to improve the household's utility. We also take into consideration the fact that healthcare expenditures in Europe are not entirely directly paid by households by assuming that the respective transfer from the state to the households is reduced accordingly and by recycling the resulting savings of the government back to the economy through a reduction of the social security contributions. The approach is identical to the approach followed with GEM-E3 model in the PESETA II assessment of the costs of climate change (Ciscar JC. et al, 2014). The input data of reduced healthcare expenditure is provided by Holland (2014).

Input data for increased crop yield is provided by Holland (2014) in terms of additional value of crop production and is introduced in the GEME3 model through an increase of agricultural total factor productivity which has been calculated so as to achieve the increased levels of production with the same factor inputs.

4 Reference Scenario

In a CGE framework, a typical analysis for policies in the mid- or long-term (here in 2030) compares counterfactual scenarios with a reference scenario. A reference scenario describes how the global economy could look like in the next couple of decades. This involves clear assumptions on the main drivers of economic growth, such as active population, technical progress and agent's expectations. For inter-model consistency all models of the 'modelling toolbox' that support an Impact Assessment need to be harmonized to a common reference scenario.

For this exercise the GEM-E3 model was calibrated consistently to the 'Reference Scenario 2013' of the 'EU Energy, Transport and GHG Emissions Trends up to 2050'[8] for the EU28. 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 follow the latest UN and ILO projections.

The GEM-E3 reference assumes that all current policies and legislated future policies are taking place. In particular, source controls established in current legislation, along with legislation included in the "2020 Climate and Energy Package", as for example the renewable, 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[9] 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.

[8] http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2050_update_2013.pdf
[9] The latest POLES reference scenario is consistent with the 2012 IEA World Energy Outlook New Policies Scenario

5 Policy Scenarios and cost-benefit inputs

This paper analyses the policy scenarios that were included in the Impact Assessment of "The Clean Air Policy Package" (European Commission, 2013), as well as the final policy option that was adopted by the European Commission. The focus of the assessed polices lies to Europe's long-term goal, as stated in the Environment Action Programme, of achieving “levels of air quality that do not give rise to significant negative impacts on and risks to human health and the environment”.

Four policy scenarios of additional technical reduction measures are assessed as those were produced by the IIASA GAINS model for the purposes of the Impact Assessment (Amann et al, 2014). The different scenarios refer to the different levels of the "Gap Closure" percentage, namely the percentage by which the new objectives would close the gap between the reference policy (0%), on the one hand, and the result of applying all technically available abatement measures (100%), on the other (the Maximum Technically Feasible Reduction, or MTFR109) (European Commission, 2013) and are thoroughly described in the Impact Assessment of "The Clean Air Policy Package". It is important to note that the input of sectoral abatement expenditure from GAINS model is based on technical measures available in 2012 and does not include any consideration of cost adjustment due to learning-by-doing and learning-by-research, nor does it assume any changes in energy structures or behavioural changes of consumers.

For reasons of simplicity 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, 2013) while scenario B7 is the final formal proposal of the European Commission, which lies between the effort required in options B2 and B3, and is analysed with GEM-E3 model in the current paper. Scenario B1 refers to a 25% Gap Closure for health impacts due to PM2.5 (PM-health), Scenario B2 to a 50% Gap Closure for PM-health, Scenario B3 to a 75% Gap Closure for PM-health, while Scenario B7 refers to 70% Gap Closure for PM-health in 2025, which was the gap-closure level agreed by the college of the European Commission in December 2013. The B7 in 2025 corresponds to a 67% Gap Closure in the year 2030[10], which 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 that has been proposed by the European Commission in its Communication on the 2014 Energy and Climate Package"(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 the discussion for scenarios B1-B3 is 2025 while for B7 it is 2030. For scenario B7, the final proposal of the European Commission, we also present an integrated assessment of costs and benefits with regards to health (morbidity, mortality and healthcare expenditures) and crop yield, while for scenarios B1-B3 we only analyse the impacts of compliance expenditures.

