CIAM 5/2011–November 4, 2011
Executive Body, twenty-ninth session, Geneva, 12 – 16 December 2011
Informal document No. 5

emep

Co-operative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe

Ammonia reductions and costs implied by the three ambition levels proposed in the Draft Annex IX to the Gothenburg protocol

Fabian Wagner[1], Wilfried Winiwarter[1], Zbigniew Klimont[1],
Markus Amann[1], Mark Sutton[2]

[1]Centre for Integrated Assessment Modelling (CIAM)
International Institute for Applied Systems Analysis (IIASA)

[2]Centre for Ecology and Hydrology, Edinburgh Research Station

CIAM report 5/2011 – Version 1.1

Centre for Integrated Assessment Modelling (CIAM)
International Institute for Applied Systems Analysis (IIASA)

International Institute for Applied Systems Analysis
Schlossplatz 1 • A-2361 Laxenburg • Austria
Telephone: (+43 2236) 807 • Fax: (+43 2236) 807 533
E-mail: publications@iiasa.ac.at • Internet: www.iiasa.ac.at

Executive Summary

The Convention on Long-range Transboundary Air Pollution has started negotiations on the revision of its Gothenburg multi-pollutant/multi-effect protocol. Among other topics, emissions of ammonia have been subject of specific scrutiny. To inform negotiations, the Task Force on Reactive Nitrogen (TFRN) has compiled a list of potential ammonia emission control measures that could form an annex to the protocol. This "Draft Annex IX" defines three ambition levels, ranging from the most stringent level "A" to the least ambitious level "C".

This report presents estimates of the ammonia emission reductions and costs of the measures that are included in the Draft Annex IX prepared for the revision of the Gothenburg Protocol. The estimates for the three different ambition levels have been derived with the GAINS model, and it is assumed that these measures are equally implemented for all countries, even if they are not cost-effective. The specific assumptions in translating the specifications provided in the Draft Annex IX into GAINS input data are described in this paper.

Costs for implementing the ambition levels vary across countries. Taking into account recent information on ammonia emission control costs that has been compiled by the Task Force on Reactive Nitrogen it is found that overall costs of the proposed measures are generally low. Per unit of emissions abated, costs are typically only up to 1 € per kg NH3-N abated with a few outliers which, however, stay below 5 € per kg NH3-N abated. Total abatement costs are modest, for the most ambitious scenario A they amount to 8/1000 of 1% of the GDP in 2020. In relative terms (e.g., expressed as percentage of GDP) costs are higher in the non-EU countries than in the EU-27.

It is found that the specific measures, if uniformly implemented in all countries, would be less cost-effective than the (country-specific) least-cost set of measures that are derived from the GAINS optimization, e.g., for the MID and LOW cases in CIAM 4/2011 report, where the model can choose from a wider set of options (Figure A).

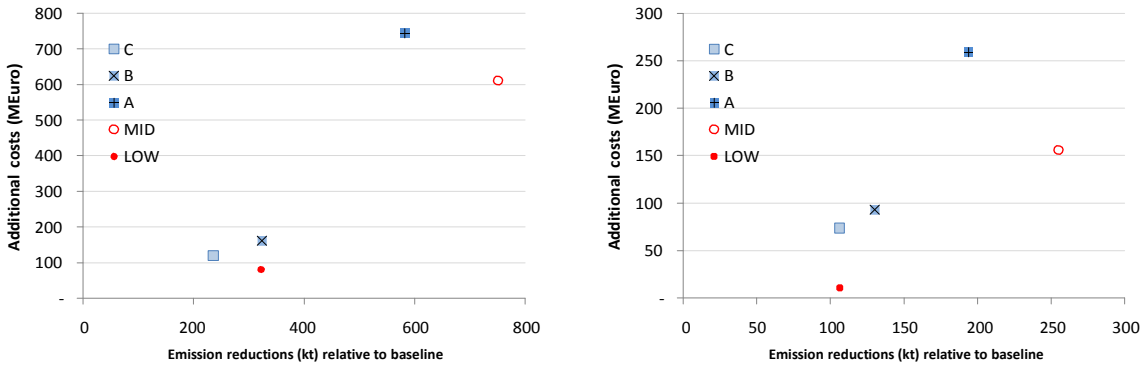

Figure A: Cost-effectiveness of the scenarios A, B and C in comparison to the MID and LOW scenarios described in the CIAM 4/2011 report. Left: EU27, right: non-EU countries.

Table of Contents

Acknowledgements

This work was financially supported by the EMEP trust funds and the LIFE financial instrument of the European Community (EC4MACS LIFE06 ENV/AT/PREP/06). The contribution of the Task Force on Reactive Nitrogen to this work has been supported by the UK Department for Environment Food and Rural Affairs

1 Introduction

The Convention on Long-range Transboundary Air Pollution has started negotiations on the revision of its Gothenburg multi-pollutant/multi-effect protocol. Among other topics, emissions of ammonia have been subject of specific scrutiny. To inform negotiations, the Task Force on Reactive Nitrogen (TFRN) has compiled informationrequired to update recommendations to reduce ammonia emissions[1].

The "Draft Annex IX on measures for the control of emissions of ammonia from agricultural sources"(ECE/EB.AIR/WG.5/2011/3)[2]was prepared by the TFRN for the revision of the Gothenburg protocol. This document, which aims to revise the current annex to the Gothenburg protocol, will in the following be referred to as "Draft Annex IX". It defines three "ambition levels", which refer to a stringent (level "A"), a moderate (level "B") and a less ambitious policy approach (level "C") regarding ammonia abatement. At this stage of preparing an agreement, countries are expected to decide for themselves which ambition level they would find necessary (and attractive) to achieve given environmental targets. In order to arrive at a well-founded decision, not only the extent of abatement needs to be known, but also the expected costs. Therefore, the chairs of the TFRN have requested for an assessment of the costs of the three ambition levels with the GAINS.

The EMEP Centre for Integrated Assessment Modelling has responded to this request and (a) developed methodologies for translating the Draft Annex IX measures into measures that are considered in the GAINS model, and (b) identified cost-effective combinations of measures that reflect the requirements at the individual emission stages in animal production.

