Marginal abatement cost curve for an ammonia reduction measure in agriculture: the case of Latvia

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Abstract. With the production of grain and livestock–derived agricultural commodities increasing, the agricultural sector has become one of the main sources of ammonia (NH_3) emissions in Latvia. In 2018, the agricultural sector contributed to 83% of the total NH_3 emissions originated in Latvia (15.46 kt) (LIIR 2020). The EU has already put in place measures to control NH_3 emissions. This includes the EU target of reducing ammonia emissions by 21% by 2030 and sets out emission reduction commitments for Latvia. Considering Latvia's indicative reduction target, the NH_3 emission reductions need to be achieved by 2030 (Directive 2016/2284) so that the emissions do not exceed the 2005 level (11.33 kt). Implementing no mitigation measures, Latvia has projected agricultural sector NH_3 emissions to be 32.4% higher than those in 2005, and therefore the mitigation of the NH_3 emissions from agriculture is important. The research aims to estimate cost-effective NH_3 emission reduction measures in agriculture in Latvia. The results of the research represent a marginal abatement cost curve (MACC) analysis, in which we have quantified the potential for reduction for selected NH_3 emission mitigation measures in Latvia. A list of the measures has been established taking into account the experience of good agricultural practices in the reduction of NH_3 emissions (UN, 2014) and of other European countries as well. The calculations carried out allowed us to group the measures according to their priorities: measures that are cost-effective and with high potential for reduction of NH_3; measures that are cost-effective but with low NH_3 emission reduction potential; measures that are not cost-effective but with high potential for reduction of NH_3; measures that are not cost-effective and with low potential for reduction of NH_3. The estimated cumulative (total) reduction of NH_3 emissions in Latvian agriculture by 2030, with the implementation of the measures analysed, is equal to 20.08 kt.

Key words: NH_3, emissions, measures, reduction, cost efficiency.

INTRODUCTION

In Latvia, agricultural output measured in value (EUR) and physical volume (tonnes) showed a steady upward trend. The key growing agricultural industries were cereal and livestock production. In the period 2013–2019, the area cropped with cereals increased by 27%. The total number of dairy cows decreased by 19%, while the number of beef cows increased by 93%, thereby resulting in a constant total number of cattle in Latvia during this period (CSB, 2020). During the analysis period, productivity in the cereal and dairy industries significantly increased, as the average cereal yield increased by 27%, while the average milk yield per cow increased by 25% (CSB, 2020). The productivity in the cereal and dairy industries increased owing to agricultural intensification, which was positively related to an increase in the amount of resources used by the industries. Ineffective management of resources leads to a number of significant negative externalities of agricultural production: greenhouse gas (GHG) and ammonia (NH_3) emissions as well as nitrogen (N) losses. The mentioned externalities make a significant impact on the natural environment; therefore, the EU has set a goal to significantly reduce the impacts on the natural environment (Directive 2016/2284). NH_3 emissions from the agricultural sector accounted for 90.5% of the total NH_3 emissions in the EU, and in the period 2013–2018 the emissions increased by 2% (Eurostat, 2020).

In Latvia in 2018, the total NH_3 emissions from agriculture amounted to 12.83 kt, and the agricultural sector accounted for 83% of the total NH_3 emissions. The main sources of NH_3 emissions from agriculture were manure management systems and the application of synthetic fertilizers and manure. The NH_3 emissions from the agricultural sector have increased by 13.2% since 2005 (LIIR 2020). The main factors contributing to the increase in NH_3 emissions were as follows: an increase in the arable land area cropped with cereals; an increase in the application of N fertilizers and the change of the manure management system in dairy farming (Priekulis et al., 2019).

The EU has already put in place measures to control NH_3 emissions. This includes the EU target of reducing ammonia emissions by 21% by 2030 and sets out emission reduction commitments for Latvia. Considering Latvia's indicative emission reduction target, the NH_3 emission reductions need to be achieved by 2030 (Directive 2016/2284) so that the emissions do not exceed the 2005 level (11.33 kt). Implementing no mitigation measures, Latvia has projected agricultural sector NH_3 emissions to be 32.4% higher than those in 2005. A comparative analysis of GHG and NH_3 emissions in the EU Member States reveals that in Latvia the emission intensity in agriculture was below the EU average (Lenerts et al., 2019). The emission reduction targets for the EU Member States are set in relative terms and must be achieved in relative terms, regardless of the absolute value; therefore, the reduction of the NH_3 emissions from agriculture is important. Reducing agricultural emissions is also a key issue in the recently launched EU Farm to Fork strategy, which is part of the European Green Deal (European Commission, 2019).