[10] In policy terms, more than by the gap closure percentage number, each scenario is defined by the set of cost-effective technical measures delivering the emission reductions. The same technical measures are associated with 70% gap closure in 2025 and 67% gap closure in 2030, the 3% gap closure difference being the result of structural changes (e.g. some reduction in the use of solid fuels) occurring on the baseline in the five intervening years.

5.1 Cost Inputs

In Table 1, the total EU-28 costs imposed on the GEM-E3 firms and households for all abated pollutants are presented for each respective policy scenario as well as for the reference case. It is important to note that for each policy scenario only the additional costs associated with the emission reduction effort beyond the Reference case are presented. Namely, the shock imposed on the GEM-E3 model is the net effort that results after deducting from the scenario abatement expenditures 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 purposes of the CGE analysis. As can be seen in Table 1, the Reference scenario follows the currently imposed legislation on Air Quality which focuses on transport and electricity supply sectors. This is both due to the cost-efficient measures available for the abovementioned sectors but also due to the more centralised production of the above, resulting in a more straightforward implementation of end-of-pipe measures. On the contrary, for the policy scenarios GAINS model indicates that the most cost-efficient sectors to undertake further emission reductions are households and agriculture followed by the energy intensive industries. As explained in the Impact Assessment (EC, 2013), the varying distributions for policy options reflects the limited further potential in sectors that have been regulated (e.g. transport and power supply sectors) in the past, and the larger potential in those that have not.

Examples of sectoral cost-effective technical measures for each policy scenario of the Impact Assessment include stricter PM2.5 and NOx control for the power generation sector, improved stoves, pellet boilers and dust filters for the fuel combustion of the domestic sector, wet flue-gas desulphurisation and stricter PM2.5 controls for industrial combustion, selective catalytic reduction and stricter control for industrial process-related emissions, tightening of emission standards for light duty vehicles beyond Euro 6 for the transport sector and substitution of urea fertilizer, reduced open burning of agricultural residuals and covered storage of manure for the agriculture sector. The measures mentioned above are among those presented in Table 12 of the European Commission 2013 Staff Document.

Table 1: 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)

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
Transport equipment	1248.8	1202.3	0.0	0.0	1.3	0.0
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	48620.3	56120.8	0.3	3.0	19.2	4.8
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
Water transport	385.3	404.8	1.0	1.4	101.4	104.7
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**

5.2 Benefit Inputs

With regards to the health benefits from air pollution control in terms of avoided morbidities Table 2 shows the rate of increase of the EU-28 active population which, as mentioned above, is introduced in the GEM-E3 model as in increase of total time endowment. This increase results in direct economic benefits since the available factors of production of the European economy become more abundant. Although for the purposes of this paper we do not present the benefit analysis for any other policy scenarios apart from the final proposal of the European Commission (i.e. scenario B7) it can be noted that the increase of population is analogous to the abatement effort seen in Table 1.

With regards to avoided healthcare expenditures and crop yield benefits, the data provided by Holland, 2014 can be found in Table 2. The avoided healthcare expenditure has been incorporated in the model as described above, by reducing compulsory consumption of the household's "Health and Medical services", while the increased crop production has been used in order to calculate the respective total factor productivity (TFP) for the agricultural sector.

Table 2: Benefit input for EU-28, B7 scenario 2030 (based on Holland, 2014)

B7 Scenario	Increase of active population (% per year)	B7_Crop production benefits (Mil. Euros 2010/yr)	B7_Healthcare expenditure (Mil. Euros 2010/yr)
EU-28	0.038%	247.1	-551.0

6 Results

6.1 Macroeconomic impacts of abatement expenditure

We first present the aggregate macroeconomic impacts of the compliance costs of sectors and households for scenarios B1-B3 and B7. Table 3 presents the aggregate impacts of the examined air pollution policies on the European economy in terms of % difference from the Reference scenario. It should be taken into consideration that the reported EU-28 imports and exports exclude intra-EU trade. In the case of B1, B2, B3 and B7 scenarios (i.e. only the costs of the air pollution abatement policies are implemented in the model), the magnitude of impacts is in line with the magnitude of the initial shock of abatement expenditures and in particular, it can be seen that the impact on GDP is in all scenarios equal to around -0.85 of the abatement expenditure expressed as a percentage of GDP. Thereby, GDP in B1 and B2 scenario is 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 case.