The objective of this report is three-fold. First, it documents the approach taken by CIAM to translate the Draft Annex IX measures into specific measures in the GAINS model. As the proposed measures reflect only in part measures that are considered in GAINS, some modifications were required. Second, the report presents estimated technology costs for implementing the three ambition levels. These costs are expressed in absolute terms, and in units that can be compared across countries. Finally, the results are compared to the ammonia emission reductions of the 'MID' scenario presented in the recent CIAM 4/21011 report to the Working Group on Strategies and Review meeting in September 2011 (Amann et al. 2011). There, however, ammonia emission reductions are to be seen in the much wider context of various environmental targets set and reductions of other pollutants.

This report is organized as follows. Section 2describes the general methodology to implement different ambition levels of NH_3 policies as emission control scenarios in the GAINS model. The underlying data and characteristics (unit costs, emission factors, etc.) are consistent with those used in (Amann et al. 2011). Emission projections focus on the year 2020. Section 3discusses resulting emissions and costs, and puts them into context of the CIAM 4/2011 report. Conclusions are drawn in Section 4.

[1] see http://www.clrtap-tfrn.org

[2] available athttp://www.unece.org/fileadmin/DAM/env/documents/2011/eb/wg5/WGSR48/ECE.EB.AIR.WG.5.2011.3.E.pdf

2 *Methodology*

The GAINS model distinguishes the following animal categories: dairy cows, other cattle, pigs, poultry, sheep/goats, and other animals. These categories can be subject to control measures, and these control measures can be applied at different stages of production/emissions (feeding, housing, manure storage, manure application). Combinations of animal categories and applicable control measures in GAINS are presented in Table 2.1.GAINS groups these measures into packages, for which the GAINS optimization identifies the least-cost sets that achieve environmental constraints.

Table 2.1. Emission control options for ammonia in agriculture, as currently implemented in GAINS

	FEED	HOUSING		STORAGE	APPLICATION		TOTAL NUMBER OF OPTIONS
Animal category	Low nitrogen feed	Low emission housing	Air purification	Covered storage	Low ammonia application of manure	Low emission application of urea	including combinations
	LNF	SA	BF	CS*	LNA*	SUB_U	
Dairy cows	x	x		x	x		18
Other cattle		x		x	x		9
Pigs	x	x	x	x	x		31
laying hens	x	x	x	x	x		20
Other poultry)**	x	x	x	x	x		21
Sheep					x		2
Mineral fertilizer						x	1
Total # of measures including this option	45	18	30	32	58	1	102

*) Both options CS and LNA differentiate between a low and high efficiency option

**) Includes also poultry manure incineration

However, not all control measures can be applied under all circumstances. Restrictions apply typically to small farms. Furthermore, premature scrapping of investment-intensive measures emission control technologies are excluded from consideration, even if at a certain point in time other measures would emerge as more cost-effective.

To consider such restrictions in a systematic interpretation of the Draft Annex IX, the following three step approach was taken:

1) Define a maximum application rate[3] for each single-stage measures for each animal type and manure system. These maximum application rates are consistent with the data used in the CIAM 4/2011 analysis (Amann et al. 2011). Applicabilities may be different for different measures, and

[3] In the following we use the term *applicability* to mean the maximum application rate. Occasionally we also use the expression *maximum applicability*.

they may vary across countries. This variation reflects specific conditions, e.g., that only farms above a certain threshold size can apply certain measures. For instance, if an animal category does not occur in a country, the maximum application rate is set to zero. For some countries and some animal categories, the maximum application rate is already reached in the baseline so that the measure cannot be implemented to any further extent. However, combinations with measures at a different stage into packages may still be feasible to reduce emissions from a given animal category.

2) Use these maximum application rates to define animal- and measure-specific implementation rates for three scenarios. The definition of the maximum may also consider the turnover rate of long-lasting equipment. For example, in the most ambitious scenario A, for housing adaptation (cattle under liquid systems) it is assumed that 10% of what is considered maximally possible could be implemented in practice until 2020. For a country like The Netherlands, the maximum number for which housing could be adapted is considered close to 90% of all cattle, so in scenario A we assume housing adaptation for 9% of all cattle. Implementation rates may vary for the three ambition levels (details will be discussed in Section 2.1).
3) Optimize to identify cost-effective combinations of measures that meet the constraints imposed in Step 2, which are technically possible and are cost-effective.

As a result, we obtain a cost-effective mix of measures that represent an interpretation of the ambition levels of Draft Annex IX. It will be useful to compare these ambition levels with a scenario from (Amann et al. 2011) with the understanding that the NH_3 reductions described there are the result of a different procedure.

Maximum applicabilities may vary significantly across countries. Their values are available in the GAINS online model,[4] and are been listed in Klimont and Winiwarter (2011). As we discuss in the context of covered storage (CS) below, applicabilities to some extent also reflect current national policies. In some cases their values can seem unintuitive, especially for competing technologies. For example, the measures CS_low and CS_high are mutually exclusive alternatives, and it is intuitive that the less demanding and less costly CS_low can be applied more widely. However, in a country like Denmark CS_high is used already widely under current policies, so that the additional potential for CS_low is smaller than the overall potential for CS_high (including baseline application rate). Thus, interpreting maximum application rates and defining implementation rates for the three levels requires that national circumstances are taken into account thoughtfully.

2.1 Measures

In this section, we describe briefly how the ambition levels of Draft Annex IX are interpreted and translated into application rates of measures. As mentioned above, the maximum application rate plays a central role in this interpretation.

2.1.1 Low nitrogen feed (LNF)

For estimating the application limits for low nitrogen feed we assume that small farms (less than 15 livestock units (LSU)) are either not suitable for LNF or that this measure cannot be enforced. Hence, we assume that LNF can only be applied to medium and large scale farms (> 15 LSU) so that the maximum application rate reflects the share of animals living on these large to medium size farms. With the

[4] http://gains.iiasa.ac.at

following definition of implementation levels for the three scenarios we ensure that the actual implementation rates of measures remain below the maximum application rates.

Level "A": LNF is applied to all animals applicable (with applicabilities as defined by (Klimont and Winiwarter 2011), i.e., excluding farms < 15 LSU)

Level "B":LNF only on farms larger than the thresholds presented in Table 2.2 We assume that other limits in applicability are distributed uniformly, also regarding solid or liquid manure systems, for farms above the size of 15 LSU, so that we just need to determine the fraction of animals on large farms (thresholds below) vs. those on medium sized farms (less than the threshold but larger than 15 LSU), and multiply applicability with this factor.

