The role of agriculture in the European Commission strategy to reduce air pollution

Z. Klimont[1], F. Wagner[1], M. Amann[1], J. Cofala[1], W. Schöpp[1], Ch. Heyes[1], I. Bertok[1], and W. Asman[1]

Abstract

One of the main EU policy instruments, the Thematic Strategy announced the revision of the Directive on National Emissions Ceilings with new emission ceilings that should lead to the achievement of the agreed objectives with priority given to fine PM. This paper highlights the role of the agricultural sector in the cost-effective emission control strategies for the EU-27. To support the quantitative cost-effectiveness analysis, the GAINS integrated assessment model has been used. In the EU-27, agricultural activities are responsible for the majority of NH_3 emissions and about 4 % of PM2.5; in the future the relative contribution to PM emissions is expected to increase. Implementation of current emission control legislation is estimated to reduce emissions of most pollutants in the EU-27 by 40 - 60 % by 2020. For ammonia, however, emissions are estimated to decline by only 10 %, mainly as a consequence of the expected decline in cattle numbers; taking full account of the Nitrate Directive impact might result in a further 10 % reduction. Also the total control costs are much lower for agriculture than in several other sectors. Although the total potential for technical emission control measures is significantly lower for ammonia than for other pollutants, ammonia offers the largest scope for further emission reductions on top of the measures required by current legislation. In the optimal strategy, a significant reduction of ammonia is expected, which is associated with relatively large costs, representing about 20 % of total additional costs over the current legislation baseline. However, with respect to the total control costs, agriculture remains among the smaller sectors. The analysis performed shows that independent of the environmental objective (excluding an ozone-only case) the emission reductions in agriculture, primarily of NH_3, play an important role in attaining targets specified in the Thematic Strategy and represent about 20 to 40 % of the additional costs of the strategies analyzed. Only in the scenario where full implementation of the Nitrate Directive was assumed is the share of agriculture lower.

Keywords: agriculture, particulate matter, ammonia, National Emission Ceilings, European policy, modelling

Introduction and policy background

A number of studies have demonstrated consistent associations between the concentrations of fine particulate matter (PM) in the air and adverse effects on human health (respiratory symptoms, morbidity and mortality) for concentrations commonly encountered in Europe and North America, e.g., Dockery D. W. et al. 1993; Pope C. A. et al. 2002.

Airborne suspended particulate matter – in the form of primary particles (PM) – are emitted directly into the atmosphere by natural and/or anthropogenic processes, whereas secondary particles are predominantly man-made in origin and are formed in the atmosphere from the oxidation and subsequent reactions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and volatile organic compounds (VOC). The typical residence time of the fine fraction of particulate matter ranges between 10 and 100 hours, during which such aerosols are transported with the air mass over long distances. Thus, as with other transboundary pollutants, fine particles at a given site originate from emission sources in a large region, typically including sources in other countries.

Considering the transboundary nature of particulate matter (PM), the Commission of the European Union and the United Nations Economic Commission for Europe's Convention on Long-range Transboundary Air Pollution (UNECE/CLRTAP) are currently developing harmonized international response strategies for a cost-effective control of PM in Europe. While the CLRTAP aims at inclusion of PM-related analysis in the review of the Gothenburg Protocol (UNECE, 1999) in 2008, the European Commission Thematic Strategy on Air Pollution outlined the strategic approach towards cleaner air in Europe (CEC, 2005) and established environmental interim targets for the year 2020 (table 1) within the 'Clean Air for Europe' (CAFE) program (CEC, 2001). As one of the main policy instruments, the Thematic Strategy announced the revision of the Directive on National Emissions Ceilings (2001/81/EC) with new emission ceilings that should lead to the achievement of the agreed interim objectives with priority given to fine particulate matter.

---

[1] International Institute for Applied Systems Analysis, Laxenburg, Austria

Table 1:
Environmental targets of the EU Thematic Strategy

Effect	Unit of the indicator	Percentage improvement compared to the situation in 2000
Life years lost from particulate matter (YOLLs)	Years of life lost	47 %
Area of forest ecosystems where acid deposition exceeds the critical loads for acidification	km^2	74 %
Area of freshwater ecosystems where acid depotion exceeds the critical loads for acidification	km^2	39 %
Ecosystems area where nitrogen deposition exceeds the critical loads for eutrophication	km^2	43 %
Premature mortality from ozone	Number of cases	10 %
Area of forest ecosystems where ozone concentrations exceed the critical levels for ozone$^{1)}$	km^2	15 %

$^{1)}$ This effect has not been explicitly modelled in RAINS. The environmental improvements in the area of forest ecosystems exceeding ozone levels resulting from emission controls that are targeted at the other effect indicators have been determined in an ex-post analysis.

