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Policy recommendations for supporting SAT implementation

Edited by Henning Lyngsø FOGED, Organe Institute ApS

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Preface

This report is prepared within the frames of the Baltic Slurry Acidification project, co-financed by Interreg Baltic and implemented by 17 partners from Baltic Sea Region (BSR) countries in the period from March 2016 to February 2019.

The report is a deliverable of work package 6 (WP6) concerning Policy Recommendations and Analyses of Markets and Legislation.

The main aim of the report is to give policy makers the best possible basis for decisions about implementation of slurry acidification in their country in the Baltic Sea Region. Thus, the report presents compiled results and recommendations of policy nature of the entire Baltic Slurry Acidification project, including the impacts of use of slurry acidification technologies in the Baltic Sea Region and the individual countries of the Region. The report is also providing documented evidence of possible barriers and enablers for disseminated use of slurry acidification in the individual Baltic Sea Region countries.

We are especially glad that co-funding from the Swedish Institute made it possible to include results and recommendations for Russia and Belarus due to cooperation with the associated project "Bringing Russia and Belarus into Baltic Slurry Acidification".

Skødstrup, Denmark

February 2019

Henning Lyngsø FOGED

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Summary

Slurry acidification technologies (SATs) have the potential to give a major lift to the economy and the environment in the Baltic Sea Region, and in the same time give substantial greenhouse gas emission reductions. Implementing the potential for use of SATs in the Baltic Sea Region countries would have a positive net economic effect of in total € 2.2 billion per year, to which come an estimated N abatement value of M€ 147 per year related to the aquatic environment, and positive healthcare sector effects in Russia and Belarus. For the entire region, the implementation of slurry acidification in accordance with the estimated, weighed potential of 234 million tonnes of slurry, would annually mean a reduced ammonia emission of 167.1 Kt, and as a result of this a reduced atmospheric N deposition of 56,000 – 91,000 tonnes. In addition, the greenhouse gas emission would be reduced with 1.5 Mt CO_{2e}.

Use of slurry acidification technologies (SATs) relates to fundamental objectives for farms, and to social objectives for air and water quality as well as climate change.

An inherited, basic objective for a normal, commercially operated farm business is economic survival, and the best guarantee for this is profit maximisation.

For the society, SATs are interesting due to the impacts on air and water quality, as well as to climate change. In combination, five EU Member States in the Region are 18.2 Kt ammonia above their 2020-ceiling, based on 2016 emission data, whereas all eight EU Member States in combination must reduce their ammonia emissions with 187.6 Kt until 2030, equal to a reduction of about 17% compared to 2016 emission levels. The 2013 HELCOM Ministerial Meeting concluded that it is necessary to reduce nitrogen inputs from land and air to the Baltic Sea with about 135,000 tonnes, which is a reduction of about 15% in comparison to the reference period from 1997 to 2003. In relation to climate change, the EU Member States in the Region are obliged to reduce greenhouse gas emissions with 354 MtCO_{2e} until 2030, equal to about 23% compared to 2015 levels.

Strengths

Availability of slurry and other liquid manures is a prerequisite for using SATs to reach the mentioned policy objectives. However, the employment of SATs also depends on various regulatory and market economic factors. Taking these into account, the estimated realistic, weighed potential for slurry acidification in the Region is an annual production of 234 million tonnes of slurry[1].

[1] Based on acidification of half of the absolute slurry production for Denmark, which is app. 14 million tonnes more than the current slurry acidification, and the entire, weighed potential for other countries in the Region.

Other strengths include that SATs are developed and already commercially used in the Region, which is an advantage in case of wider use. SATs are officially recognised as BATs that livestock farms can use for obtaining environmental permits, not only in Denmark, but since February 2017 in the entire EU, however with prejudice given to national legislation that might set up barriers for that.

All countries in the Region have established regulations for transport and handling of sulphuric acid.

Weaknesses

It would require investments of M€ 1,482 in 11,504 slurry acidification installations to acidify the weighed potential. The relative competitiveness between the SAT types – in-house, in-storage and in-field is assumed to be alike the situation in Denmark, where the market share is 20, 24 and 56%, respectively, based on treated slurry amounts. The annual costs for depreciation, interest payment and maintenance of 5,004 in-house, 2,625 in-store, and 3,885 in-field acidification systems would be M€ 215.