Level "C": same as for Level "B"

Table 2.2 Lower limits on farm sizes (LSUs) that are used to assign measures in ambition levels "B" and "C". Note some differences to those presented in Draft Annex IX, as EUROSTAT[5] statistics only allow differentiation between 50/100 or 500 LSU (limits of 200 and 400 cannot be translated one-to-one into EUROSTAT statistics)

	cattle	pigs	Poultry
Level "B"	50	100*	500**
Level "C"	50	500**	500**

*) It is not straightforward to translate the Draft Annex IX threshold of 200 into the EUROSTAT statistics

**) Of the easily available limit used in EUROSTAT this is closest to the Draft Annex IX threshold of 400

2.1.2 Housing adaptations (SA)

Housing adaptations (in GAINS, the acronym of the previous term *stable adaptation SA* is used) are meant to be applied to new housings only ("Table 1" in Draft Annex IX). With less than 10 years to go until 2020 and a natural rate of capital stock turnover, we assume that SA can be applied to 10% of housing only, or less at lower ambition levels. Thus, we obtain rather small additional implementation rates. As we observe rather small additional costs for SA compared to standard housing, these costs are ignored in GAINS. Given the minor potential for implementing SA, the resulting error in overall costs from neglecting these costs is likely to be very small.

Here and in some of the following cases, the extent of implementation of a measure in the GAINS model is used to mimic a given efficiency of a measure as suggested by the Draft Annex IX draft. While in reality a number of different strategies exist to reduce emissions, GAINS limits itself to the abatement option SA, for which country-specific abatement efficiencies and costs for each animal class are defined. Differentiation between ambition levels (in reality, different techniques that may be associated with different costs) can only be modelled in GAINS by varying the implementation rate for the respective ambition level.

[5] Relevant (EUROSTAT 2011) statistical data are found in table: *ef_ls_ovlsureg* – "Livestock: Number of

farms and heads by livestock units (LSU) of farm and region"

The currently projected implementation levels ("baseline") are difficult to map and compare at the very detailed level. Notably, measures defined in GAINS for pigs do not achieve the 60% reductions of NH_3 emissions from pigs, which are deemed achievable in the Draft Annex IX. On the other hand, GAINS sees larger abatement potential for most of the other targets. In order to capture the suggestions of Draft Annex IX as closely as possible, implementation rates as presented in Table 2.3have been used. These implementation rates imply that the GAINS measures over-achieve the targets for poultry, so that rather low implementation rates are required: a maximum of 10% of applicability due to the slow turnover of buildings. Temperature dependence (as suggested by Draft Annex IX for pig housing) has not been considered, as GAINS emission factors established in cooperation with country experts should cover this effect of local climate at least partly.

Table 2.3 Implementation rates (as percentage of maximum applicability) for housing measures ("SA")

	cattle	pigs	poultry (layers)	poultry (broilers)
Level "A":	10%	10%	9%	3%
Level "B":	10%	6%	7%	3%
Level "C":	10%	4%	4%	3%

As implementation factors are fairly low and SA measures are generally among the most expensive, the reservations mentioned above do not affect overall results significantly.

2.1.3 Covered storage (CS)

We assume new storage measures to be included in new housing, as in GAINS this is an integral part of this measure. Thus, we may underestimate the potential from separate covered storage, especially those to be built in the EU27 in response to the nitrates directive. Unfortunately, it was difficult to obtain reliable estimates in the timeframe given for the task. Also, the implementation of CS on new storage needs to be seen as a baseline activity (legally binding and performed for other reasons than air quality). Therefore, we decided not to consider CS for the present task of ambition level calculations.

As a consequence, measures implemented in GAINS refer to existing storages only, which is consistent with the cost estimates described in Klimont and Winiwarter (2011). Measures for existing storage are required only for ambition level "A". The stringency of the measure described in Draft Annex IX corresponds to the average of the GAINS options "CS_low" and "CS_high" (60% reduction). Therefore, in case "A" we apply both measures equally, with the exceptions discussed below.

To determine the implementation rate for CS for ambition level "A", the following rules have been used. First, we determine the maximum application rate for CS_low, which is typically higher than the potential for CS_high. Then, we use half that potential to implement CS_low and the other half to implement CS_high. If the potential for CS_high is higher than that of CS_low we do the same, i.e., we use up half the potential for CS_high and CS_low each.

The only exception to this rule is when the potential for CS_high is more than twice the potential for

CS_low: this reflects that CS_high is widely used in the baseline, which leaves little potential for CS_low (see discussion before Section 2.1). In this case, we implement all potential for CS_low first, and then

use as much CS_high so that the total of CS_low and CS_high is equal to the maximum application rate of CS_high. For example, suppose the applicability for CS_high is 90% and for CS_low it is 10%. Then ambition level A is interpreted to mean 10% CS_low and 80% CS_high.

2.1.4 Low-emission application of manure (LNA)

GAINS offers two options, LNA_low and LNA_high (Klimont and Winiwarter, 2011). These have been adapted to arrive at the efficiency suggested in Draft Annex IX.

LNA_high tends to be more cost-effective than LNA_low, and our translation into implementation rates gives preference to cost-effective solutions. In the context of LNA the ambition levels are specific to farm sizes: "C" only applies to large farms, "B" applies uniformly to large and medium farms (but not to the small farms (< 15 LSU) which we exclude generally), and "A" applies to large and medium size farms, with stricter measures for large farms, above the thresholds listed in Table 2.2, based on the Draft Annex IX.

Level "B": In many countries there are strong technical limitations to the implementation of LNA_high, due to geomorphological and soil conditions, while LNA_low could be implemented at a much wider scale. Therefore, it is useful to keep these two elements separate. In order to achieve the required emission reductions, we implement 37.5% of the maximum applicability of LNA_high, and for the remaining activity (difference between LNA_high and LNA_low) we implement 75% as LNA_low. After this procedure there may still be potential remaining. As the aim of the exercise is to mimic system behaviour by introducing these parameters, this should not imply that measures are taken only for part of the area.

Level "C" is similar to level "B", but refers only to large farms. As for LNF, large farms are defined as those where certain thresholds are exceeded in LSU numbers: cattle (50) pigs (100) and poultry (500), somewhat different to the Draft Annex IX (50 LSU / 200 LSU / 40,000 animals, respectively), but matching the underlying Eurostat data. The fraction of large-farm animals in total (except <15 LSU) farm animals in a country is multiplied to the level "B" values.

Level "A" uses all reductions of level "B", and requires stricter measures to be taken on large farms (same definition as for level "C"). These stricter measures require further reductions from "B" of the same quantity as "C" needs from the baseline. Therefore, implementation of LNA_low and LNA_high in level "A" can be calculated as the sum of implementation rates in levels "B" and "C". In addition, the LNA_low implementation rate needs to be kept below its applicability.