In 2006, the European Commission began the process to develop national ceilings for the emissions of the relevant air pollutants with close involvement of numerous stakeholders including national experts and industrial associations (Amann M. et al. 2006). As a starting point, the analysis developed baseline projections of emissions and air quality impacts to be expected from the envisaged evolution of anthropogenic activities taking into account the impacts of the present legislation on emission controls. Subsequently, a series of reports explored sets of cost-effective measures that achieve the environmental ambition levels of the Thematic Strategy. The reports analyzed potential emission ceilings that emerge from the environmental objectives established and studied the robustness of the identified emission reduction requirements against a range of uncertainties (Amann M. et al. 2007a).

This paper highlights the role of measures in the agricultural sector in the cost-effective emission control strategies, drawing on analyses presented in the NEC reports (Amann M. et al., 2007b) and outcomes of the study on integrated measures in agriculture (Klimont Z. et al. 2007).

Methods

To maximize the cost-effectiveness of emission control strategies, measures for reducing the various precursor emissions of particulate matter (primary and secondary) need to be balanced across all contributing economic sectors, including agriculture, in view of the contributions they make to the various environmental problems. To support the quantitative cost-effectiveness analysis, the GAINS (Greenhouse gas - Air pollution Interactions and Synergies) integrated assessment model has been used to allocate emission control measures across economic sectors.

The GAINS model, which has been developed at the International Institute for Applied Systems Analysis (IIASA), is an integrated assessment model that brings together information on the sources and impacts of air pollutant and greenhouse gas emissions and their interactions. GAINS is an extension of the earlier RAINS (Regional Air Pollution Information and Simulation) model, which addressed air pollution aspects only. GAINS brings together data on economic development, the structure, control potential and costs of emission sources, the formation and dispersion of pollutants in the atmosphere and an assessment of environmental impacts of pollution. GAINS addresses air pollution impacts on human health from fine particulate matter and ground-level ozone, vegetation damage caused by ground-level ozone, the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition to soils, in addition to the mitigation of greenhouse gas emissions. GAINS describes the interrelations between these multiple effects and the range of pollutants (SO_2, NO_x, PM, NMVOC, NH_3, CO_2, CH_4, N_2O, F-gases) that contribute to these effects at the European scale. A detailed description of the air pollution component of the GAINS model can be found in Schöpp W. et al. (1999) and http://www.iiasa.ac.at/rains/review.html; the model is also available in the Internet from http://www.iiasa.ac.at/rains.

Several emission sources contribute via various pathways to the concentrations of fine particulate matter in ambient air. While a certain fraction of fine particles found in the ambient air originates directly from the emissions of those substances (the “primary particles”), another part is formed through secondary processes in the atmosphere from precursor emissions, involving SO_2, NO_x, NMVOC and NH_3. Inter alia, agricultural activities contribute to primary emissions of particulate matter, e.g., livestock housing, arable farming, managing crops, energy use, burning of agricultural waste and unpaved roads. In addition, NH_3 released from agricultural activities constitute an important precursor to the formation of secondary aerosols.

GAINS allows the estimation of emissions from livestock housing, fertilizer application, energy use in agriculture (small stationary combustion and mobile sources) and, to some extent, from handling of crops. Size-specific PM emission factors were developed, drawing on the results of Takai H. et al. (1998), Louhelainen K. et al. (1987), Donham K. J. et al. (1986 and 1989), ICC &SRI (2000), and Heber A. J. et al. (1988). GAINS estimates country-specific emission rates per animal per year considering the length of the housing periods (for cattle and pigs). Details of the GAINS methodology for the assessment of particulate matter emissions and control costs from agriculture are documented in Klimont Z. et al. (2002). For ammonia the detailed methodology is presented in Klimont Z. and Brink C. (2004).

Historical activity data for agriculture originates from FAO (2006), IFA (2004), and is supplemented by national information collected from national experts. Forecasts up to 2020 have been developed for the review of the National Emission Ceilings Directive of the European Community and are documented in Amann M. et al. (2006 and 2007a).