The decrease in GDP in the B1-B3 and B7 scenarios is 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, in order to comply with the required abatement expenditure, but also as a result of higher production costs of the goods produced by the abating sectors. In particular, the policies result in an increased cost of energy, hence leading to a higher reduction with regards to the consumption categories related to transportation, heating and cooking and other energy related services. The unit cost of energy for production increases analogously to the abatement effort as refineries and power industry pass-through the expenditure for air pollution control technologies to their output price.

Table 3: Macroeconomic impacts of air pollution abatement policies on EU-28 GDP, GDP components and Employment, year 2025 for B1-B3 scenarios, year 2030 for B7, 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

6.2 Decomposition analysis of macroeconomic impacts of abatement expenditure and benefits

B7_All scenario incorporates all policy related benefits that are analysed in this paper along with the compliance expenditure and thus provides an integrated insight with regards to the impacts of the proposed policies. In Table 4 we present the aggregate macroeconomic impacts of the B7_All and a decomposition analysis of the impacts of each benefit feature (3 additional scenarios which only incorporate one category of benefits and abatement expenditure) and of compliance expenditures (B7 scenario which does not incorporate any benefits). We note that there is a linear cumulative effect of each respective benefit and cost thereby the sum of the GDP impacts of scenarios B7, B7_Health, B7_Crops and B7_Healthcare and the sum of each GDP component result in the aggregate GDP impacts and GDP components of scenario B7_All, while the same linear properties hold for the impacts on the EU-28 employment levels.

The results of the decomposition analysis indicate that the benefits from avoided morbidity due to improved air quality are significant and offset the negative impacts of abatement expenditures. This is due to the higher availability of human capital in the economy which results in higher employment levels and thus to higher disposable incomes. 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. The latter effect leads to a reduction of the unit cost of production, which combined with an increase in the total European disposable income, results in an increase of private consumption and welfare. In addition, investment demand also increases as prices for investment goods decrease more than the price of capital as compared to the reference case. Lastly, in the case of B7_Health scenario, the net trade balance is unchanged as both exports and imports are increasing from reduced production costs and increased overall household demand respectively.

With regards to crop yield benefits, the results indicate that their impacts in the overall economy are negligible but are significant for the agricultural sector as they represent almost 30% of the abatement expenditure of the sector and form a change in the productivity of the sector through the calculated TFP. The avoided healthcare expenditures have a negligible impact on the aggregate economy due to the relatively small magnitude in relation to the expenditure levels of the households.

Table 4: Decomposition analysis of macroeconomic impacts of B7 scenario on EU-28, 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

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

The impacts of the proposed policy differ significantly on a sectoral basis depending on the sector's contribution to air pollution and on the cost-efficiency of available measures for abatement of emissions of this sector. In this section we present a sectoral analysis of the impacts of the final proposal of the European Commission for both B7_All and B7 scenario (only abatement expenditures).

In Figure 1, the impacts on the sectorial production on the EU-28 level are presented. A group of sectors presents an increase in production for both B7_All and B7 scenarios as a result of the economic opportunity created by the demand for abatement products. Thereby sectors that according to the GEM-E3 abatement matrixes provide abatement products may increase their production despite the abatement efforts that they have to carry (e.g. Chemical products, Electricity supply). Electricity supply, for example, is used both as an abatement good for air pollution abatement techniques[11], and as an intermediate input for the production of other abatement goods such as products of the Chemical Industry. The Transport equipment sector also slightly increases production since there is no decrease in demand for intermediate goods from the Transport sector (the latter does not carry a significant abatement effort in the B7 scenario since most abatement potential has been exploited within the Reference scenario) but provides abetment products for the water transport sector that contributes to the abatement effort. The rest of the energy intensive sectors only marginally reduce production in the expenditure-only scenario (B7) despite the significant abatement costs and increased unit cost of energy they bear, since they also deliver intermediate and final goods for firms' and households' pollution control according to the GEM-E3 abatement matrixes. Overall production is turned marginally positive in the B7_All scenario for most sectors due to the increased demand for goods stemming from greater disposable incomes of the households that result mainly from avoided morbidity