2.1.5 Low emission application of urea (SUB)

Actual implementation is assumed as a share of applicability:

Level "A": maximum applicability, i.e., for most countries for 90% of total activity (some countries claim this measure to be applicable to a somewhat lower rate extent)
Level "B": 60% of applicability
Level "C": 40% of applicability

2.1.6 Other measures

GAINS considers a few more measures (e.g., treatment of exhaust air of animal houses (GAINS acronym BF)[6], and the incineration of poultry manure (PM_INC)), which however are not referred to in the Draft Annex IX.

2.2 Limitations

These measures typically apply to different stages of manure handling, and can therefore be considered rather independent of each other. As indicated above, the GAINS model does not model measures implemented at the individual farm level, but rather describes implementation rates for the whole sector. The implementation rate alone does not specify whether two measures are implemented on the same or on different farms. For example, in a scenario with 20% SA, 20% LNA and 20% LNF for 20% of animals all three measures are implemented, or that in total 60% are subject to one of the measures. These two examples may result in different total emissions. In a scenario with 40% SA, 40% LNA and 40% LNF the implementation rates add to more than 100%, which means that at least some (20%) of the animals are subject to more than one control. Both cases are represented in GAINS by combined measures.

There are, however, a few limitations to this combined measures approach:

> "High" and "low" efficiencies (for "CS" and for "LNA") cannot be handled separately in combination with other measures (with each other, or with "LNF" and "SA", respectively).Including these options would vastly increase the number of options in the model, which would jeopardize its overall balance and transparency. Thus, the "combined" removal efficiency may not fully reflect the situation as understood in Draft Annex IX. Draft Annex IX considers the combined system by specifying the package of measures that cover the chain of nitrogen flow in the farming system, as a basis to avoid potential leakage at another emission stage compensating part of the benefit. This is emphasized by the list of 5 priority measures describe by the TFRN (ECE.EB.AIR.WG.5.2011.16.e., paragraph 16) [7]
>
> The option "incineration of poultry manure" (PM_INC) cannot be used in combination with other measures. This blocks further measures to be implemented according to Draft Annex IX in countries where "incineration" is an issue (UK, Ireland, Netherlands), leading to potential underestimation of achievable reductions. However, consequences on overall results are likely to be small, as this applies to only one sector ("other poultry") in very few countries that already apply considerable abatement measures.

Several abatement options refer to the size of animal husbandry operations. We use a EUROSTAT dataset (see Table 2.3) to derive animal numbers by farm size category. This dataset is not available for all UNECE countries, but limited to EU27 plus Norway. For other countries we have used expert estimates on farm sizes. For instance, for Switzerland we assumed the same size structure as for Austria, for the Balkan countries of South-Eastern Europe we use the structure of Bulgarian farms, and for Russia and Belarus the same farm structure as in Lithuania have been assumed.

[6]This is already included in animal housing for poultry and pigs. It is considered to be an effective, albeit rather expensive measure.
[7]The Guidance Document describes that combinations must be implemented.

GAINS uses an optimization approach to identify least-cost solutions that meet the requirements of the levels A, B and C. However, other combinations of measures may exist that also meet these levels although at higher costs.

3 Results

This section presents estimates of costs and emissions for implementing the three levels of ammonia abatement provided in the Draft Annex IX.

3.1 Emissions

Figure 1and Figure 2 present estimates of NH_3 emissions in 2020 by country (for Russia, only the European part is included), for the different "ambition levels". Figure 1uses absolute numbers, Figure 2 presents emissions relative to the baseline so that the differences can also be discerned for smaller countries. For comparison, the emission level of the "MID" policy scenario as described in CIAM 4/2011 report (Amann et al. 2011) is displayed. For Turkey, Iceland and Malta, limited information for optimization is available, such that results are identical to the baseline.

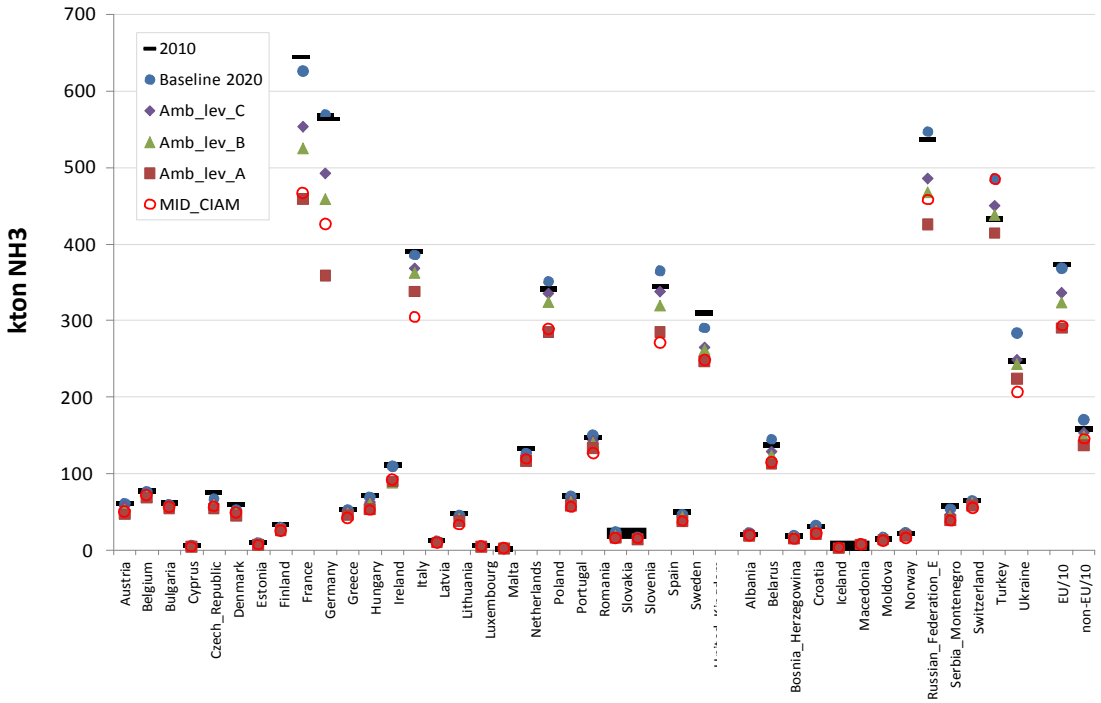

Figure 1NH_3 emissions of 2020 (data in Table 3.1) [NB that total emissions for EU and non-EU have been divided by 10 so that they fit on the same scale]

Figure 1 indicates lower NH_3 emissions for higher ambition levels, for all countries. In total, the measures implied in the Draft Annex IX would result in approximately 20% lower NH_3 emissions compared to the baseline, both for EU countries and for non-EU countries. While the moderate ambition (level B) would be sufficient for non-EU countries to arrive close to the "MID"

scenario level, for EU countries the more ambitious level A would be needed.