An integrated assessment needs to link changes in the precursor emissions at the various sources to responses in impact-relevant air quality indicators at a receptor grid cell. Traditionally, this task is accomplished by comprehensive atmospheric chemistry and transport models, which simulate a complex range of chemical and physical reactions. The GAINS integrated assessment analysis relies on the detailed analyses conducted with the Unified EMEP Eulerian model (Simpson O. et al. 2003), and represents the responses in air quality towards changes in emissions as computed by the EMEP model through computationally efficient response surface functions. Such source-receptor relationships have been developed for changes in emissions of SO_2, NO_x, NH_3, VOC and PM2.5 from the 27 Member States of the EU, Croatia, Norway and Switzerland, and five sea areas, describing their impacts for the EU territory with the 50 km × 50 km grid resolution of the geographical projection of the EMEP model (see www.emep.int/grid/index.html).

Quantitative environmental objectives have been established by the European Commission in its Thematic Strategy on Air Pollution for four environmental indicators: Years of life lost (YOLL) from PM2.5 exposure, areas unprotected from eutrophication or acidification, premature deaths from ozone, or jointly on all indicators (see table 1). The optimization module of GAINS has then been used to find cost-optimal control strategies that meet the environmental objectives established in the Thematic Strategy.

Results and discussion

Agricultural activities in the EU-27 are responsible for typically 85 to 90 % of total emissions of ammonia, and they contribute on average about 4 % to primary PM2.5 emissions from anthropogenic sources. For individual countries, the shares of agriculture in PM2.5 vary from less than 1 % to nearly 10 %, due to structural differences in other sources (e.g., the use of solid fuels for home heating, etc.). Because emissions from other sources will decline in the future due to emission control legislation (e.g., tightened emission standards for mobile sources) and ongoing structural changes (e.g., phase-out of solid fuels), agricultural sources will gain in relative importance and will contribute on average up to 6.5 % in the current legislation baseline projection. Typically, about half of the agricultural emissions of PM2.5 originate from open burning of agricultural residue.

To assess the cost-effective scope for further emission reductions, it is necessary to analyze the impacts of the full implementation of current emission control legislation for all pollutants. Figure 1 compares the effects of current legislation with the scope for further technical emission control measures. Full implementation of current emission control legislation is estimated to reduce emissions of most pollutants in the EU-27 by 40 - 60 % by 2020. A notable exception, however, is ammonia where emissions are estimated to decline in the current legislation case by only 10 %, mainly as a consequence of the expected decline in cattle numbers and not due to more stringent emission legislation. While the baseline projection includes likely impacts of the IPPC Directive for farming, it does not take full account of the Nitrate Directive (ND). The latter was analyzed in Klimont Z. et al. (2007), who estimated that by 2020 an additional 10 % of ammonia emissions could be avoided by proper enforcement of the ND (figure 4, left chart).

Although the total potential for technical emission control measures is significantly lower for ammonia than for other pollutants, ammonia offers the largest scope for further emission reductions on top of the measures required by current legislation (figure 1). While for other pollutants more than half of the technical potential forms part of existing law, for ammonia current regulations involve less than one third of the possible measures.