Opportunities

Use of SATs according the weighed potential would provide ammonia emission reductions of 167.1 Kt, which is 89% of the reductions needed to meet the committed 2030 ceilings. Similarly, the nitrogen load to the Baltic Sea would be reduced with 56,000 – 91,000 tonnes per year, which is app. 41-67% of the needed reductions of 135,000 tonnes N per year. For greenhouse gas emissions, the use of in-house acidification for treatment of 20% of the weighed potential of slurry, would give emission reductions of 1.5 Mt CO_{2e} per year.

Ammonia emission reductions affects the risk for EU penalties for non-compliance as well as health sector costs.

By implementing their SAT potential, four of the EU Member States in the Region, DA, DE, EE and SE, would avoid EU penalties of a total value of a minimum of M€ 16.6, provided the implementation happen latest in 2020. For these countries, the use of SATs would mean, that they would meet their ceilings for ammonia emissions by 2020. FI, LT and PL are already on track to meeting their defined ammonia emission ceilings but would due to the human healthcare sector and other advantages anyway have considerable economic benefits from using SATs. For LV, the situation is that current ammonia emission levels are far above the ceiling, and the use of SATs would contribute to meeting the ceilings, but other measures have to be employed as well.

The health sector savings from cleaner air are considerable and the capitalised value amounts for the eight EU Member States M€ 2,421. Cleaner air has especially high value in Germany, Poland and Denmark, respectively 22, 12 and 10 € per kg N in ammonia emissions (Sutton et al., 2011).

For greenhouse gases, the value on the emission trade market is currently € 21.9 per ton, and the value of 1.5 Mt CO_{2eq} is M€ 33.4.

Threats

In perspective of the farms, SATs affect business economy via impacts on revenues, investments and operational costs. At normal livestock densities, the main impact on the farm business economy is related to the investment costs, whereas slurry acidification has minor impacts on the operational costs. This minor impact on operational costs is conditioned the purchase of S as sulphuric acid is not exceeding the need for crop fertilising, and in case the purchase of mineral N fertiliser is reduced with an amount that equals the avoided N loss via ammonia emissions.

Field trials and other research carried out in the project has not given any clear picture related to impacts on yields, soil microbial activity, soil pH, or corrosion of concrete; some countries have for some crops experienced higher crop yields, others none or lower yields, and effects are not consistent across the Region. According international research, any fertilisation has an acidifying impact on soils. In line with that, research within the project has not proven any significant effect on soil pH due to use of acidified slurry.

Use of high levels of sulphuric acid per tonnes of slurry, such as the case for in-house acidification or acidification of digestates, would in combination with high doses of acidified slurry per ha result in a high S application rate per ha, well above the S fertilising need of crops, normally within the range of 15-50 kg per ha. This would result in leaching of S to the aquatic environment. Elevated S-concentrations in water bodies, following such practices over a long-term, would firstly affect the organoleptic quality (WHO, 2004) of drinking water.

Recommendations

Based on the combined advantages and disadvantages as appear from a SWOT matrix method analysis, the recommendation to the eight EU Member States in the Region is to implement the use of SATs, whereas the immediate recommendation is to establish official expert work groups to consider the impacts of this, and the way to do it. Hence, it is recognised that analysed information and results related to the individual countries as presented in this report are made without knowledge to possible specificities of the legal and institutional context that were not comprised by the studies.

For the five north-western regions in Russia as well as for Belarus, there is no immediate and sufficient basis for recommending the implementation of SATs use. The policy context in these countries is different from that of EU, and the value of SATs use is unclear.

1: Introduction to the slurry acidification technology environment; related objectives and policy context

Livestock manure is the main source of ammonia-nitrogen emissions in the Baltic Sea Region (BSR), which through atmospheric deposition accounts for an important share of the nitrogen entering the Baltic Sea.

Slurry acidification has been developed and tested over the last three decades (Fangueiro, 2015). The technology is widely recognized, for example by the Danish Environmental Protection Agency through VERA verifications and admission to the Danish Technology List (DEPA, 2018), and by the EU (2017) which has given Slurry Acidification status as Best Available Technique (BAT) in all EU Member States, i.e. made it one of the BATs that the environmental authorities in all EU countries can condition the environmental permitting of intensive livestock farms.