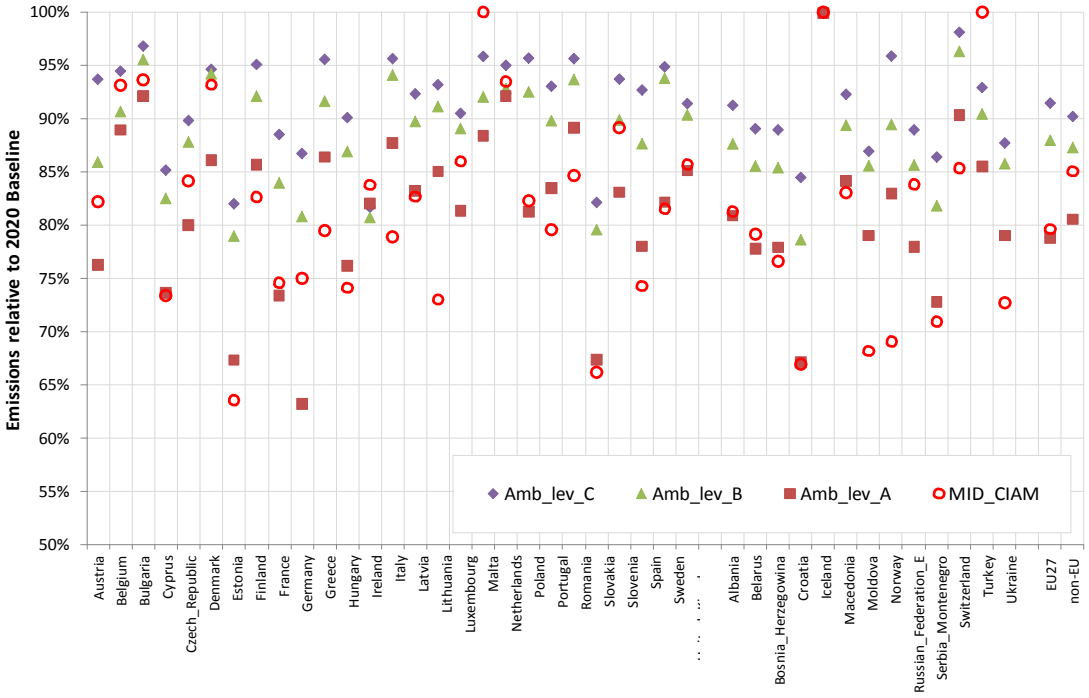

Figure 2NH_3 emissions relative to the baseline scenario

However, larger differences occur for some countries (Figure 2).As only little additional measures are available in countries that have already invested considerably in abatement, even ambition level A will not be sufficient to achieve the environmental objectives of the MID scenario in areas with high NH_3emission densities.

Table 3.1 NH3 emissions (kt) for the baseline, the three ambition levels and the MID scenario described in the CIAM 4/2011 report.

	Baseline					
	2010	2020	C	B	A	MID
Austria	60.6	61.4	57.5	52.7	46.8	50.5
Belgium	76.8	77.1	72.8	69.8	68.5	71.8
Bulgaria	61.6	59.8	57.9	57.1	55.1	56.0
Cyprus	6.0	5.8	5.0	4.8	4.3	4.3
CzechRepublic	75.4	67.4	60.5	59.2	53.9	56.8
Denmark	59.2	52.5	49.7	49.4	45.2	48.9
Estonia	10.4	10.2	8.4	8.1	6.9	6.5
Finland	33.1	30.4	28.9	28.0	26.1	25.1
France	645.3	625.9	553.7	525.3	459.2	467.0
Germany	567.5	568.2	492.6	459.1	359.1	426.4
Greece	53.4	52.8	50.4	48.3	45.6	41.9
Hungary	71.6	70.0	63.0	60.8	53.3	51.9
Ireland	111.7	109.4	89.3	88.3	89.8	91.7
Italy	389.8	385.5	368.5	362.6	338.1	304.1
Latvia	12.9	12.1	11.1	10.8	10.0	10.0
Lithuania	47.5	45.0	41.9	41.0	38.3	32.9
Luxembourg	5.9	5.6	5.0	5.0	4.5	4.8
Malta	2.5	2.3	2.2	2.1	2.0	2.3
Netherlands	132.4	127.1	120.7	117.9	117.0	118.8
Poland	342.0	351.0	335.7	324.6	285.2	288.8
Portugal	70.7	70.3	65.4	63.1	58.7	55.9
Romania	147.9	149.9	143.3	140.3	133.5	126.9
Slovakia	26.3	23.7	19.4	18.8	16.0	15.7
Slovenia	18.4	16.9	15.8	15.2	14.0	15.1
Spain	344.6	364.9	338.1	319.8	284.6	271.1
Sweden	50.6	46.3	43.9	43.4	38.0	37.7
United Kingdom	309.8	290.2	265.2	262.1	247.0	248.6
Albania	20.5	23.3	21.3	20.4	18.9	19.0
Belarus	137.6	144.9	129.0	123.9	112.7	114.7
BosniaHerzegovina	18.4	19.1	17.0	16.3	14.9	14.7
Croatia	31.0	31.9	27.0	25.1	21.4	21.4
Iceland	2.8	2.9	2.9	2.9	2.9	2.9
Macedonia	8.9	8.9	8.2	8.0	7.5	7.4
Moldova	15.0	17.3	15.0	14.8	13.7	11.8
Norway	21.8	22.4	21.5	20.0	18.6	15.5
Russia	536.8	546.5	485.9	467.9	426.0	457.9
Serbia-Montenegro	57.7	54.3	46.9	44.4	39.5	38.6
Switzerland	64.1	64.5	63.3	62.1	58.2	55.0
Turkey	432.3	484.8	450.3	438.3	414.4	484.8
Ukraine	247.4	283.8	248.9	243.4	224.2	206.4
EU27	**3733.6**	**3681.6**	**3365.9**	**3237.7**	**2900.5**	**2931.2**
Non-EU	**1594.2**	**1704.8**	**1537.0**	**1487.6**	**1372.9**	**1450.0**

3.2 Costs

Total costs for range between 295 mln€/yr for level C, 412 mln€/yr for level B, and 1273 mln€/yr for level A. .Figure 3present costs by as the share of GDP in 2020.