[11] E.g. electrostatic precipitators for PM reduction (Brandley, 2005), non-thermal plasma technique for NO_x emission reduction (EPA, 1999), non-evaporative cooling system and Venturi scrubber techniques for NH_3 abatement (Handley et al, 2001)

and avoided health expenditure. On the other hand, the agricultural sector shows the highest decrease in both B7 and B7_All scenarios, in line with the abatement effort presented in Table 1. However, this decrease in production[12] is reduced by more than half when the crop yield benefits are taken into consideration in the B7_All scenario.

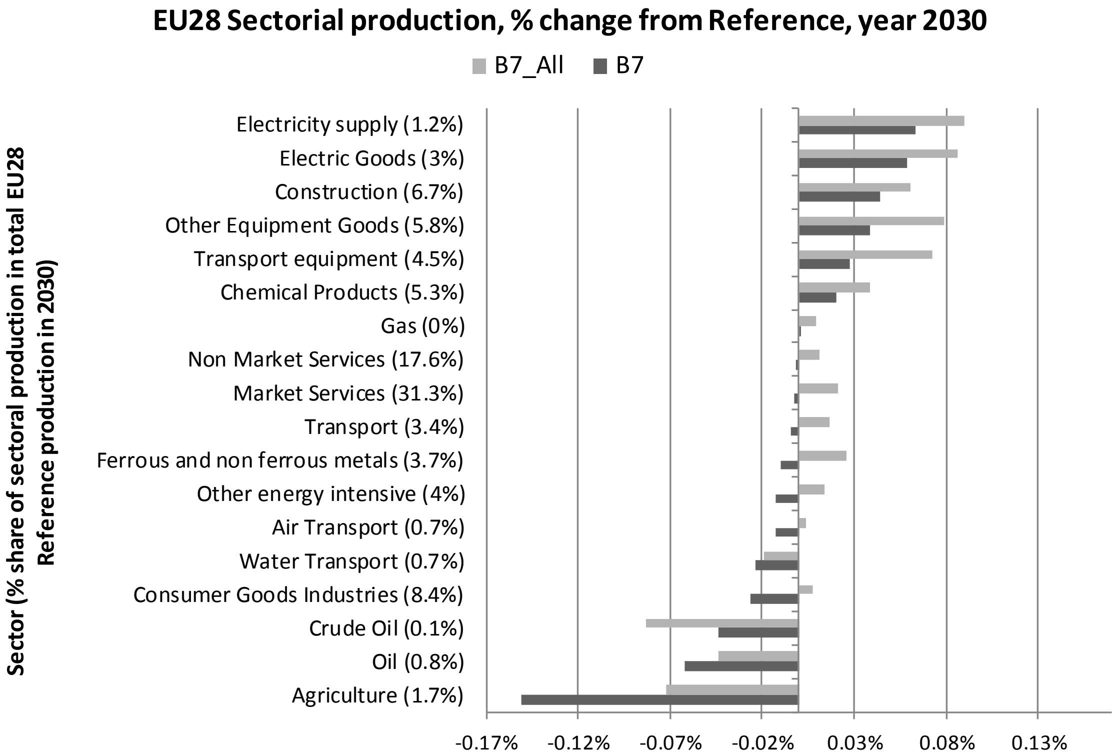

Figure 1: EU-28 Sectorial Production as a change from Reference case, year 2030 for scenarios B7-B7_All, GEM-E3 JRC

With regards to trade, the impact of the examined environmental policies on sectoral European imports and exports as a percentage change from the Reference case is presented in Figure 2 and Figure 3. It should be taken into consideration that intra-EU trade is not presented in order to depict the impacts of air pollution abatement policies 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.

