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Costs of Ammonia Abatement and the Climate Co-Benefits

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Foreword

Ammonia emissions represent a key emerging challenge for European environmental and agricultural policies. Ammonia contributes to several environmental problems, including threats to human health through the formation of fine particulate matter (PM) in the atmosphere and threats to biodiversity through nitrogen deposition to sensitive ecosystems. It causes both nitrogen saturation and soil acidification, with losses of key plant species. At the same time, ammonia contributes to greenhouse gas emissions through indirect contributions to nitrous oxide and to water pollution, where deposited nitrogen causes eutrophication of both freshwater and coastal ecosystems.

If these problems were not enough, ammonia emissions also represent a huge loss of nitrogen from farming systems. Ammonia losses can account for as much as 50 % of the added nitrogen when spreading animal manure or urea fertilizer. The result is substantial economic loss for farmers, while also wasting the energy used to produce fertilizers in the first place. As 1–2 % of total world energy goes to the manufacture of ammonia-based fertilizers, this is far from trivial.

In this context, the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) has put substantial effort to reaching agreements that reduce ammonia emissions. This includes new emission ceilings in the Gothenburg Protocol, which was recently revised in 2012, and complements actions in the European Union to revise its National Emission Ceilings Directive.

In order to make progress in these agreements, it has been essential to demonstrate that there is a substantial economic and environmental benefit to be gained from reducing ammonia emissions. From a wide 'societal view' of the Green Economy, it needs to be shown that the environmental, health and agronomic benefits outweigh the costs. Similarly, from a 'farmers view' of the Green Economy, it needs to be shown that measures are not prohibitively expensive, and in many cases can pay for themselves. The costs data derived can then be included in the integrated assessment that supports decision making by the CLRTAP and the European Union.

This book provides a key resource to support this process, which has been prepared as part of the work of the CLRTAP Task Force on Reactive Nitrogen

(TFRN). Starting with an expert workshop in Paris (25–26 October 2010), the contributors have since worked to bring together the key evidence to prepare the present synthesis. The work has benefited from financial support to TFRN from the UK Department for Environment, Food and Rural Affairs (Defra) and from dissemination activities within the ÉCLAIRE project, funded by the European Commission.

The outcome delivers a very clear message. Expressed per kg of nitrogen, abatement of ammonia emissions is rather cheap compared with further abatement of nitrogen oxides (NO_x). Substantial progress has already been made for NO_x emission reduction, but the remaining measures start to become increasingly expensive. By comparison, with a very little ammonia abatement accomplished todate, the 'low-hanging fruit' of low-cost measures is still available.

Since they can deliver nitrogen savings for farmers at the same time, such ammonia measures should become increasingly attractive for policy makers as they consider the next generation of international air pollution agreements.

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Acronyms & Abbreviations

BNF	Biological nitrogen fixation
CAFÉ	Clean Air for Europe
CAP	Common Agricultural Policy of the European Union
CBA	Cost-benefit analysis
CEA	Cost-effectiveness analysis
CBD	UN Convention on Biological Diversity
CLE	Critical level
CL	Critical load
DIN	Dissolved inorganic nitrogen
DON	Dissolved organic nitrogen
EMEP	European Monitoring and Evaluation Programme of the LRTAP Convention
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies Model developed by IIASA
GAW	Global Atmospheric Watch
GHG	Greenhouse Gas – includes carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), water vapour and various other gases
GWP	Global warming potential
GPNM	Global Partnership on Nutrient Management – established under the lead of UNEP
IAM	Integrated assessment model(ling)
IIASA	International Institute for Applied Systems Analysis
ICP	International Cooperative Programme of the LRTAP Convention
IPCC	Intergovernmental Panel on Climate Change
LRTAP	UNECE Convention on Long-Range Transboundary Air Pollution
N_2	Di-nitrogen – unreactive nitrogen gas making up 78 % of the atmosphere
N_2O	Nitrous oxide – a greenhouse gas
NEC(D)	National Emission Ceilings (Directive) of the European Union