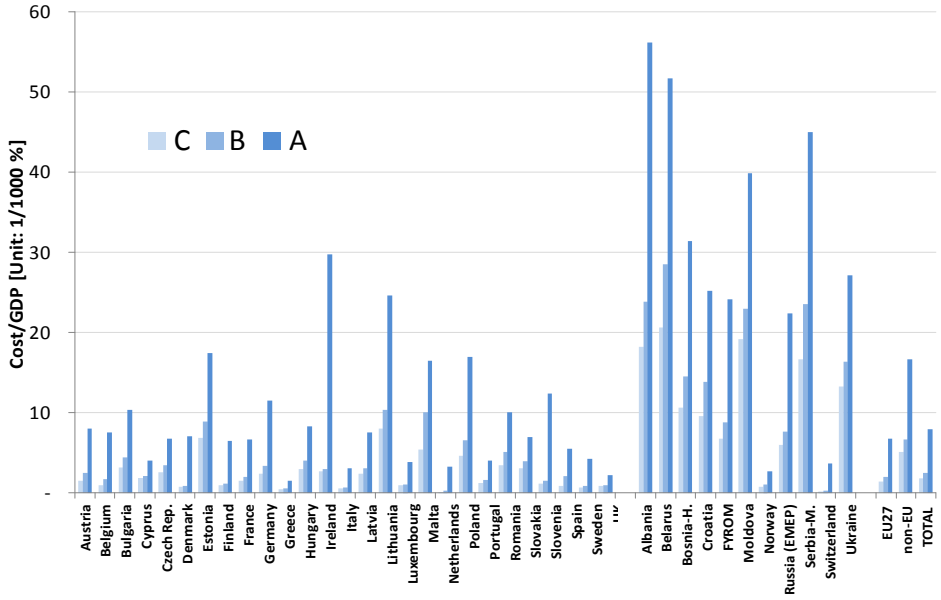

Figure 3 Emission control costs for the three ambition levels, expressed as share of GDP_{2020} for comparability.

Costs per unit of ammonia reduced (Figure 4) amount to a few € per kg NH_3-N abated, which is significantly less than earlier estimates. While, in general, more ambitious targets involve higher costs. In some cases, costs of the least ambitious level C exceed costs of level B. This is caused by the requirement of all levels to implement low emission housing for dairy cattle. This measure is less cost effective than many other measures. In case B, these more cost-effective measures reduce a larger share of emissions than in case C, and thereby read to lower average costs in a country.

Table 3.2 NH_3 emission control cost above baseline for the options A. B and C (portfolios of measures that could be included in an Annex of a revised Gothenburg protocol) described in the text, in absolute figures [mln€/yr] and in relation to the GDP in 2020 (1.0 = 1/100.000 of GDP)

	C		B		A	
	mln Euro/yr	share of GDP (1%/1000)	mln Euro/yr	share of GDP (1%/1000)	mln Euro/yr	share of GDP (1%/1000)
Austria	4.8	1.6	7.7	2.5	24.9	8.0
Belgium	3.8	1.0	6.8	1.7	29.3	7.5
Bulgaria	1.1	3.1	1.5	4.5	3.6	10.3
Cyprus	0.4	1.8	0.5	2.0	0.9	4.1
Czech Rep.	3.9	2.6	5.4	3.5	10.5	6.8
Denmark	1.9	0.8	2.1	0.8	17.5	7.1
Estonia	1.1	6.8	1.4	9.0	2.7	17.5
Finland	1.9	0.9	2.4	1.2	13.0	6.5
France	32.1	1.5	44.5	2.1	143.2	6.7
Germany	66.4	2.4	91.5	3.4	313.9	11.5
Greece	1.2	0.4	1.8	0.6	4.4	1.5
Hungary	3.4	2.9	4.7	4.1	9.6	8.4
Ireland	5.9	2.6	6.6	3.0	66.1	29.8
Italy	8.7	0.5	11.1	0.7	51.8	3.1
Latvia	0.4	2.4	0.5	3.1	1.3	7.6
Lithuania	2.4	8.1	3.1	10.3	7.5	24.6
Luxembourg	0.4	0.9	0.5	1.1	1.8	3.9
Malta	0.4	5.4	0.7	10.1	1.1	16.5
Netherlands	0.4	0.1	2.1	0.3	20.8	3.3
Poland	18.7	4.6	26.8	6.6	69.2	17.0
Portugal	2.1	1.2	3.0	1.7	7.2	4.0
Romania	4.7	3.5	7.0	5.2	13.6	10.1
Slovakia	2.3	3.1	2.9	4.0	5.2	7.0
Slovenia	0.5	1.1	0.7	1.5	5.5	12.4
Spain	10.5	0.8	27.5	2.1	70.9	5.5
Sweden	2.5	0.7	3.4	0.9	16.3	4.3
UK	19.4	0.8	22.9	1.0	52.1	2.2
Belarus	8.7	20.7	12.1	28.5	21.9	51.8
Bosnia-H.	1.6	10.7	2.2	14.5	4.8	31.5
Croatia	4.5	9.6	6.5	13.8	11.8	25.2
FYROM	0.6	6.7	0.7	8.8	2.0	24.2
Moldova	0.8	19.2	1.0	23.0	1.7	39.9
Norway	2.4	0.7	3.6	1.1	8.9	2.7
Russia (EMEP)	50.0	6.0	64.2	7.7	186.6	22.4
Serbia-M.	6.6	16.7	9.3	23.6	17.8	45.0
Switzerland	0.7	0.2	1.2	0.3	14.9	3.7
Ukraine	15.6	13.2	19.4	16.4	32.1	27.2
non-EU	93.6	5.1	122.7	6.7	308.8	16.7
TOTAL	294.7	1.8	411.7	2.6	1,272.9	8.0