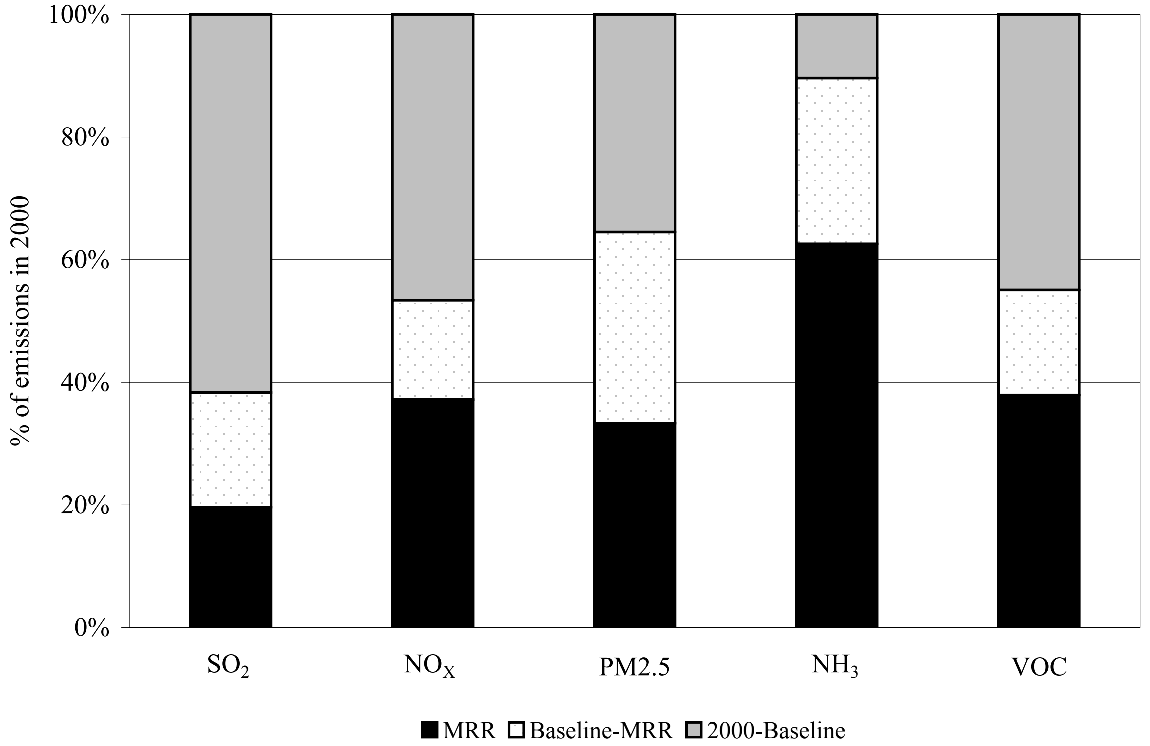

Figure 1:

Scope for further emission reductions in the baseline scenario in 2020, in relation to the emissions in the year 2000.The grey bars indicate emission reductions as a consequence of the full application of current emission control legislation and the white ranges display the potential for further emission reductions that can be achieved with currently available technical emission control measures. The black ranges indicate residual emissions that cannot be reduced with present day emission control technologies.

This paper presents two scenarios that have been explored in the course of the development of the NEC Directive. The first case is the NEC baseline scenario where national perspectives on development of the agricultural sector are considered together with impacts of national and European emission legislation as well as the mid-term review of the EU Common Agricultural Policy (CAP). Its development has been documented in the series of NEC reports, e.g., Amann M. et al. 2007a. Although the principal assumption in the baseline scenario is that the current legislation impacts are included, analysis performed by e.g., Onema O. et al. (2007) shows that stringent interpretation and enforcement of water directives (Nitrate and Water Framework Directives) would require more effective controls and possibly structural changes in agricultural production. Results of the above study were interpreted and implemented in GAINS (Klimont Z. et al. 2007) and this paper presents the potential impacts of such development in the scenario referred to as Baseline + ND (Nitrate directive).

Table 2 shows emissions and total control costs by pollutant for the baseline scenario as well as the optimal multi-effect strategy where TSAP targets (table 1) are met.

Table 2:

Emissions and total costs of the baseline scenario for EU27+Norway (Amann M. et al., 2007b)

	Emissions [Tg/year]			Total costs [billion €/year]		
Pollutant	2000	Baseline - 2020	Baseline - OPT	2000	Baseline - 2020	Baseline - OPT
SO_2	10.3	4.1	2.2	11.0	16.9	19.6
NO_X [1)]	12.5	7.2	5.1	9.8	47.8	51.4
NH_3	4.0	3.6	2.8	1.8	3.4	5.7
PM2.5	1.8	1.2	0.82	8.0	9.3	10.2
NMVOC	11.4	6.4	5.3	0.79	2.3	3.3

[1)] Total transport costs (excluding sulphur-related) included in the NO_x costs

As already shown in figure 1, the agricultural sector emissions do not decline significantly in the baseline and the total costs are far lower than for other pollutants; note that PM2.5 and NMVOC costs exclude the transport sector as all of those costs are associated with NO_x, representing the largest share. In the optimal strategy, significant reductions of ammonia are expected, which are associated with relatively large costs, representing about 20 % total additional costs over the baseline (compare also figure 2 and 3). However, with respect to the total control costs, agriculture remains among the smaller sectors.

Apart from calculating reduction costs of the optimal multi-effect strategy (Joint optimization – figure 2; Baseline – figure 3), we have also assessed the control costs for single effect scenarios (figure 2 and figure 3; Baseline-PM only). For all of the above scenarios the targets were as in table 1. Independent of the environmental objective (excluding the ozone-only case) the agricultural sector emission reductions, primarily of ammonia, play an important role and represent about 20 to 40 % of additional costs in the strategies analyzed. Only in the scenario where full implementation of the Nitrate Directive was assumed (figure 3; Baseline+ND) is the share of agriculture lower. This is, however, largely compensated for by the additional costs in the baseline, as the implementation of ND has been estimated to cost about 0.9 billion € (figure 4, right chart, see the difference in CLE-2020 value).