Figure 2 presents an increase in imports of sectors undertaking a high abatement effort, like the agricultural sector, since their production cost increases due to the compliance expenditure. However, as mentioned above, the general equilibrium framework assumes a full free-market sector and no incorporation of cross-border tariff adjustments or equivalent has been implemented. The benefits from the increased crop yield lessen the negative impacts of the expenditure of the agricultural sector. The increase in imports of

[12] Note however that the negative impacts in the agricultural sector are likely to be 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)

sectors that also increase their domestic production is due to the increased demand for abatement products that can be also partially met by imported goods. On the other hand, significant 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 health benefits (only in B7_All scenario) but also due to the release of human capital from the abating sectors, which in turn becomes available for other sectors in order to substitute capital or labour.

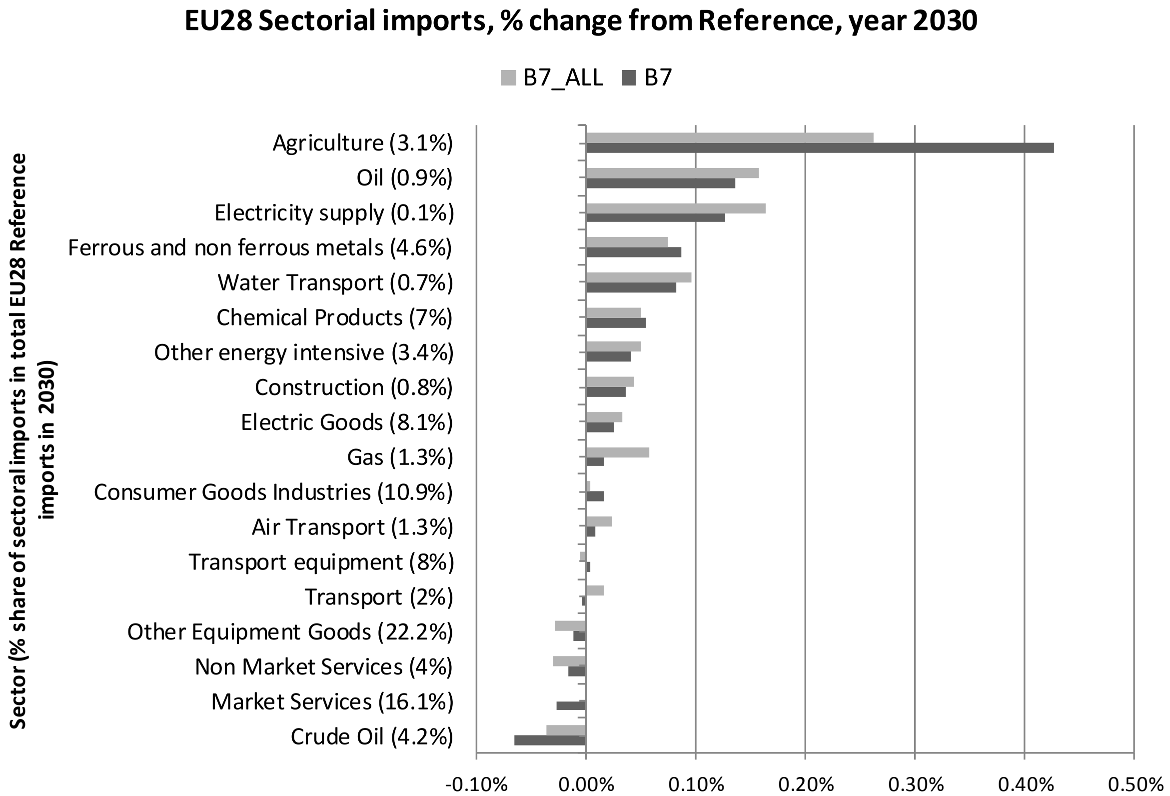

Figure 2: EU-28 Sectorial imports as a change from Reference case, year 2030 for scenarios B7-B7_All, GEM-E3 JRC