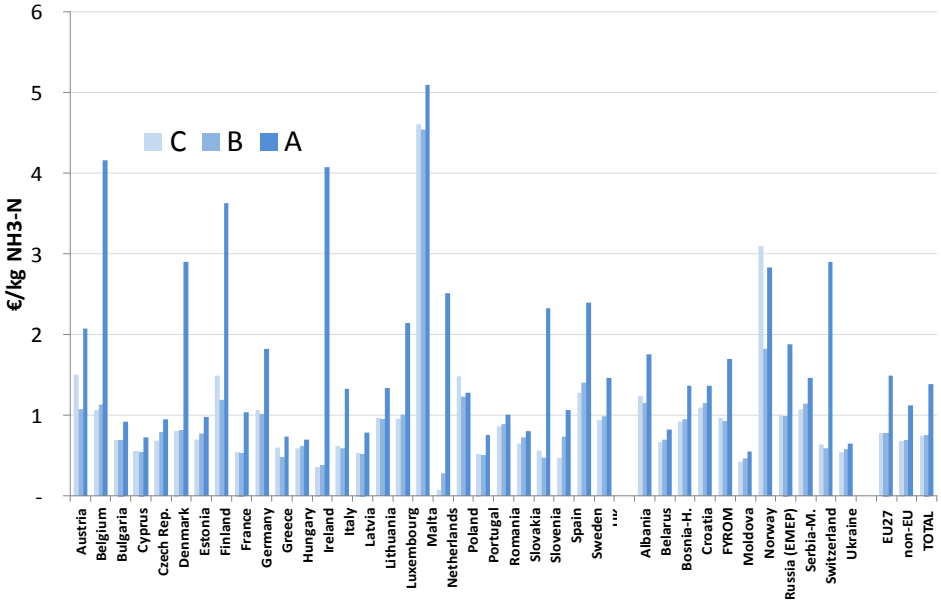

Figure 4 Emission control cost per kg of N reduced.

On a sectoral basis, Draft Annex IX would lead to largest emission reductions for dairy cattle and pigs in the EU countries, and for chicken farms in the non-EU countries. Low emission application of urea offers considerable emission reduction potential throughout Europe (Figure 5).

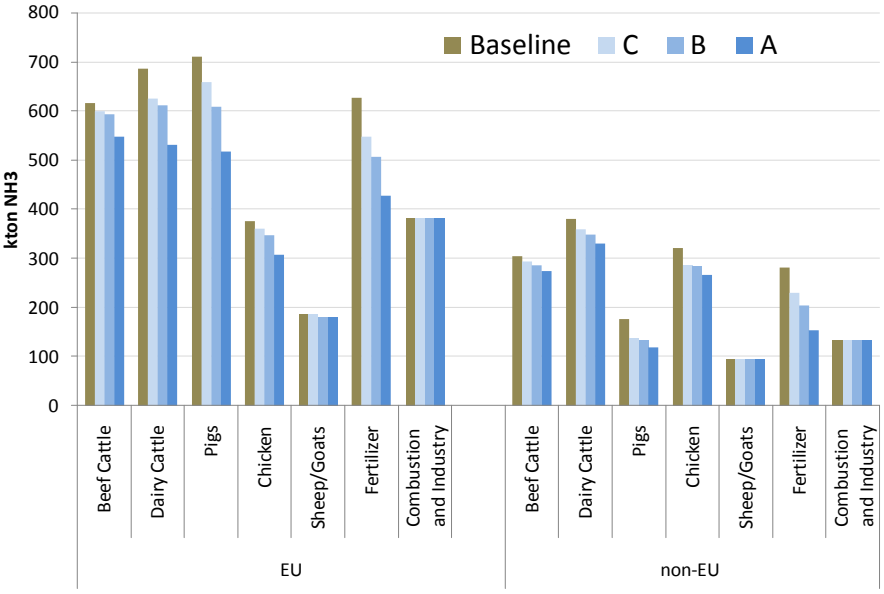

Figure 5 Emissions by source sector for different ambition levels

In terms of costs, there are some 'low hanging fruits' in some sectors, while costs for other sectors can be significant (Figure 6).For chicken around half the additional cost (32 mln€) in the EU between B and A emerge from the CS requirement in Germany, another 10 mln€ in France and 7mln€ in Italy. Similarly, the extra 250 mln€ for cattle arise from the CS requirement in Germany (+80 mln€), France (+54 mln€), Italy (+20 mln€), Spain (+14 mln€) and the other countries. For dairy cows the CS requirement imposes extra costs for Germany of 95 mln€, while for e.g. France (+26 mln€) the relative shares are lower.

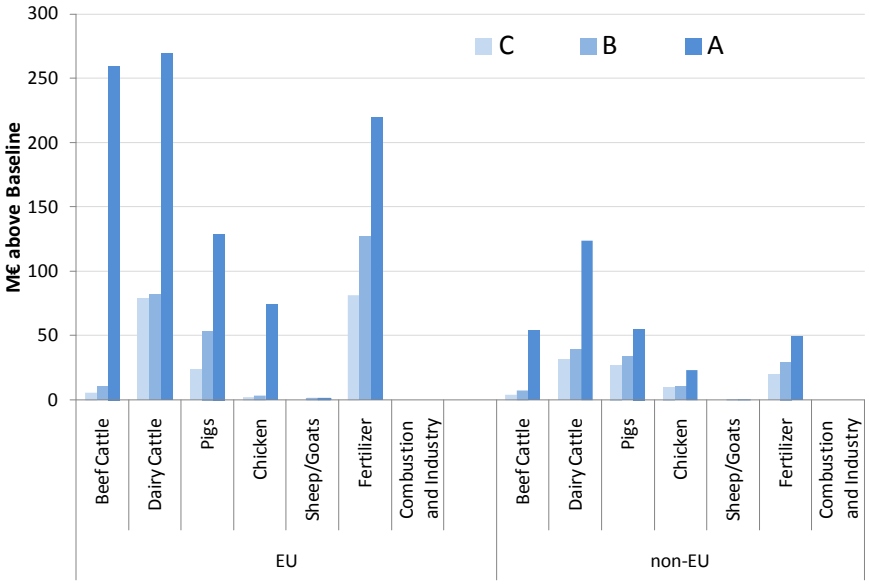

Figure 6 Abatement costs by source sectors for different ambition levels

Low-ambition measures of most sectors have highest cost efficiency (often less than 1 €/kg NH_3-N abated), and do not exceed 5 €/kg NH_3-N abated even for ambition level A (Figure 7).