The pH of liquid manure or processed residues thereof, for instance digestate from biogas plants, has typically pH levels between 6.5 and 8, lowest in pig slurry and highest in digestate. pH is by use of slurry acidification technologies (SATs) lowered to a level between 5.5 and 6.4, which is comparable to or a bit higher than the normal pH of rain water[2]. The acidification is usually done with sulfuric acid, as the cost of the acid thereby results in savings for purchase of mineral fertiliser sulphur for the crops. Slurry acidification can also be done by other means, e.g. by use of acetic acid (Hjorth, 2016), which may be interesting for certified organic farming, which does not allow the use of sulphuric acid. The addition of acid affects the buffer systems in the slurry, and of special interest is the equilibrium between volatile ammonia (NH_3) and non-volatile ammonium (NH_4^+). By reducing the pH to 6.4, the equilibrium is shifted towards non-volatile ammonium and the evaporation of ammonia reduced to a minimum. Normally, about two thirds of the nitrogen in raw, liquid manure is found on ammonia or ammonium form, together called mineralised nitrogen or total available nitrogen (TAN). The rest of the nitrogen is organic bound and not readily available for the crop before further decomposition has taken place. Processed residues of manure, such as digestates or separation liquids, may even have a higher share of mineralised nitrogen than raw slurry.

There are three main types of slurry acidification technologies; in-house, in-storage and in-field acidification. In-house acidification reduces ammonia emissions from livestock housing and slurry storing as well as from field spreading, while the other two

[2] For comparison, pH in rain water is normally within the range of 5-6, whereas acid rain has a pH below 5, and pure, distilled water a neutral pH of 7 according various sources, e.g. https://chemistry.stackexchange.com/questions/71592/difference-in-ph-of-water-and-rainwater.

types alone affects ammonia emissions during field spreading. However, in-storage acidification may be done so early in the process that ammonia emissions are reduced from storage as well. Depending on the acidification method and manufacturer, the VERA verified effect of slurry acidification is between 40 and 64% according the Technology List (DEPA, 2018).

Picture 1: Slurry acidification technologies comprise in-field, in-house, and in-storage technologies.

The farm business economy is affected by use of SATs due to investment costs and operational costs as well as associated savings and benefits, while the use also have wide impacts for the society via effects on air quality, water quality and greenhouse gas emissions.

The following table summarizes the mentioned advantages of SATs:

Table 1: Advantages of slurry acidification technologies.

Perspective	Advantages of slurry acidification technologies
Society, politicians, policy makers	Agriculture is the source of 93% of all ammonia emissions in the EU (Eurostat, 2017) and BSR countries are committed to improving air quality with strict targets for reducing ammonia emissions (EMEP, 2014; HELCOM, 2013; UNECE, 2012). SATs can reduce ammonia emissions between 40 - 64% from livestock houses, slurry storage tanks and from field application of slurry depending on which SAT is used (Danish EPA, 2018). Furthermore, SATs can decrease greenhouse gas emissions from livestock production by reducing nitrous oxide emissions that are indirectly related to ammonia emissions (IPCC, 2006) and, since sulfuric

Perspective	Advantages of slurry acidification technologies
	acid inhibits methanogenesis, by reducing methane emissions from slurry storages (Petersen et al., 2011). Due to documented benefits, SATs appear in chapter 5 of the Reference Document for the Intensive Rearing of Poultry or Pigs (BREF) (European Commission, 2017) and EU has in line with that made SATs mandatory BATs in all EU Member States (European Commission, Joint Research Centre, 2017).
Farmers	Farmers benefit directly from reducing ammonia emissions by saving nitrogen in their slurry which reduces the need to purchase mineral nitrogen fertiliser or gives increased crop yields without changed fertiliser application. Further benefits arise from using sulfuric acid which acts as a S fertilizer and thus saves the cost of mineral S fertilizers. Via legislation, Danish farmers have been given an additional advantage that they do not need to inject slurry on bare soils or grass fields when using acidified slurry. Also, they save investment costs for storage tank covers in case they use in-house acidification.
Biogas plants	Research results indicates that 10 – 20% acidified slurry can stimulate the methane yield during anaerobic digestion by almost 20%, whereas larger amounts negatively affect the biogas production. Also, when using slurry separation there are very promising results with addition of 30% separation solids, which increases biogas yields with approximately 50% compared to a biogas plants utilizing only slurry. (Møller & Moset, 2013)

The following sections presents the objectives and impacts related to the use of SATs, seen in the perspective of the farming businesses and the society, respectively.