The research **aims** to estimate cost-effective NH_3 emission reduction measures in agriculture in Latvia.

To achieve the aim, the following specific **research tasks** were set: to examine a methodology for calculating and assessing a marginal abatement cost curve (MACC) for agricultural NH_3 emissions; to select potential theoretical NH_3 emission mitigation

measures for agriculture in Latvia; to perform an assessment and a MACC analysis of NH_3 emissions from agriculture in Latvia.

The research used the data from Central Statistical Bureau of Latvia (CSB): fertilisers and manure used (tonnes); livestock (number); land used in agriculture (hectares), Agricultural Data Centre (ADC): animal herds and holdings (feeding; manure management; intensive and extensive holding); animals (live weight; bulk; number of lactating), Latvian Rural Advisory and Training Centre (LRATR): costs of implementing and maintaining measures to reduce ammonia emissions and Eurostat databases. To process the data, the following economic **research methods** were employed: data grouping for statistical indicator calculation; time series; analysis and synthesis; induction and deduction.

MATERIALS AND METHODS

EU Directive 2016/2284 adopted in 2016 has set an NH_3 emission reduction target of 1% per year for Latvia for the period 2020–2029 and the period after 2030. In order to meet the target set in the directive and taking into account forecasts (Cabinet Regulation, 2020), NH_3 emissions must be reduced by 4.13 kt in Latvia by 2030 (LIIR, 2020). Reaching this target is possible through introducing measures for reducing NH_3 emissions, which would change the production or management systems that make the largest effects on emissions. In the agricultural sector, emission reduction measures need to target the systems of cereal production, manure management and manure storage. Changing any management system, however, requires investments. Before implementing NH_3 emission reduction measures, it is necessary to perform a detailed assessment of the reduction measures through performing cost-effectiveness calculations and emission reduction potential calculations. One of the most suitable research methods for solving such a complex problem is marginal abatement cost curve (MACC) analysis. The method is quite widely used for analysing GHG reduction measures (Moran et al., 2011; Eory et al., 2018) and assessing NH_3 emission reduction measures (Buckley C. & Krol D.J. 2020) before the measures are included in policy documents.

MACC analysis provides several kinds of information, as it:

➢ makes it possible to assess the cost-effectiveness of certain measures for reducing NH_3 emissions,

➢ makes it possible to identify the total reduction of NH_3 emissions over time,

➢ provides information on which NH_3 emission reduction measures could be introduced under certain conditions.

A marginal abatement cost analysis and curve construction consists of three important steps:

➢ identifying measures suitable for the agricultural sector of Latvia to reduce NH_3 emissions,

➢ assessing the NH_3 emission reduction potential of the measures selected for the agricultural sector of Latvia,

➢ calculating NH_3 marginal abatement costs for the selected measures.

The present research analysed 16 various NH_3 emission reduction measures aimed at the efficient application of nitrogen (N) fertilizers, efficient off-site manure management and the expansion of organic farming. The list of the measures was based on the Code of Good Agricultural Practice for Reducing NH_3 Emissions (UN, 2014), the

experience of other European countries, as well as the opinions of experts from the Ministry of Agriculture and scientists from Latvia University of Life Sciences and Technologies.

The NH_3 emission reduction potential of the measures selected for the agricultural sector of Latvia was identified by using the guidelines and methodologies provided by the Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2016). For each category of ammonia emissions given in the relevant nomenclature, three potential levels for emission calculations were identified according to the guidelines:

➢ **Tier 1** methods make full use of the EMEP guidelines,

➢ **Tier 2** methods use the EMEP guidelines and additionally apply country-specific emission factors,

➢ **Tier 3** methods include country-specific calculation methodologies.

The **TIER 2** methods are mainly applied to calculate agricultural NH_3 emissions from the livestock industry, as there are scientifically substantiated regional differences in emission factors (VS) (LIIR, 2020). The research employed Eq. 1 to calculate NH_3 emissions from manure management systems.

$$NH_3 = \Sigma_{(T)}\, N_T \cdot VS_S \qquad (1)$$

where NH_3 – Ammonia emissions from manure management systems, kg NH_3 year^{-1}; N_T – total livestock manure production for livestock group T, kg year^{-1}; VS_S – emission factor for Latvia, manure management system S, livestock group T, (kg NH_3-N emissions).