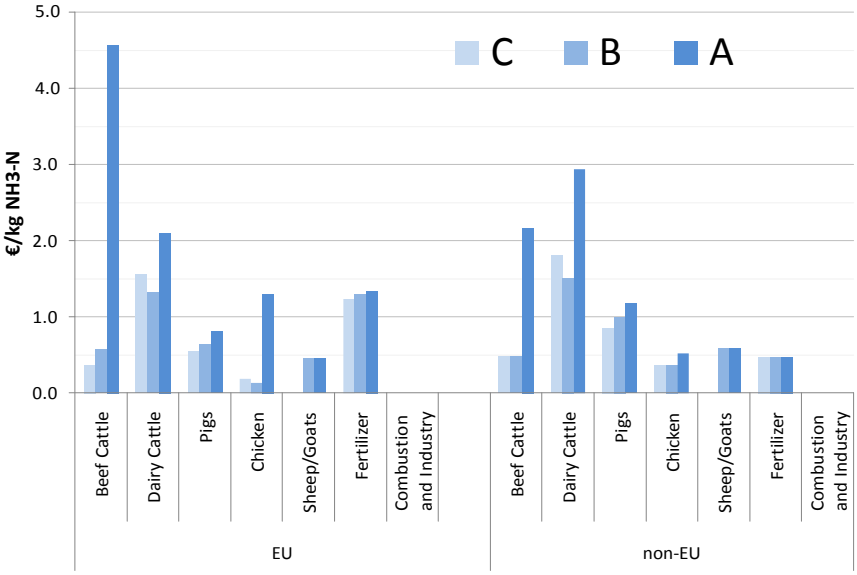

Figure 7 Cost efficiency of abatement measures for source sectors

While it is difficult to precisely mimic the measures of Draft Annex IX options in GAINS, results show clearly plausible costs for many cases. Even if on the level of individual countries there are some outliers which require explanation, on a more aggregated level the outcomes are explainable and costs match those of the input input information (Klimont and Winiwarter, 2011). We may conclude that the overall result, costs of a few € per kg NH_3-N abated, and higher costs for higher ambition levels, remains a stable result.

Finally, Figure 8 compares the cost-effectiveness of the scenarios presented here with the MID and LOW scenarios described in the CIAM 4/2011 report. Recall that the latter scenarios were obtained by minimizing the cost for achieving a variety of environmental targets, while levels A, B and C in the Draft Annex IX require equal measures for all countries, even if they are not the most cost-effective measures.

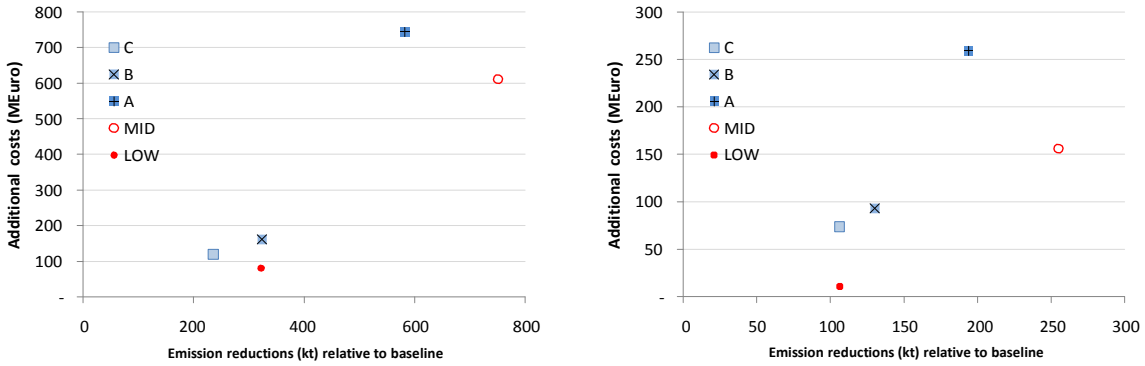

Figure 8 Cost-effectiveness of the scenarios A, B and C in comparison to the MID and LOW scenarios described in the CIAM 4/2011 report. Left: EU27, right: non-EU countries.

Consequently, for example, emission reductions in the MID scenario are achieved in a more cost-effective way than in the prescribed scenario A. For example, both for EU27 and for non-EU countries separately, the MID scenario achieves lower emissions at lower costs than scenario A. For EU27 the MID scenario reduces approximately 170 $ktNH_3$ (+29%) more than scenario A, while emission control costs are approximately 150 million Euro lower (-18%). For non-EU countries as a whole the extra reduction is 60 $ktNH_3$ (+31%) while costs are 105 million Euro lower (-40%).

Similarly, the LOW scenario is more cost-effective than the technology driven scenarios B and C. Interestingly, the LOW scenario reaches comparable emission reductions as the B scenario in EU27, while for non-EU countries the LOW scenario implies emission reductions that are only comparable to those achieved in the C scenario.

4 Conclusions

This report presents estimates of the ammonia emission reductions and costs of the measures suggested in the Draft Annex IX prepared for the revision of the Gothenburg Protocol. The estimates for three different ambition levels have been derived with the GAINS model, and the specific assumptions in translating the specifications provided in the Draft Annex IX into GAINS input data are described in the paper.

Costs for implementing the ambition levels vary across countries. Taking into account recent information on ammonia emission control costs that has been compiled by the Task Force on Reactive Nitrogen, it is found that overall costs of the proposed measures are generally low. Per unit of emissions abated, costs are typically only up to 1 € per kg NH3-N abated with a few outliers which, however, stay below 5 € per kg NH3-N abated. Total abatement costs are modest, for the most ambitious scenario A they amount to 8/1000 of 1% of the GDP in 2020. In relative terms (e.g., expressed as percentage of GDP) costs are higher in the non-EU countries than in the EU-27.

It is found that these measures, if uniformly implemented in all countries, would be less cost-effective than the (country-specific) least-cost set of measures that are derived from the GAINS optimization, e.g., for the MID and LOW cases in CIAM 4/2011 report.

5 References

Amann M, Bertok I, Borken-Kleefeld J, et al. (2011) An Updated Set of Scenarios of Cost-effective Emission Reductions for the Revision of the Gothenburg Protocol - Background paper for the 49th Session of the Working Group on Strategies and Review, Geneva, September 12-15, 2011. Centre for Integrated Assessment Modelling (CIAM), International Institute for Applied Systems Analysis, Laxenburg, Austria

EUROSTAT (2011) Statistics database. http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed 5 Sep 2011

Klimont Z, Winiwarter W (2011) Integrated Ammonia Abatement - Modelling of emission control potentials and costs in GAINS. International Institute for Applied Systems Analysis (IIASA), IR-11-027, Laxenburg, Austria