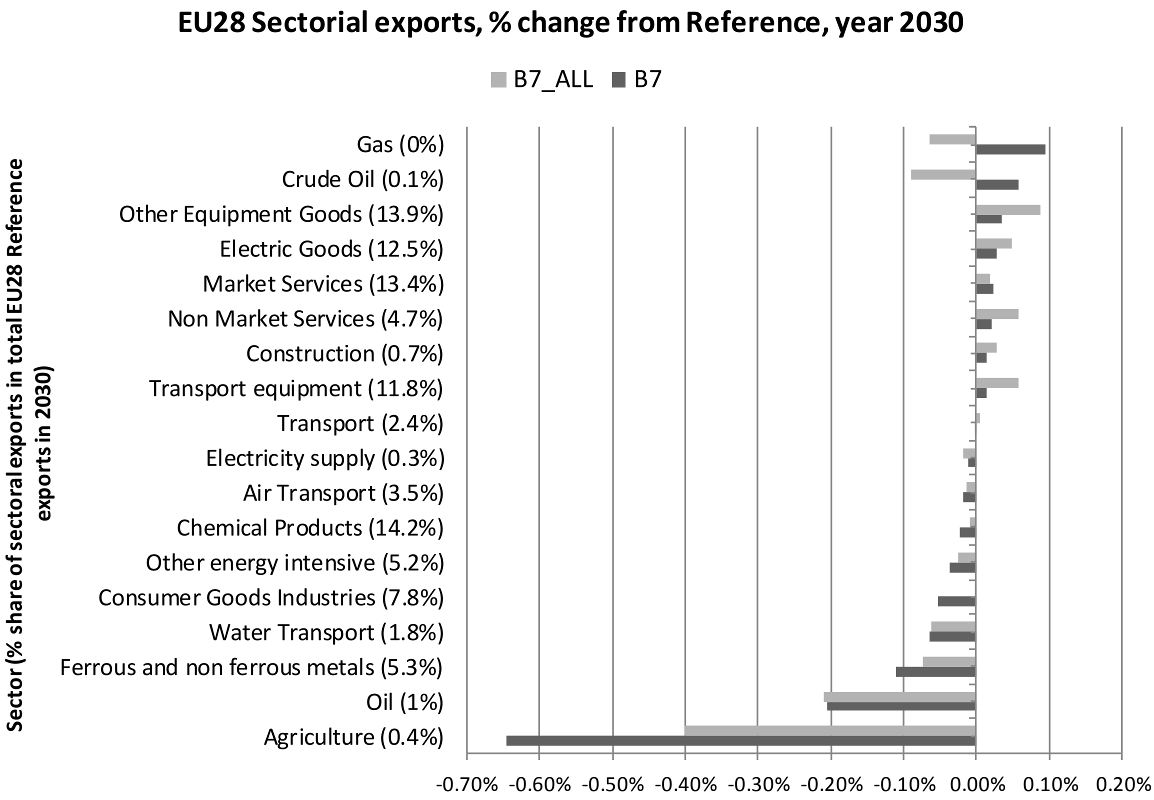

Figure 3: EU-28 Sectorial exports as a change from Reference case, year 2030 for scenarios B7-B7_All, GEM-E3 JRC

Changes 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. This finding is consistent with the EPA (2012) report which concludes that the net employment effects of pollution abatement policies have been small and not affecting the economy in a significant way. We find that the latter holds when the benefits from the examined policy have not been explicitly taken into consideration. A positive employment effect is found in the B7_All scenario (close to 100000 jobs equivalents) due to the increase of the available labour force resulting from health benefits of environmental policies (equal to 76000 equivalents in 2030[13]) but also due to the secondary positive effects of policies that lead to a net job creation of 24000 in 2030. In particular, the GEM-E3 sectors that provide abatement goods (e.g. Construction, Transport equipment and Other Equipment goods) are labour intensive and represent a significant share of EU employment; thus increased demand for these goods along with a lower unit cost of labour due to the higher labour availability result in an increase in employment.