Calculations of NH_3 emissions from soils used in agricultural production by the cereal industry were performed by using the TIER 1 methods according to Eq. 2.

$$NH_3 = \Sigma_{(T)}\, N_T \cdot EF_T \qquad (2)$$

where NH_3 – ammonia emissions from N-containing fertilizers applied to soil, kg NH_3 year^{-1}; N_T – fertilizers applied to soil for group T, kg year^{-1}; EF_T – emission factor for fertilizer group T as defined in the EMEP guidelines, (kg NH_3-N emissions).

The model of an algorithm for calculating the marginal abatement cost of an NH_3 emission reduction measure and constructing a MACC curve is shown in Fig. 1.
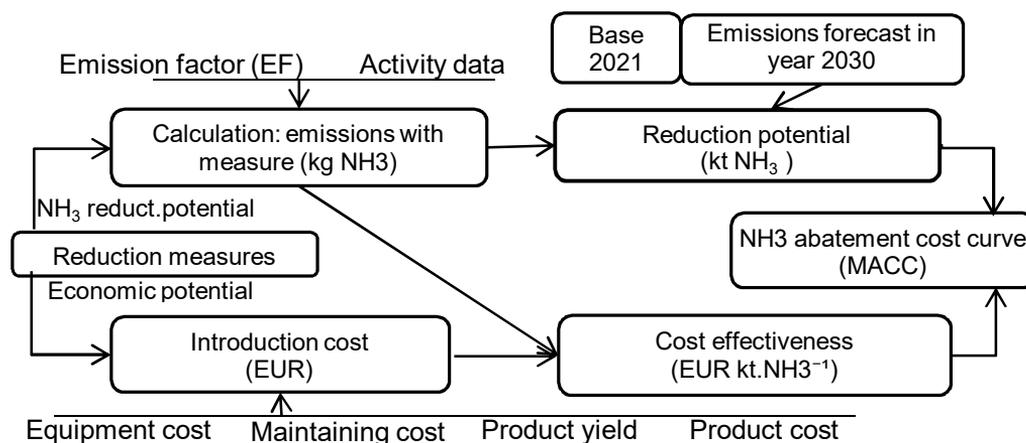
Figure 1. Model of an algorithm for calculating the marginal abatement cost of an NH_3 emission reduction measure and constructing a MACC curve.

The marginal abatement cost of implementing NH_3 emission reduction measures was calculated by using Eq. 3.

$$C_{p.c.} = \sum_{i=1}^{T} (Y_c \cdot P_c) - I_{p.c.} - I_{m.c.} \tag{3}$$

where $C_{p.c.}$ – marginal abatement cost of an NH_3 emission reduction measure after it has been introduced, EUR; T – duration of the measure after it has been introduced, T = 10 years; Y_c – average yield of product c after measure p has been introduced; P_c – 10 years average selling price of product c; $I_{p.c.}$– investment cost of implementing measure p for sproduct c; $I_{m.c.}$ – 10 years cost to investment maintain the implemented measure p.

The cost-effectiveness of NH_3 emission reduction measures was calculated according to Eq. 4.

$$MAC_{p.} = \frac{C_{p.c.}}{NH_{3p}} \tag{4}$$

where MAC_p – cost-effectiveness of NH_3 emission reduction measure p, EUR/kt; $RI_{p.c}$ – marginal abatement cost for product c after measure p has been introduced, EUR; NH_{3p} – NH_3 emissions after measure p has been introduced, kt.

RESULTS AND DISCUSSIO

In 2018, the agricultural sector contributed to 83.0% (12.83 kt) of the total NH_3 emissions in Latvia (15.46 kt). The agricultural sector was the largest producer of ammonia emissions in the country. Ammonia emissions from agricultural soils and crops (including emissions from nitrogen fertilizers, manure and other organic fertilizers) accounted for 49% (6.29 kt) of the total ammonia emissions from the agricultural sector in 2018. Ammonia emissions from manure management systems accounted for 51% of the total or 6.54 kt. Changes in NH_3 emissions from the agricultural sector in the period 2013–2018 are summarized in Table 1.