NH_3	Ammonia – a reactive gas air pollutant
NH_4^+	Ammonium – ion present in aerosols and precipitation
NH_x	Collective term for NH_3 and NH_4^+, inorganic reduced nitrogen
NO	Nitric oxide – a reactive gas air pollutant
NO_2	Nitrogen dioxide – a reactive gas air pollutant
NO_2^-	Nitrite – ion present in water samples
NO_3^-	Nitrate – ion present in aerosols, precipitation and water samples
NO_x	Nitrogen oxides (the sum of NO and NO_2)
NO_y	Collective term for inorganic oxidized nitrogen, including NO_x, NO_3^-, HONO, HNO_3, etc.
N_r	Reactive nitrogen – collective term for all nitrogen forms except for unreactive di-nitrogen (N_2), including NH_x
NUE	Nitrogen use efficiency
O_3	Ozone – tropospheric ozone (ozone in the lowest 10–20 km of the atmosphere) unless specified in text
$PM_{2.5}/PM_{10}$	Particulate Matter – aerosol mass contained in particles with an aerodynamic diameter below 2.5 (or 10 for PM_{10}) micrometre, measured with a reference technique
SIA	Secondary inorganic aerosol
SOA	Secondary organic aerosol
TFEIP	Task Force on Emission Inventories and Projection of the LRTAP Convention
TFIAM	Task Force on Integrated Assessment Modelling of the LRTAP Convention
TFRN	Task Force on Reactive Nitrogen of the LRTAP Convention
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
VOCs	Volatile organic compounds
WGE	Working Group on Effects of the LRTAP Convention
WGSR	Working Group on Strategies and Review of the LRTAP Convention
WMO	World Meteorological Organization

Contents

Chapter 1
Overview, Aims and Scope

Stefan Reis, Mark A. Sutton, and Clare Howard

Abstract This chapter presents an overview of the volume, introducing the background and setting out the aims and scope of the workshop and this book. Ammonia emissions primarily originate from agricultural sources and present a substantial contribution to a wide range of environmental problems (see as well Sutton et al., Atmospheric ammonia – detecting emission changes and environmental impacts – results of an expert workshop under the convention on long-range transboundary air pollution. Springer, Heidelberg, 2009; Managing the European nitrogen problem: a proposed strategy for integration of European research on the multiple effects of reactive nitrogen. Centre for Ecology & Hydrology, Edinburgh, 2009; The European nitrogen assessment. Cambridge University Press, Cambridge, 2011; Our nutrient world: the challenge to produce more food and energy with less pollution. Global overview of nutrient management. Centre for Ecology & Hydrology, Edinburgh, 2013; Philos Trans R Soc London, Ser B 368(1621):20130166, 2013), ranging from the deposition of acidifying substances and excess nutrients on soils, the formation of secondary inorganic aerosols, climate change and nutrient loads for freshwater and coastal ecosystems (Galloway et al., Bioscience 53:341–356, 2003). Yet, ammonia emissions have to date not been subject to stringent emission control policies, in contrast to sulphur dioxide or nitrogen oxides. As a consequence, ammonia emissions and the agricultural activities they originate from are discussed in detail, with the aim to identify the most promising emission sources and policy options to reduce their harmful environmental effects.

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Keywords Ammonia emissions • Transboundary air pollution • Agriculture • Ecosystem effects • Health effects

1.1 Overview

Emissions of ammonia (NH_3) into the atmosphere contribute substantially to local, regional and transboundary air pollution effects. Ambient concentrations and the deposition of reactive Nitrogen (N_r) contribute to a range of adverse effects on human health and ecosystems. Ammonia emissions, stemming mainly from agricultural sources (Fig. 1.1), have remained relatively stable (Fig. 1.2) in contrast to for instance sulphur dioxide or nitrogen oxide emissions in the last decades, the relative contribution of ammonia to future impacts of nitrogen and acidity on terrestrial ecosystems in Europe can be expected to increase. At the same time, ammonia is contributing an increasing share to the formation of secondary inorganic aerosols (SIA), a major constituent of particulate matter, with associated human health risks.

Recent episodes of high levels of ambient levels of fine particulate matter ($PM_{2.5}$) in the UK (Vieno et al. 2014) and in France have been to a large extent due to long-range transport of ammonium nitrates originating from spring manure spreading and fertiliser application in the agricultural regions of Europe. To date, there is no robust scientific evidence identifying specific components of $PM_{2.5}$ as less or not harmful to human health, policy measures aim at a reduction of human exposure to all components of $PM_{2.5}$, including secondary inorganic aerosols (SIA), which comprise ammonium sulphates and nitrates.

