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Assessing ammonia emission abatement measures in agriculture: Farmers' costs and society's benefits – A case study for Lower Saxony, Germany

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ABSTRACT

Ammonia (NH_3) emissions have adverse impacts on the environment and, being a precursor for fine particulate matter, also on human health. About 95% of NH_3 emissions in Germany originate from agriculture, mainly from livestock husbandry. This case study is aimed at presenting an approach that evaluates NH_3 emission abatement measures in agriculture regarding their abatement costs for farmers and their benefits for the society in terms of avoided external costs of health damages and loss of terrestrial biodiversity. Following the impact-pathway chain, an economic-ecological farm model for estimating NH_3 emission reductions and abatement costs was combined with an environmental impact assessment model for estimating the benefits for human health and biodiversity. The case study analysed a variety of manure storage cover and application techniques in Lower Saxony, a region in the north-west of Germany with the highest livestock density in Germany and high NH_3 emissions. In the reference situation, the damage costs of NH_3 emissions were EUR 2.7 billion. The implementation of concrete storage covers and slurry injection, the most effective measures, reduced NH_3 emissions by 25% and achieved net benefits of EUR 505 million. Farmers' abatement costs averaged over all farms ranged from EUR 3.6 to 6.8 per kilogramme NH_3 reduced. The abatement costs per farm type ranged from EUR 2.4 to 16.6 for floating plastic covers and from EUR 2.2 to 11.4 for concrete covers. The abatement costs for floating plastic covers were lower for grazing livestock specialists, while the abatement costs for concrete covers were lower for pig specialists, poultry specialists and mixed farms. Farm type specific abatement costs for manure application techniques ranged from EUR 4.5 to 9.6 per kilogramme NH_3 reduced with little variation between trailing shoe and cultivator/injector techniques. Abatement costs for trailing shoe application were lower than for cultivator/injector application for grazing livestock specialists, poultry specialists and mixed farms. The average benefits per kilogramme NH_3 reduced were EUR 14.1 for health and EUR 10.4 for biodiversity, totalling EUR 24.5. As the benefits exceed the abatement costs for all measures analysed in this study, principally, they can be recommended for implementation. However, the variation in abatement potentials and costs per farm type indicate differences in suitability. While manure covers should above all be implemented by pig specialists because of their high abatement potential, manure application techniques should be implemented by grazing livestock specialists. Among manure storage covers, floating plastic covers are more favourable for grazing livestock specialists, whereas concrete covers are more suitable for all other farm types. The analysis with the farm model was considered more appropriate than recent analyses at technical or macroeconomic level, because the abatement costs reflect differences in farm types, detailed production processes and farmers' profit-maximising behaviour. Overall, it can be concluded that an assessment of NH_3 emission abatement measures should be carried out for farm types and should consider impacts of NH_3 emission abatement both on human health and biodiversity. The presented modelling approach enables to estimate abatement costs for farm types and benefits for human health and biodiversity. Cost-efficient NH_3 emission abatement measures tailored to farm types can be identified and farm type specific regional abatement strategies can be developed.

1. Introduction

Ammonia (NH_3) is an air pollutant and may have adverse impacts on the environment and on human health. After emission to the atmosphere, NH_3 is subject to dispersion and transport and is either quickly deposited close to its source or converted into ammonium aerosols travelling over long distances before being deposited. Aerosols are part of the fine particle fraction (diameter $< 2.5\ \mu m$). Hence, NH_3

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is a precursor for secondary fine particulate matter ($PM_{2.5}$) (Krupa, 2003). After deposition to land, NH_3 can contribute to the acidification and eutrophication of natural ecosystems and to the loss of terrestrial biodiversity. It can form the greenhouse gas nitrous oxide, affecting the climate, or nitrates that can leach into ground and surface waters, affecting aquatic biodiversity (Krupa, 2003). The atmospheric deposition of NH_3 is considered a major threat to terrestrial biodiversity in Europe (Dise et al., 2011; Townsend, 2010). $PM_{2.5}$ emissions may cause respiratory and cardiovascular diseases and a reduction in life expectancy (Brunekreef and Holgate, 2002; World Health Organization, 2013). To reduce the health and environmental damages caused by NH_3 emissions, air quality policies in the European Union (EU) and beyond demand their reduction (European Communities, 2001a, 2001b, 2008, 2010, 2005, 2006; United Nations Economic Commission for Europe, 1999).

About 95% of all NH_3 emissions in Germany in 2012 (545 gigagram [Gg]) originated from agriculture, with 80% from livestock manure and 20% from mineral fertiliser application (Umweltbundesamt, 2013). Recent estimates, however, indicate that annual NH_3 emissions in Germany were about 670 Gg in past years and thus exceeded the NH_3 emission ceiling at 550 Gg that had been agreed in air quality legislation (Umweltbundesamt, 2016). Hence, the implementation of effective NH_3 emission abatement measures in the agricultural sector is crucial for NH_3 emission reduction and for compliance with air quality policy.