1.1: General objectives and SAT impacts for the farming businesses

An inherited, basic objective for a normal, commercially operated farm business would be economic survival, and the best guarantee for this be maximisation of the profit.

This view is largely confirmed by Thiermann (2018), an agro-economic student of Christian-Albrechts-Universität Kiel, who for her master thesis conducted Discrete Choice Experiments to assess the factors that influence farmers willingness to use in-house and in-field SATs. Thiermann (2018) concludes on basis of 130 responding farmers that the most important factors for choice of in-house acidification are the amount of refund of costs, and relief of regulations to avoid investments in solid cover on slurry tanks and costs for slurry injection. It is also important for the farmers to reduce ammonia emissions, but the economic factors are most important. The willingness to use in-house acidification is lowest for the oldest farmers, the largest farms, and those who on beforehand use slurry separation. For in-field acidification, Thiermann (2018) concluded on basis of 144 responding farmers that the emission reduction effect is of highest importance, whereas the amount of refunds also is important, and these farmers also see the higher amount of nitrogen as negative. 82, respectively 91% of the respondent farmers said they are willing to participate with their own farm in promotional programs concerning in-house and in-field acidification.

The main aim of this section is on this background to analyse the farms business economic impacts of SATs use. Hence, the following lists the general types of farm effects and their typical economic impacts for individual farms businesses, whereas detailed feasibility studies must be made for specific cases.

Investments

Investment costs for SATs may vary for the individual farm, especially for in-house acidification equipment, depending on the required capacity and the given conditions. Based on Foged (2017a), we assume average investment costs follows these price indications:

- An in-house slurry acidification facility as offered by JH Agro costs at least € 90,000 and is often more expensive for pig farms with several barn buildings, than for cattle farms with all animals kept in one building. In round figures it is assumed that an average plant cost € 135,000.
- In-storage equipment costs approx. € 13,500, a little cheaper for ØRUM's equipment and a little more expensive for HARSØ's.
- An in-field SyreN system from BioCover costs approx. € 65,000 incl. mounting.

In-field and in-storage technologies are add-on equipment to other, slurry handling machinery, such as slurry pumps and slurry tankers. The investment costs for the basic machinery are not included in the above price indications.

There are according Danish Environmental Protection Agency (Peters, 2016) 140 facilities for in-house acidification, 75 for in-storage acidification and 110 for in-field acidification in Denmark, a total of 325 installations that can produce approx. 6.6 million tons of acidified slurry per year, given a capacity per installation of approx. 9,300, 21,300 and 33,600 tonnes per year for in-house, in-storage and in-field acidification, and a market share of the three SAT types of 20, 24 and 56%, respectively. SAT installations are of course most cost-effective in case their capacity is fully utilised. Whereas an in-house acidification system is stationary and alone used by one farm, in-storage and in-field acidification systems are mobile and having capacities above most farms' needs, which makes them relevant investment objects for contractors.

Operational costs

Operational costs for SATs comprise consumption of sulphuric acid, extra needed liming, extra consumption of energy and extra labour consumption. In case the in-storage or in-field acidification is done by a contractor as part of slurry spreading services, these would normally be more expensive:

- The consumption of sulphuric acid has over several years been followed by SEGES in connection with field trials with slurry acidification – see Table1.

  Table 1: Average consumption of sulphuric acid, litres per tonne of slurry / digestate (after Nørregaard Hansen and Knudsen, 2017).

	SAT type		
	In-house	In-storage	In-field
Cattle slurry	4.5	3.6	3
Pig slurry	3.5	3.0	2.6
Digestate	N/A	-	7.9

  For sulphuric acid, a typical price level is € 0.27 per litre, the density 1.84 kg per litre, and the weight-based sulphur content app. 35% = 0.64 kg sulphur per litre.