By 2020, it is estimated that NH_3 will be the largest single contributor to the deposition of acidifying substances and nutrients and thus the challenges posed by acidification, eutrophication and secondary particulate matter formation in Europe. This increasing share reflects the success of European policies in reducing SO_2 and NO_x emissions and thus the contributions of anthropogenic emission sectors such as power generation and road transport. As a consequence, NH_3, which is mainly emitted from agricultural sources (Fig. 1.1) which have so far not been subject to equally stringent regulations, is increasingly dominating nitrogen and acidifying inputs. In this context, reducing ammonia emissions and the associated environmental impacts remain major challenges for the future (Fowler et al. 2013).

This book is the result of an Expert Workshop held under the auspices of the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and organised by the Task Force on Reactive Nitrogen (TFRN). It summarises the current state-of-the-art regarding abatement measures, their associated costs and implications from the co-benefits for greenhouse gas emissions arising from reducing ammonia emissions from agricultural sources.

The Expert Workshop was organised in Paris from 25^{th}–26^{th} of October 2010 and reported to the 5^{th} meeting of the Task Force on Reactive Nitrogen on the following day. The findings of this workshop have informed the development of documents

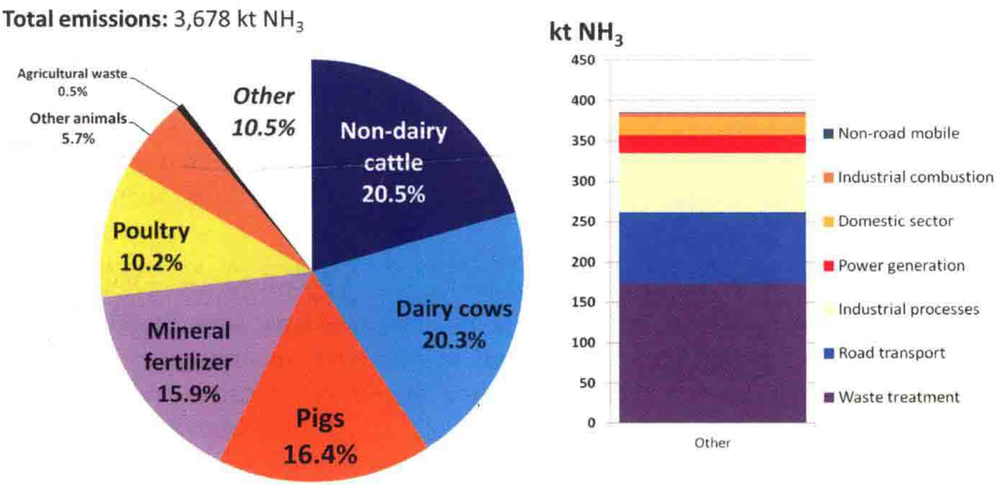

Fig. 1.1 Share of anthropogenic source sectors in total ammonia emissions in the year 2010 for the EU28 (Source: IIASA)

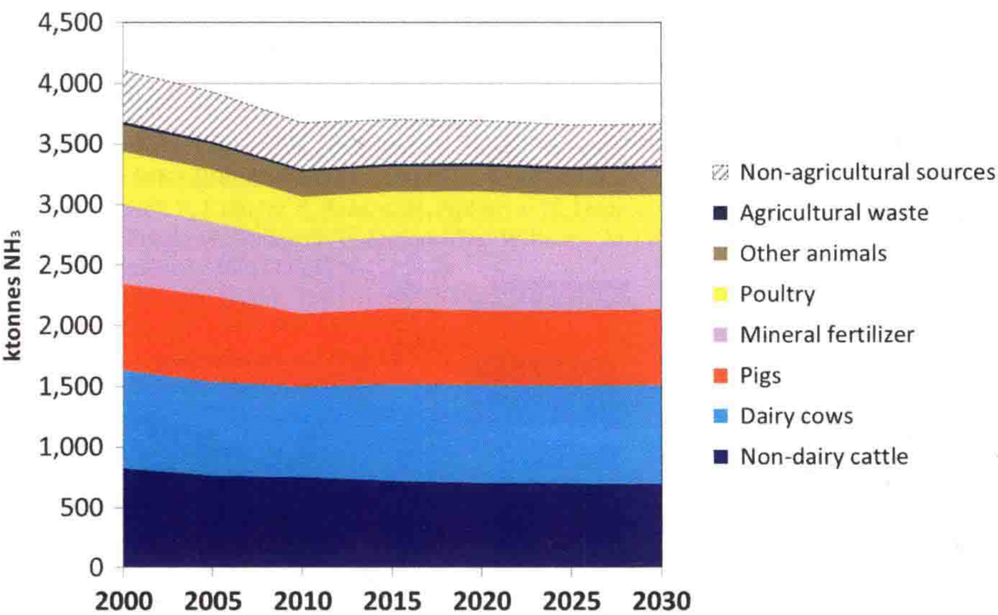

Fig. 1.2 Projected development of EU28 ammonia emissions (in kT NH_3) from 2000 to 2030 (Source: IIASA)