For the "Baseline+ND" optimal scenario the emission levels of the "Joint optimization" case were assumed as emission ceilings, but the underlying activity data and penetration of abatement measures take into account full implementation of the Nitrate Directive. The Nitrate Directive enforcement has been estimated to bring further reductions of ammonia emissions, about 300 kt NH_3 in the EU-27 baseline by 2020, at an estimated cost of 0.9 billion € (figure 4). The actual costs might be higher when accounting for revenue loss by the farmers who would not be allowed to expand their operations or would have to downscale them, specifically in nitrate vulnerable zones. In the optimal scenario, the overall level of emissions would remain about the same as in the baseline; the total costs to the agricultural sector would be smaller than in the baseline case (figure 4; right panel). This effect is associated with the distribution and level of ammonia emission reductions achieved in the baseline including ND regulation. More details about the implementation and results of this scenario are available from Klimont Z. et al. (2007) and Amann M. et al. (2007b).

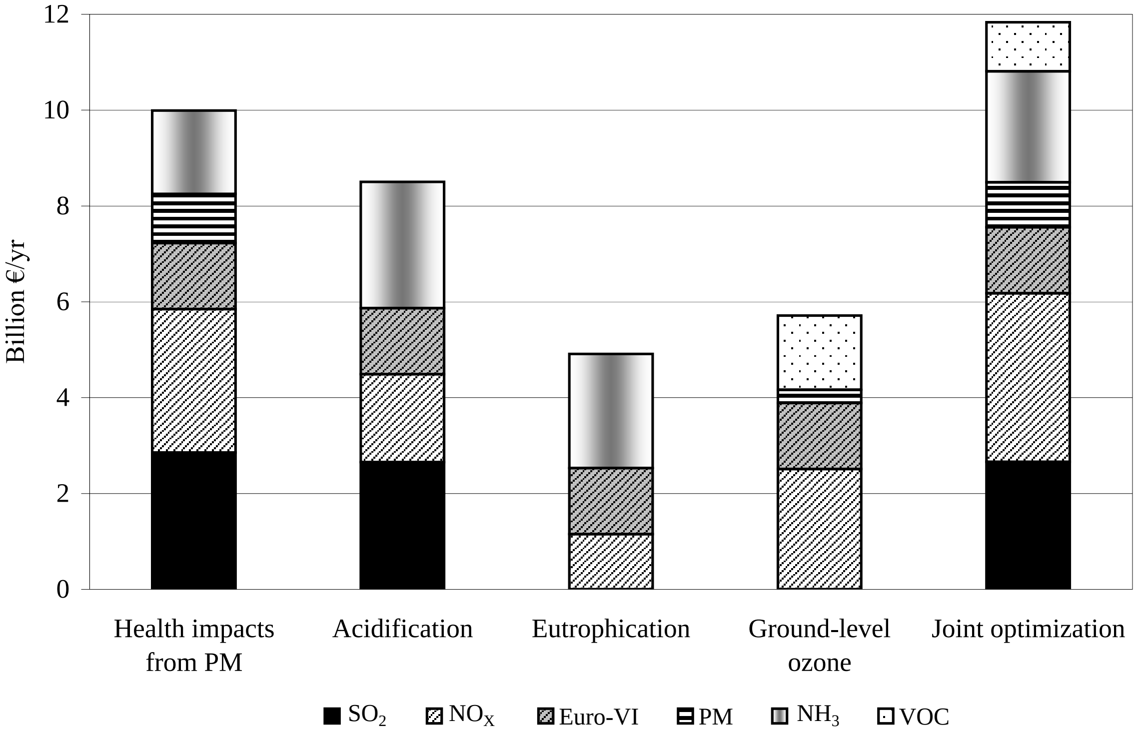

Figure 2:
Emission control costs by pollutant for achieving the four environmental objectives separately compared to the multi-effect (joint) optimization (Where more than one pollutant is reduced by a particular control measure, the allocation of costs by pollutant follows an arbitrary sequence; this may result in otherwise surprising associations between pollutants and impacts, e.g. the apparent influence of PM on ground-level ozone.)