- Agricultural lime costs under € 25 per tonnes. The amount of lime needed to neutralise the sulphuric acid could vary with the soil type and other parameters. It can be expected that extra liming would amount to 1 - 1.8, or averagely 1.4 kg of lime per liter of sulfuric acid consumed (after Nørregaard Hansen and Knudsen, 2017). However, other ways of fertilising and use of mineral fertiliser also acidify the fields and require periodic liming, e.g. according University of Adelaide (Undated).
- Extra consumption of electricity would alone be considerable for in-house acidification and be relatively small compared to the entire economy for using SATs. The same is the case for costs for extra consumption of fuel in case of in-storage and in-field acidification, and extra labour costs. We will therefore disregard these costs in a macro-economic perspective.
- Contractor services for slurry spreading with band laying system costs according DM&E (2017) in Denmark averagely € 2.44 per tonnes, and an extra cost of averagely € 0.18 per tonnes if this is done in combination with in-storage or in-field acidification, for covering the contractors' investment in SAT technology.

Avoided investments

The use of in-house acidification would justify the saving of investments in solid covers on slurry tanks, which typically makes a slurry storage tank of a size of 10,000 m^3 approximately € 75,000 cheaper, with variations that e.g. depends on the type of solid cover.

The avoided investment is of course alone relevant for farms, where solid covers on slurry tanks are required.

Avoided costs for natural crust or alike are marginal in a macroeconomic perspective.

Avoided operational costs

Potentially avoided operational costs includes the saving of extra costs for injection of slurry, and saving on the purchase of nitrogen and sulphur fertiliser:

- Contractors' slurry spreading service prices are in cased of injection and according DM&E (2017) € 14.77 per hour, or about 8% higher than similar services done by use of band laying systems. Consequently, taking prices and capacities per time unit into account, the savings would amount to about € 0.50 per tonnes of slurry for acidified slurry spread by band laying systems rather than raw slurry spread by use of injection.

  These possible savings are especially relevant for farms that have legal requirements for slurry injection.

- The avoided nitrogen loss via ammonia emissions by use of SATs corresponds according Nørregaard Hansen (2017) to 29-30 kg N per ha in case of in-house acidification, and 13-17 kg N per ha in case of in-storage or in-field acidification. For these indications, the avoided N losses are highest for cattle slurry and smallest for pig slurry. The figures assume normal slurry dosing rates in Denmark, typically 30 tonnes per ha, and corresponds therefore to app. 1 kg, respectively 0.5 kg avoided N loss per tonnes of acidified slurry for in-house acidification, respectively in-storage or in-field acidification. In case the nitrogen part of mineral fertilisers costs € 0.75 per kg N, the conserved nitrogen in the slurry has a corresponding value of € 0.75, respectively € 0.38 for in-house acidification, respectively in-storage or in-field acidification.

  Another way to calculate the value of the reduced ammonia emission would be to base this on the VERA verified ammonia emission reduction[3]. This would theoretically be a more correct way in case of feasibility studies for

[3] VERA Verifications are found at http://www.vera-verification.eu/vera-statements/.

individual farms, where the currently used field spreading technology, practice for incorporation, slurry qualities and other parameters are known.

- The use of sulphuric acid replaces the purchase of S-fertiliser in so far, the amount of S in the consumed sulphuric acid does not exceed the S-fertilising needs for the crop production on the farm in question, which could be the situation e.g. in case the farm has its own biogas production based on maize silage, or in case the animal density, and thus the net-use of purchased feed is very high on the farm. Assuming a typical sulphuric acid consumption as shown in Table 1 and an animal density of 0.5 Animal Unit[4], the average slurry dose per ha would be around 12.5 tonnes per ha per year, which for pig, respectively cattle slurry in case of in-storage acidification would give a consumption of (12.5 tonnes per ha x 3 litre sulphuric acid per tonnes x 0.64 kg S per litre sulphuric acid =) 24 kg S per ha, respectively 28.8 kg S per ha per year. This level of S-fertilising corresponds largely to the fertilising needs for crop rotations based on winter wheat and rape seed. In case S in mineral fertiliser has a value of € 0.5 per kg, the savings for purchase of S fertiliser would be app. € 1 per tonnes slurry.