Table 1. Changes in NH_3 emissions from the agricultural sector in Latvia in the period 2013–2018

Indicator	2010	2014	2015	2016	2017	2018
NH_3, kt	11.91	13.98	13.09	13.17	13.42	12.83
Annual change rate, %	-	+15	-6.4	+0.6	+1.9	-4.4
Change from base year, %		+15	+9	+10	+12	+8

Ammonia emissions from manure management systems showed a declining trend in the period 2014–2018, while the emissions from agricultural soils (including urine and manure left on pasture by livestock during the grazing period) were volatile, i.e. both increased and decreases.

The emission trends are summarized in Fig. 2.
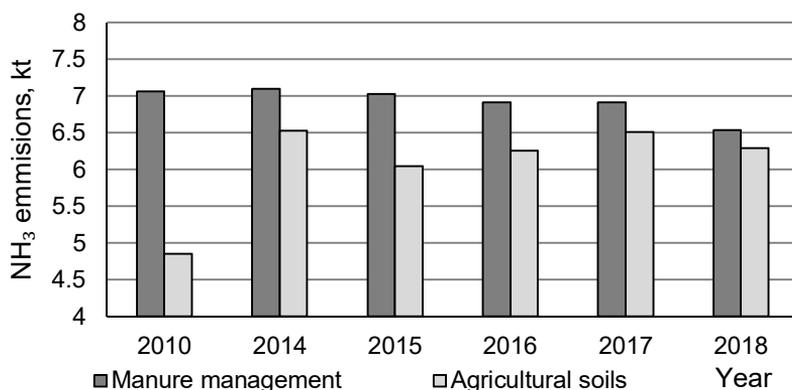
Figure 2. NH$_3$ emissions from manure management systems and soil use in Latvia in the period 2014–2018.

The NH$_3$ emission reduction measures analysed in the research were selected with the aim of improving manure and agricultural soil management systems. The reduction measures were aimed at the efficient application of fossil nitrogen (N) fertilizers, as well as efficient off-site manure management and organic farming development in the dairy industry. The measures for reducing NH$_3$ emissions adapted to conditions in Latvia and the area affected by the measures are summarized in Table 2.

Table 2. Measures for reducing NH$_3$ emissions adapted to conditions in Latvia and their impacts.

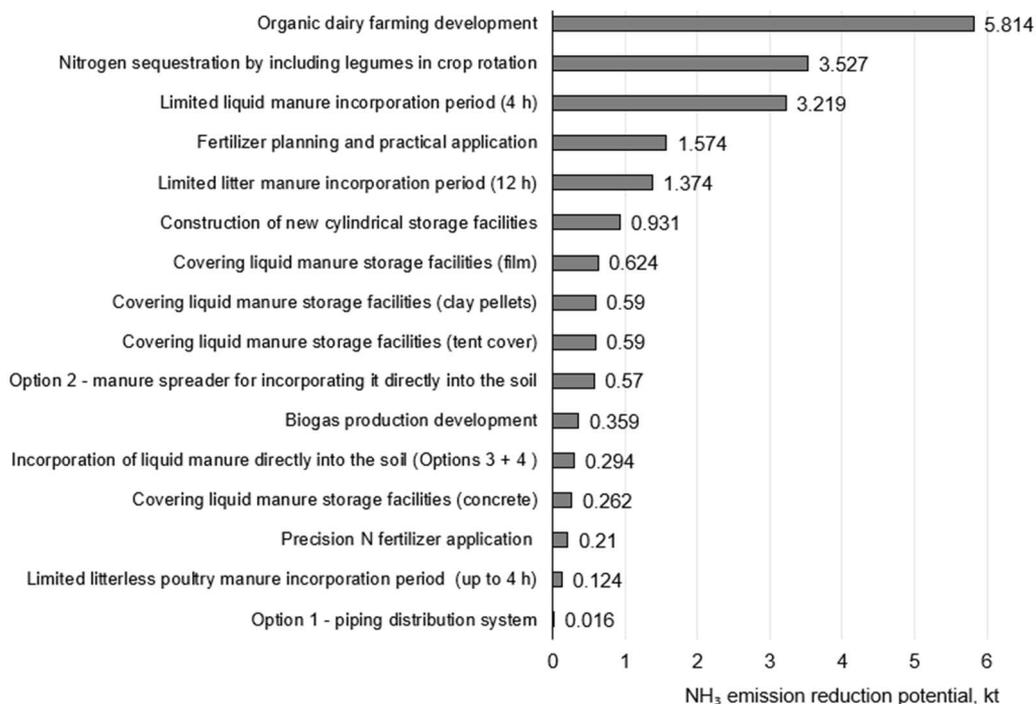| Measure-affected area	NH$_3$ emission reduction measure
Efficient application of nitrogen fertilizers	Precision N fertilizer application
	Fertilizer planning and practical application
	Nitrogen sequestration by including legumes in crop rotation
	Incorporation of manure directly into the soil:
	Option 1 – by means of a piping distribution system
	Option 2 – by means of a manure spreader for incorporating it directly into the soil
	Option 3 – by means of a belt spreader with hanging pipes
	Option 4 – by means of a belt spreader with hanging pipes equipped with nozzles
	Limited liquid manure incorporation period (4 h)
	Limited litterless poultry manure incorporation period (4 h)
	Limited litter manure incorporation period (12 h)
Efficient manure storage management	Covering liquid manure storage facilities
	Option 1 – a floating layer of expanded clay pellets
	Option 2 – a floating plastic film cover
	Option 3 – a concrete cover
	Option 4 – a tent cover
Organic farming development	Organic dairy farming development (extensive dairy farming with use of grazing)