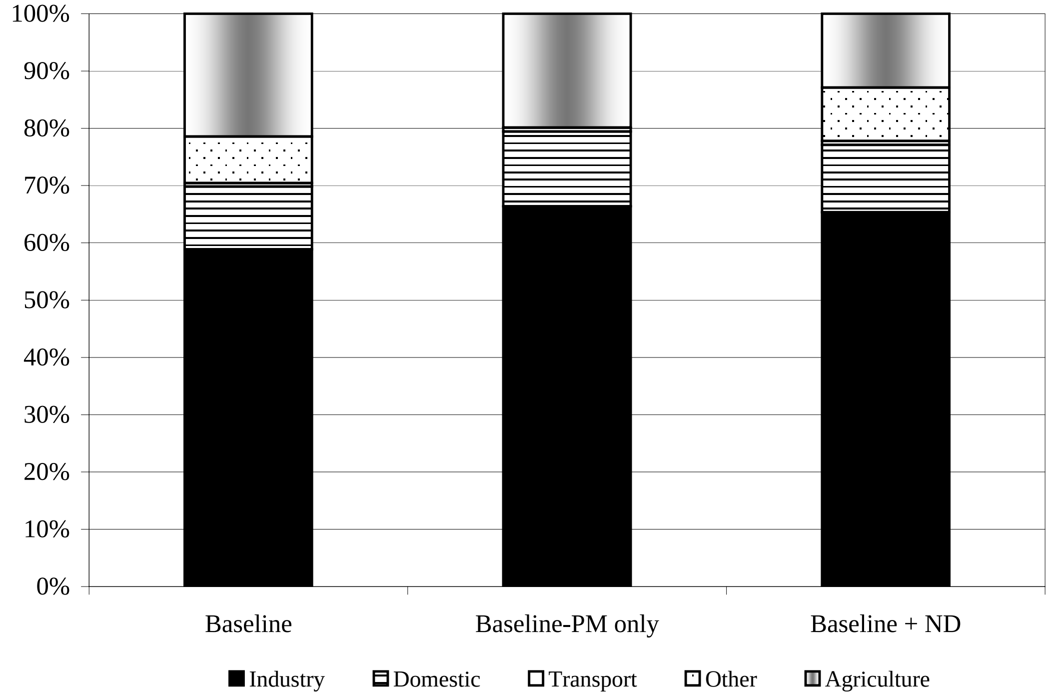

Figure 3:
Distribution of additional (over the current legislation) control costs between sectors for the two optimal multi-effect scenarios (Baseline and Baseline+ND) and the scenario where only the health impacts of PM2.5 are considered (Baseline-PM only).