supporting the revision of the Gothenburg Protocol (UNECE 2013) under the Convention on Long-Range Transboundary Air Pollution. In addition to that, updated and revised cost information emerging from the workshop have been included in the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model (Klimont and Winiwarter 2015), which has been developed by the International Institute of Applied Systems Analysis (IIASA) and widely applied to conduct integrated assessment model analysis in support of the Gothenburg Protocol revision (Reis et al. 2012). The workshop has thus significantly improved the understanding and provided vital new data and information into the CLRTAP.

1.2 Aims and Scope

The aims of this book are to summarise the current state-of-the-art in determining best available techniques to reduce ammonia emissions from agricultural practises at every stage, starting from animal feed and housing, including the storage of liquid and solid manure and the application of mineral fertiliser and manure to the fields (Fig. 1.3). The complexity of controlling ammonia from these sources is that nitrogen conserved at each stage is available for volatilisation of NH_3 in the next stage and measures need to consider the knock-on effects on downstream emissions.

In each of the Chaps. 2, 3, 4, 5 and 6, the book addresses one of the agricultural production stages, the measures available to control emissions, issues of their implementation and related costs. In Chap. 7, the relationship between ammonia control and greenhouse gas emissions is explored and in Chap. 9, the implications of the revised abatement cost figures for integrated assessment modelling and resulting cost-effective control strategies, including environmental effects of these strategies, are discussed. Chapter 8 provides examples and case studies for

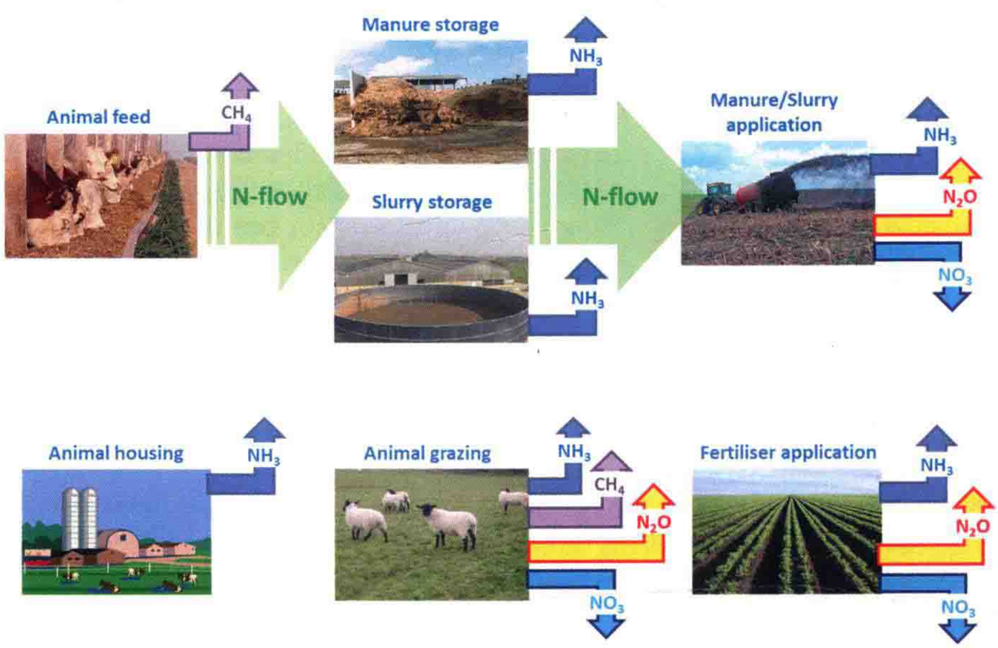

Fig. 1.3 Schema of different stages of nitrogen management in the agricultural production process with illustrations of control points for different forms of N_r emissions