[13] The 76000 job equivalents can be interpreted, among others, as a lower rate of absenteeism due to air pollution related illness.

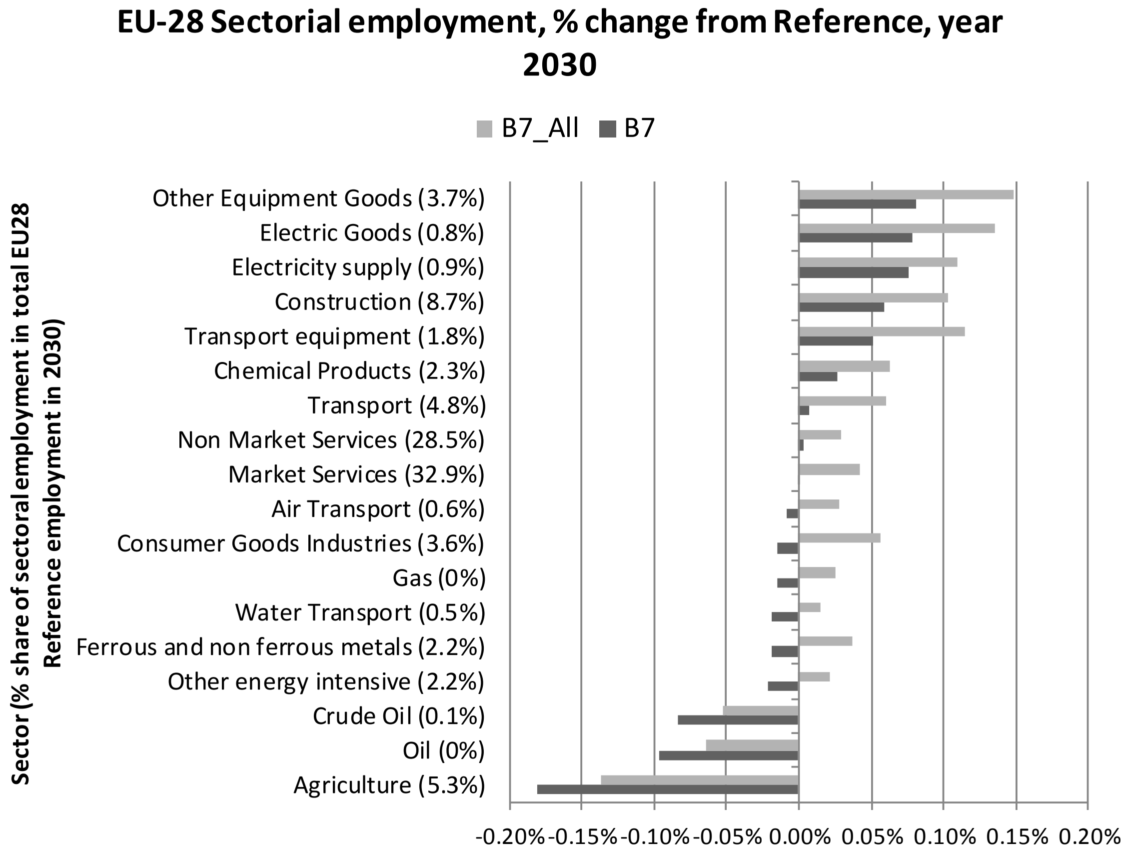

Figure4: EU-28 Sectorial Employment change from Reference case, year 2030 for scenarios B7-B7_All, GEM-E3 JRC

7 Conclusions and further research proposals

The GEM-E3 model has been used to quantify the socioeconomic impacts of the "The Clean Air Policy Package", proposed by the EC in December 2013. More particularly, we assess the main macroeconomic impacts of the proposed policies as well as impacts on sectoral production, demand, trade competitiveness and employment. This article presents the scenarios analysed in the corresponding Impact Assessment as well as the final compromise proposal by the EC. The soft-link and harmonization between GEM-E3 and the GAINS model allow for a consistent analysis of the air policy scenarios, while exploiting the best available modelling tools for the impact assessment.