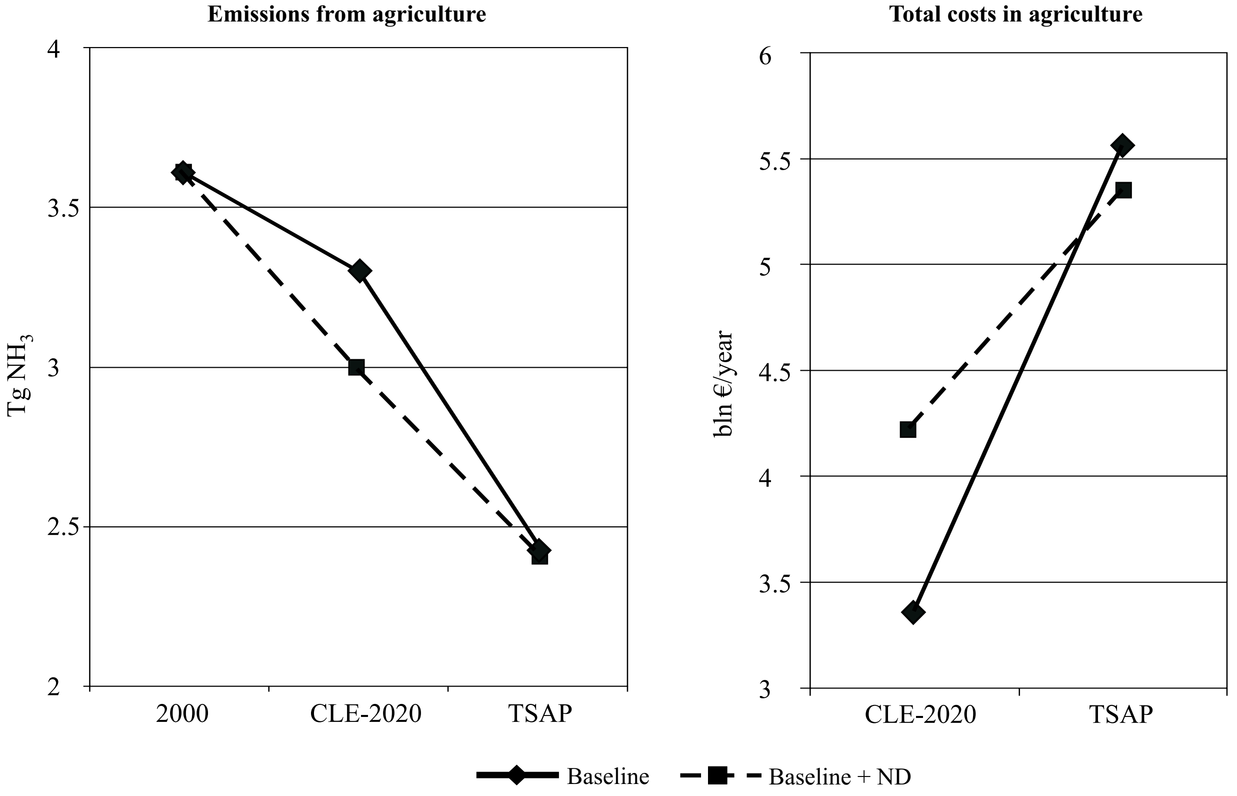

Figure 4:
Expected impact of the Nitrate Directive on agricultural emissions and costs for the year 2020 baseline and optimal scenario with TSAP targets (table 1).

Conclusions

Achieving the health and environmental targets specified in the EU Thematic Strategy will require significant further reductions of emissions of air pollutants in Europe. The analysis performed for the review of the NEC Directive indicates potential for cost-effective reductions of agricultural emissions, primarily ammonia, that contribute to the formation of secondary fine particulate matter and play an important role in excess deposition of nitrogen in sensitive areas. Although total European ammonia emissions are expected to decrease by 2020 by about 10 % compared to 2000, this decline is significantly lower than reductions for other pollutants, so that for secondary aerosols the importance of the contribution from the agricultural sector is expected to grow.

PM emissions from European agriculture are not expected to grow in the next decades. However, in the absence of specific control measures taken in the agricultural sector, its relative contribution to total PM will further increase, from about 4 to nearly 7 %. This is mainly a consequence of stringent emission controls being introduced in other sectors (e.g., stationary energy combustion, mobile sources). Only limited potential for further reductions of primary PM in agriculture has been identified, the main being an effective ban on open burning of agricultural residue that is responsible for about half of the total agricultural emissions of fine PM.

The analysis performed shows that independent of the environmental objective (excluding the ozone-only case) the emission reductions in agriculture, primarily of ammonia, play an important role in attaining targets specified in the Thematic Strategy and represent about 20 to 40 % of additional costs of the analyzed strategies. Only in the scenario where full implementation of the nitrate directive (ND) was assumed is the share of agriculture lower. This is, however, largely compensated for by the additional costs in the baseline associated with the implementation of ND.

Although the calculated emission reductions and additional costs for agriculture are significant, they have to be seen in the perspective of spending already committed by other sectors to control emissions of SO_2, NO_x, PM2.5 and NMVOC. Such comparison shows that the total costs to reduce emissions in agriculture in the analyzed strategies do not exceed 10 % of the total strategy price.

References

Amann M., Bertok I., Cabala R., Cofala J., Gyarfas F., Heyes C., Gyarfas F., Klimont Z., Schöpp W., Wagner F. (2005). A further emissions control scenario for the Clean Air For Europe (CAFE) CAFE Report #7. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austri

Amann M., Bertok I., Cofala J., Heyes C., Klimont Z., Posch M., Schöpp W., Wagner F. (2006). Baseline scenarios for the revision of the NEC Emission Ceilings Directive Part 1: Emission projections. NEC Scenario Analysis Report Nr. 1. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Amann M., Asman W., Bertok I., Cofala J., Heyes C., Klimont Z., Schöpp W., Wagner F. (2007a). Updated Baseline Projections for the Revision of the Emission Ceilings Directive of the European Union. NEC Scenario Analysis Report #4. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Amann M., Asman W., Bertok I., Cofala J., Heyes C., Klimont Z., Schöpp W., Wagner F. (2007b). Cost-effective Emission Reductions to meet the Environmental Targets of the Thematic Strategy on Air Pollution under Different Greenhouse Gas Constraints. NEC Scenario Analysis Report #5. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

CEC (2001). The Clean Air for Europe (Cafe) Programme: Towards a Thematic Strategy for Air Quality. Communication from the Commission. Commission of the European Communities, COM(2001)245 final, Brussels, Belgium

CEC (2005). Communication from the Commission to the Council and the European Parliament on a Thematic Strategy on Air Pollution. SEC(2005) 1132. Commission of the European Communities, Brussels, Belgium.