Abatement costs are associated with abatement potentials for one period of time without giving information on what happened before that period and what is assumed to happen afterwards (Kesicki, F. & Strachan, N. 2011). The emission reduction potential for the period 2021–2030 was calculated for all the selected and analysed NH_3 emission reduction measures.

➢ The calculations showed that the measures could be divided into three categories: **measures with high reduction potential**: organic dairy farming development; nitrogen sequestration by including legumes in crop rotation; limited liquid manure incorporation period (4 h); fertilizer planning and practical application; limited litter manure incorporation period (12 h), which together accounted for 77% of the total reduction potential,

➢ **measures with medium reduction potential**: construction of new cylindrical storage facilities; covering liquid manure storage facilities (tent cover, clay pellets, film); incorporation of liquid manure directly into the soil (Option 2); biogas production development, which together accounted for 18% of the total reduction potential,
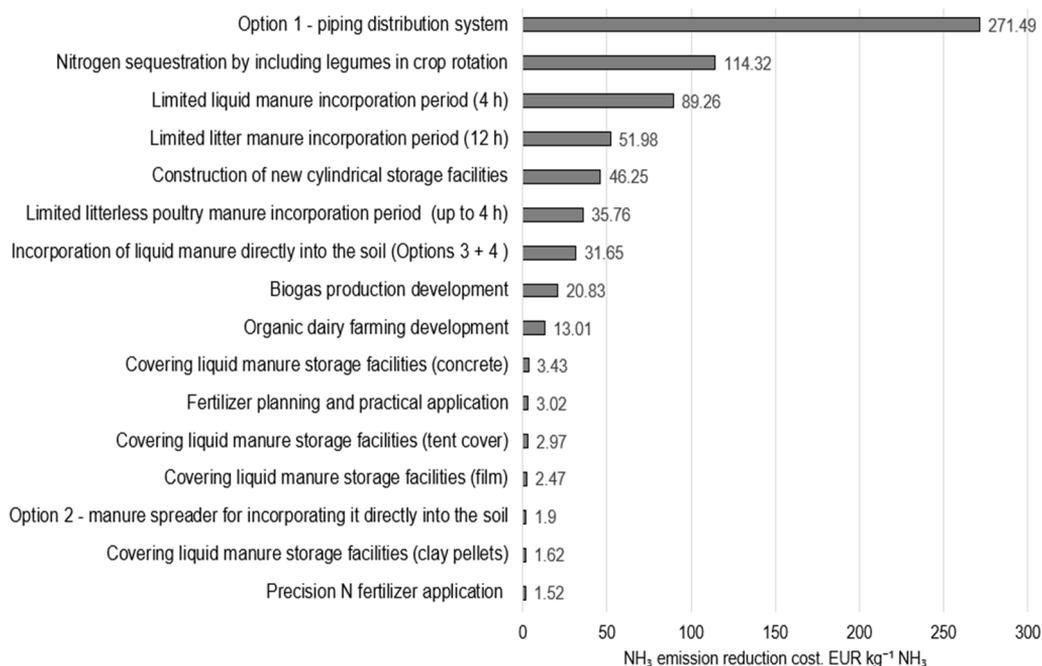
➢ **measures with low reduction potential**: incorporation of liquid manure directly into the soil (Options 1+3+4); precision N fertilizer application, covering liquid manure storage facilities (concrete), limited litterless poultry manure incorporation period (4 h), which together accounted for 5% of the total reduction potential.