A common criterion for the selection of suitable NH_3 emission abatement measures is their abatement costs for farmers. Abatement costs can be estimated in various approaches (Vermont and De Cara, 2010). Some studies have estimated the potentials and costs of NH_3 emission abatement in engineering approaches. They described technical reduction potentials and costs (Döhler et al., 2011) or analysed implementations of measures to meet specific reduction targets at least cost to farming and obtained cost curves (Webb et al., 2006) (NARSES model) (Amann et al., 1999; Holland et al., 2005b) (RAINS model). Few studies included an economic model into their engineering approach (Oenema et al., 2009) (MITERRA model, CAPRI model).

From an economic welfare point of view, abatement measures need to be evaluated not only with regards to their costs for farmers, but also as to their benefits for society. Measures may only be implemented if benefits exceed abatement costs. Benefits result from damage costs that are avoided by the abatement of NH_3 emissions, which again are derived by monetising impacts of NH_3 emissions. Benefits can be estimated in impact assessments following NH_3 emissions along their pathway from the location of origin through the atmosphere to the location of impact. Thus, to link emissions to impacts, the location of origin and the atmospheric processes need to be known or simulated. The dispersion and conversion of NH_3 in the atmosphere and its deposition are simulated with atmospheric dispersion models. They work at spatially explicit grid levels at various spatial scales and need geo-referenced NH_3 emission data as input (e.g., Norwegian Meteorological Institute, 2012; Stern, 2009). However, emissions estimated in agricultural modelling approaches usually refer to administrative and not to geo-referenced units. Approaches linking these units have been developed in Leip et al. (2008) and Weinmann et al. (2006).

Some studies estimated the health damage costs caused by NH_3 emissions and the impacts on biodiversity with a critical load exceedance approach (Bak, 2014; Brandt et al., 2013; Holland, 2012, 2014; Holland and King, 1999; Holland et al., 2005b, 2005c; Pye et al., 2008; Wamelink et al., 2007). However, it has been recognised that impacts on biodiversity should also be expressed in monetary terms, resulting in more reliable benefit estimates (European Communities, 2005).

The aim of this study is estimating and comparing costs and benefits of NH_3 emission abatement measures and thereby identifying cost-efficient measures in agriculture with a bottom-up approach at a spatially explicit scale. To this end, we combined two models: an economic-ecological farm model estimating NH_3 emission abatement potentials and costs of abatement measures at the farm and at the regional level, and an integrated environmental assessment model estimating benefits in terms of avoided damage costs of health damages and biodiversity loss. We reasoned that including farmers' economic behavioural responses at the farm level in addition to mere technical costs in the farm model would result in more appropriate estimates of farmers' abatement costs compared to engineering approaches. Quantifying benefits of reduction measures and including different types of damages, such as those on human health and biodiversity, would avoid underestimating total benefits and provide more reliable benefit estimates.

Our modelling approach assessed a selection of promising NH_3 emission abatement measures. The analysis focused on a case study of the north-western German Federal State of Lower Saxony. This approach is also applicable to other air pollutants in agriculture such as primary particulate matter or nitrogen emissions and to the evaluation of abatement measures simultaneously affecting different types of atmospheric emissions and different types of damages, as shown in Wagner et al. (2015), and to EU Member States.

2. Method

2.1. Overview

We combined the economic-ecological farm model EFEM (Economic Farm Emission Model, Neufeldt and Schäfer, 2008; Neufeldt et al., 2006) and the environmental impact assessment model EcoSense. In the past, the latter model had been applied to the energy sector (Bickel and Friedrich, 2005; Krewitt, 1999; Preiss and Klotz, 2008). EFEM estimated NH_3 emissions, abatement potentials and abatement costs, while EcoSense estimated the benefits of NH_3 emission abatement in terms of avoided damage costs. The benefit analysis followed the impact-pathway approach that traces the air pollutant from its source along its dispersion and chemical conversion in the atmosphere to the physical impacts on affected receptors (e.g. human population, ecosystems and materials), complemented by the monetary valuation of these physical impacts. This approach comprises four steps, categorized into emissions, dispersion, impact and costs (Fig. 1), which are described in detail in chapter 2.

2.1.1. Emissions

Abatement measures, their abatement potentials and related abatement costs were analysed. Emission results of EFEM at the administrative level were geo-referenced and linked to the grid level of EcoSense in a spatial resolution procedure.

2.1.2. Dispersion

Subsequent atmospheric dispersion modelling simulated the passage of NH_3 and its chemical reactions in the atmosphere and resulted in $PM_{2.5}$ concentration and nitrogen (N) deposition.

2.1.3. Impact

The physical impacts of changes in $PM_{2.5}$ concentration on human health and of changes in N deposition on terrestrial biodiversity were estimated.

2.1.4. Costs

The physical impacts were weighed with monetary values and aggregated into one value, the damage costs. The damage costs that are avoided by NH_3 emission abatement represent the benefits of NH_3 emission abatement and are finally compared to the farmers' abatement costs.

2.2. Emissions and abatement costs

The model EFEM is a static linear supply model maximising farms' gross margins. Production factors, prices and production capacities in