Dockery D. W., Pope C. A. III, Xu X., Spengler J. D., Ware J. H., Fay M. E., Ferris B. G. Jr., Speizer F. E. (1993). An Association between air pollution and mortality in six U.S. cities. New England J. of Medicine 329:2753-1759

Donham K. J., Scallon L. J., Popendorf W., Treuhaft M. W., Roberts R. C. (1986). Characterisation of dusts collected from swine confinement buildings. Am. J. of Ind. Med., 10:294-297

Donham K. J., Haglind P., Peterson Y., Rylander R., Belin L. (1989). Environmental and health studies of workers in Swedish swine buildings. Brit. J. Ind. Med. 46:31-7

FAO (2006) FAOSTAT: FAO Statistical Databases [on-line]. Italy, to be found on the United Nations Food and Agriculture Organization web site: http://apps.fao.org/

Heber A. J., Stroik M., Faubion J. M., Willard L. H. (1988). Size distribution and identification of aerial dust particles in swine finishing buildings. Transactions of the ASAE, 31(3):882-887

ICC &SRI (ICConsultants and Silsoe Research Institute) (2000) Atmospheric emissions of particulates from agriculture: a scoping study. Final report for the Ministry of Agriculture, Fisheries and Food (MAFF) Research and Development, London, UK, 97 p

IFA (2004). IFA Data Statistics; from 1973-1973/74 to 2002-2002/03. CD-ROM International Fertilizer Industry Association, Paris, November 2004

Klimont Z., Bertok I., Amann M., Cofala J., Heyes Ch., Gyarfas F. (2002). Modelling Particulate Emissions in Europe: A Framework to Estimate Reduction Potential and Control Costs. Interim Report IR-02-076, IIASA, Laxenburg, Austria, 169 p

Klimont Z., Brink C. (2004). Modelling of Emissions of Air Pollutants and Greenhouse Gases from Agricultural Sources in Europe. Interim

Report IR-04-048. International Institute for Applied Systems Analysis, Laxenburg, Austria, 69 p

Klimont Z., Asman W. A. H., Bertok I., Gyarfas F., Heyes C., Wagner F., Winiwarter W., Höglund-Isaksson L., Sandler R. (2007). Measures in Agriculture to Reduce Ammonia Emissions. Final Report under European Commission Service Contract No 070501/2006/433072/FRA/2C1. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Louhelainen K., Vilhunen P., Kangas J., Terho F.O. (1987). Dust exposure in piggeries. European J. of Resp. Diseases, 71(152):80-90

Oenema O., D. A., Oudendag H. P., Witzke G. J., Monteny G. L.,Velthof S., Pietrzak M., Pinto W., Britz E., Schwaiger J. W., Erisman W., de Vries J. J. M., van Grinsven M. Sutton (2007). Integrated measures in agriculture to reduce ammonia emissions. Final summary report. European Commission service contract 070501/2005/422822/MAR/C1. Alterra, Wageningen, the Netherlands.

Pope C. A., Burnett M. J. T. R., Calle E. E., Krewski E., Ito K., Thurston G. D. (2002). Lung cancer, cardiopulmonary mortality and long-term exposure to fine particulate air pollution. J. of the Amer. Med. Assoc. 287(9):1132-1141

Schöpp W., Amann M., Cofala J., Heyes Ch., Klimont Z. (1999). Integrated assessment of European air pollution emission control strategies. Env. Modelling & Soft. 14(1):1-9

Simpson D., Fagerli H., Jonson J. E., Tsyro S., Wind P., Tuovinen J.-P. (2003). Transboundary Acidification, Eutrophication and Ground Level Ozone in Europe. Part 1: Unified EMEP Model Description. EMEP Status Report 1/2003. EMEP Meteorological Synthesizing Centre - West, Norwegian Meteorological Institute, Oslo.

Takai H., Pedersen S., Johnsen J. O., Metz J. H. M., Groot Koerkamp P. W. G., Uenk G. H., Phillips V. R., Holden M. R., Sneath R. W., Short J. L., White R. P., Hartung J., Seedorf J., Schröder M., Linkert K. H., and Wathes C. M. (1998). Concentrations and emission of airborne dust in livestock buildings in Northern Europe. J. Agric. Engng. Res., 1(70):59-77.

UNECE (1999). Protocol to the 1979 convention on long-range transboundary air pollution to abate acidification, eutrophication and ground-level ozone. United Nations Economic Commission for Europe (UNECE), Geneva