The calculations results are summarized in Fig. 3.

Figure 3. Estimated reduction potential of the NH_3 emission reduction measures for the period 2021–2030.

The effectiveness of an NH_3 emission reduction measure is determined by calculating the unit cost (kg NH_3) of reducing NH_3 emissions (EUR kg^{-1} NH_3). The calculation results are summarized in Fig. 4.

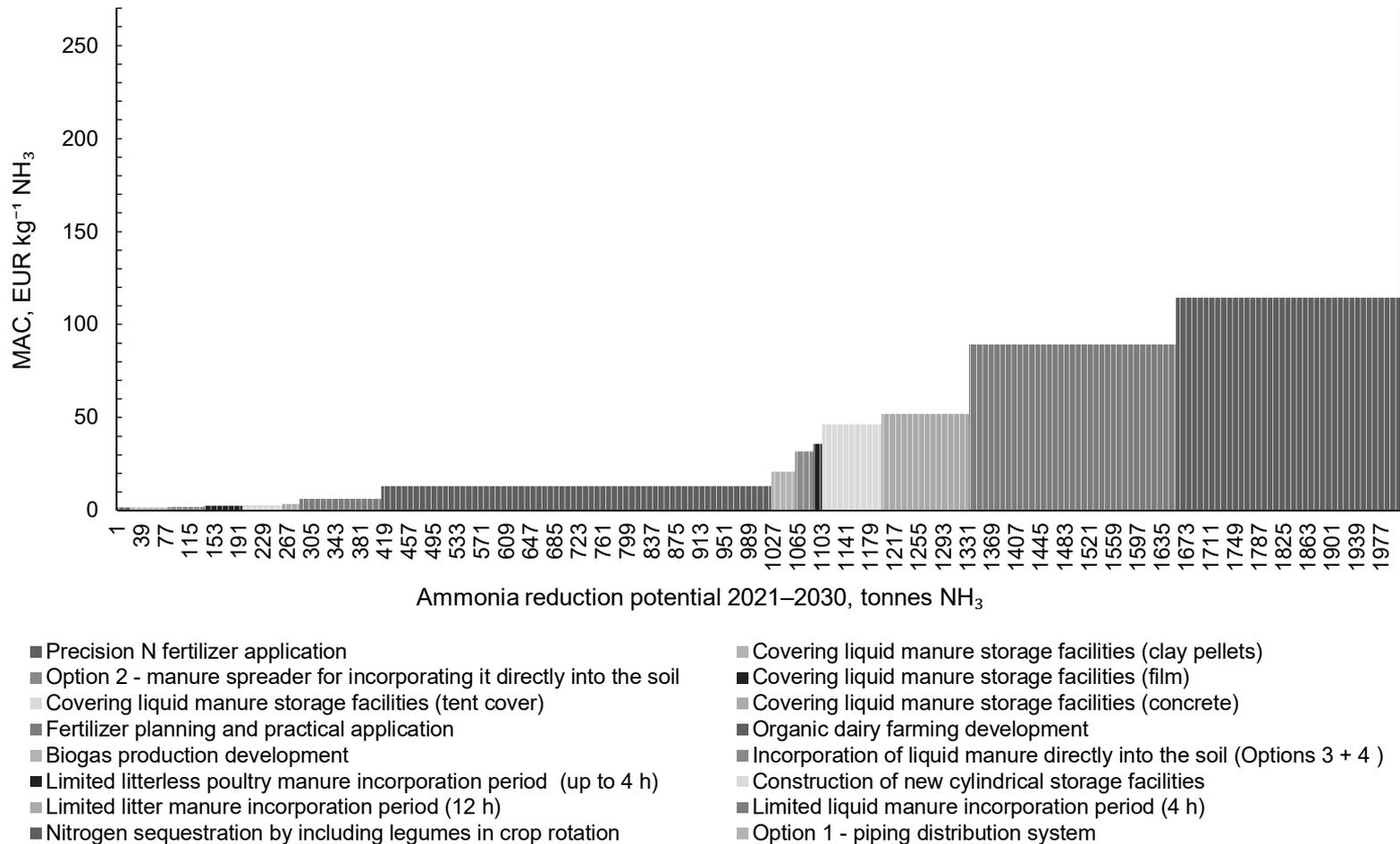**Figure 4.** Rankings of measures by ammonia emission reduction cost, EUR kg^{-1} NH_3.