The analysis with GEM-E3 model enables an assessment of both direct and indirect effects of the air pollution policies. We show that the expenditure on pollution abatement represents a cost for the abating sectors thus increasing production costs and leading to slightly reduced domestic demand and 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, we show that the expenditure in abatement technologies is also an economic opportunity for the sectors that produce these technologies. We find that this is an important driver of our results, although not explicitly taken into consideration in other similar previous analysis. In particular, according to the GEM-E3 abatement matrixes, abatement expenditures create additional demand for sectors like Transport Equipment, Electric goods, Electricity production and Construction and thus domestic production and imports of these products are increased.

Accordingly, we see a sectoral reallocation of jobs leading to neutral employment impacts, while if the health-related benefits are taken into consideration, employment levels increase. Through our decomposition analysis we demonstrate that the improved labour productivity from air quality improvements has positive macro-economic impacts on the European economy, almost dominating the costs of the policy. Also taking into consideration other benefits such as the reduced healthcare expenditure and increased crop yield, we see that the implementation of the 'Clean Air Policy Package' may be beneficial for the European economy.

The inclusion of the direct benefits of air pollution mitigation has an important effect on the impact assessment of the proposed policy both on an aggregate and on a sectoral level, thus providing a clearer insight to the policy-makers. In our analysis we assess the effects of reduced morbidity, healthcare costs and increased crop yield, however, further feedback mechanisms could be envisaged, such as impacts on the building stock and the water aquifer. Furthermore, the use of financial instruments to subsidise some of the pollution abatement measures (e.g. agro-environmental measures through the EU's Rural Development Programme) could deliver important policy insights on the distributional impacts.

In our analysis we have not examined the possible synergies or antagonistic effects of air pollution polices and climate change mitigation policies (beyond the EU 20-20-20 polices that are considered in the reference case), which may prove to 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. Moreover, a further field of analysis involves the assessment of possible trade benefits in case other regions of the world go forward with ambitious air pollution policies. By committing to improve air quality and combat climate change, Europe is developing a competitive industry of green technologies and a potential first-mover advantage could lead to further positive effects to the economy when other continents start to use these technologies. Lastly, our comparative-statics analysis focuses on the impacts of the implemented policies in the final year of the proposed target period, while a dynamic analysis could take into consideration the effects of chronic exposure and the cumulative effects of health benefits.

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Title: **Impact Assessment of European Clean Air policies in a CGE framework**

Authors: **Zoi Vrontisi, Jan Abrell, Frederik Neuwahl, Bert Saveyn, Fabian Wagner**

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Abstract

In March 2014 the UN World Health Organization (World Health Organization, 2014), released a study reporting that in 2012 one in eight of global deaths were a result of air pollution exposure. As part of a long-term effort, in late 2013, the European Commission (EC) adopted the "The Clean Air Policy Package", where it proposes new air pollution reduction objectives for the period up to 2030, as well as instruments to deliver those objectives. This paper explains in detail the modelling conducted with a Computable General Equilibrium model, GEM-E3, for the EC Impact Assessment of this recent EU policy proposal along with an additional analysis of the benefits deriving from the proposed policies. We show that the expenditure on pollution abatement represents a cost for the abating sectors but also that the expenditure in abatement technologies is an economic opportunity for the sectors that produce these technologies. Moreover, we find that the inclusion of benefits in our analysis, especially those related to health, can offset the resource costs and yield overall marginally positive macro-economic impacts on the European economy.

JEL Classifications: Q53, Q58, C68, H51

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