The calculations showed that the measures could be divided into three categories:

➤ **low cost** measures: precision N fertilizer application; covering liquid manure storage facilities (tent cover, clay pellets, tent, film); incorporation of liquid manure directly into the soil (Option 2); fertilizer planning and practical application,

➤ **medium cost** measures: organic dairy farming development; biogas production development; incorporation of liquid manure directly into the soil (Options 3 + 4); limited litterless poultry manure incorporation period (4 h),

➤ **very high cost** measures: construction of new cylindrical storage facilities; limited litter manure incorporation period (12 h); limited liquid manure incorporation period (4 h); nitrogen sequestration by including legumes in crop rotation; incorporation of liquid manure directly into the soil (Option 1).

The calculation results are summarized in Fig. 5, which shows a marginal abatement cost curve for the ammonia reduction measures (MACC). The vertical axis of the MACC curve shows the cost of reducing 1 kg of ammonia emissions (EUR kg^{-1} NH_3) and the horizontal axis shows the reduction potential of each measure (kt NH_3) for a certain period of time, i.e. from 2021 to 2030.

Figure 5. Marginal abatement cost curve (MACC) for the ammonia reduction measures.

Legend:
- Precision N fertilizer application
- Option 2 - manure spreader for incorporating it directly into the soil
- Covering liquid manure storage facilities (tent cover)
- Fertilizer planning and practical application
- Biogas production development
- Limited litterless poultry manure incorporation period (up to 4 h)
- Limited litter manure incorporation period (12 h)
- Nitrogen sequestration by including legumes in crop rotation
- Covering liquid manure storage facilities (clay pellets)
- Covering liquid manure storage facilities (film)
- Covering liquid manure storage facilities (concrete)
- Organic dairy farming development
- Incorporation of liquid manure directly into the soil (Options 3 + 4)
- Construction of new cylindrical storage facilities
- Limited liquid manure incorporation period (4 h)
- Option 1 - piping distribution system

CONCLUSIONS

The calculations allowed us to draw conclusions on the economic and natural environment conditions for the implementation of NH_3 emission reduction measures and to categorize the measures according to their priority:

1. The measures that are cost-effective and have high NH_3 reduction potential: fertilizer planning and practical application; organic dairy farming development. Total estimated reduction potential is 7.384 ktNH_3. These measures are considered to be the most effective from both an economic and an environmental perspective and should be supported as a priority and implemented in practice.

2. The measures that are cost-effective but have low NH_3 emission reduction potential: precision N fertilizer application; covering liquid manure storage facilities (tent cover, clay pellets, tent, film); incorporation of liquid manure directly into the soil (Option 2); biogas production development. Total estimated reduction potential is 2.929 ktNH_3. These measures are considered to be effective, yet they make low effects on reducing NH_3 emissions. To increase the effects, the possibilities to increase the numbers of target farms, the target area and the number of target livestock need to be considered.

3. The measures that are less cost-effective but have high NH3 reduction potential: construction of new cylindrical storage facilities; limited litter manure incorporation period (12 h); limited liquid manure incorporation period (4 h); nitrogen sequestration by including legumes in crop rotation. Total estimated reduction potential is 9.051 ktNH_3. These measures are considered to be economically inefficient but very effective from an environmental perspective, as they make a significant effect on reducing NH_3 emissions. Therefore, financial support for farms is needed to facilitate the practical implementation of these measures.

4. The measures that are not cost-effective and have low NH_3 reduction potential: incorporation of liquid manure directly into the soil (Options 1 + 3 + 4), limited litterless poultry manure incorporation period (4 h). Total estimated reduction potential is 0.716 ktNH_3. Financial support for these measures is not a priority, as their effects on reducing NH_3 emissions are insignificant.

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