Increased revenues

In Denmark, the conserved amount of nitrogen in acidified slurry was an appreciated possibility for giving crops more nitrogen than farmers due to tight nitrogen quotas were able to purchase in the years 1999 to 2016. Thus, the extra, preserved nitrogen in acidified slurry gave the crops higher yields (Vestergaard, 2015).

However, field trials organised in different countries within the frames of the Baltic Slurry Acidification project has not proven any general effect on crop yields, probably because involved countries have less tight fertiliser dosing regulations than Denmark had until 2016. However, weather conditions were atypical in both 2017 and 2018, wherefore more field trials must be carried out before solid conclusions can be made.

Changed subsidies

Farming subsidies in EU and other countries are prioritised according political objective and can be important incentives for investments or use of agro-environmental technology.

[4] Animal Units are used in Denmark and is defined as 100 kg N in the manure after storing according normative figures for manure.

Other impacts

Other farm-level impacts of slurry acidification include:

- Corrosion of concrete: Trials during the project period have been undertaken to measure the impact of acidified slurry on corrosion of concrete. Conclusions were not clear, and it may be needed to make tests over many more years to reveal any impacts, or opposite, to clarify the concrete quality needed for slurry channels etc. for acidified slurry. Danish experiences are that concrete qualities that are demanded for manure facilities are not corroded by acidified slurry. pH levels going down to 5.5 is a mild acidification, for instance being within the normal pH variation for rain water[5]. Besides that, any effect on corrosion of concrete would alone be relevant for in-house acidification. It could also be relevant in the case of in-storage acidification, but the period the concrete tanks might be exposed to acidified slurry would in that case normally alone count a few hours per year.
- Labour accidents: Sulphuric acid is classified as a substance with pH < 2 that is highly corrosive to skin and eyes. It damages the eyes irreversibly. It is so powerful that it leaves behind only carbon from organic materials such as paper. Skin is very quickly damaged in the same way. Sulphuric acid vapours can also be harmful to the respiratory tract and mucous membranes. Sulphuric acid is carcinogenic when inhaled as an aerosol.

  Due to the human health hazards when working with sulphuric acid, the SATs are to the extent possible designed to avoid the possibility for contact with the acid. Further, regulations prescribe the use of warning signs and safety clothing, as well as requirements to training, and in some cases also certification of people transporting the acid and managing the slurry acidification processes.

  In Denmark, where slurry acidification has been used commercially in more than 15 years, there has so far not been officially reported any labour accidents in connection to use of professional SATs. Nevertheless, rumours are that accidents have happened in Denmark in connection to amateurish handling of sulphuric acid by persons, who were not trained, did not use professional SAT technology, and neither understood or respected the needs for use of personal protection gear.

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[5] See e.g. https://chemistry.stackexchange.com/questions/71592/difference-in-ph-of-water-and-rainwater

Calculation models for individual farms

A report analysing a scenario for acidification of half of the Danish slurry production showed for selected types of farms that the losses due to slurry acidification amounts to € 0.4 – 1.5 per tons of slurry, where it is cheapest with in-field acidification on pig farms and most expensive with in-house acidification due to higher investment costs (Foged, 2017). Without investment costs, the losses are € 0.1 – 0.5 per tons of slurry. Similarly, acidification of degassed cattle slurry was estimated to costs € 3.0 and 2.3 per ton for respectively in-tank and in-field acidification due to the high sulfuric acid consumption and were not included in the scenario for acidification of half of Danish slurry production. The scenario calculations did not include any impacts on crop yields, and they applied a "worst case scenario" concerning additional need for liming of 1.4 kg extra lime per litre of sulphuric acid, which according University of Adelaide (Undated) is doubtful.

The scenario calculations were based at 100 kg N in manure ex storage per ha, which are considered to be a normal livestock density for Denmark. The main impact on the farm business economy were, with reference to the mentioned results, related to the investment costs, whereas slurry acidification has minor impacts on the operational costs in case the purchase of sulphuric acid is levelled out with savings on purchase of mineral S fertiliser, and in case the purchase of mineral N fertiliser is reduced with an amount that equals the captured nitrogen amount in the slurry. The overall conclusion of the Danish scenario report is therefore that operational costs of slurry acidification is of minor importance, compared to the investment costs.

The project has under work package 5 developed calculation models for the economic feasibility of SAT investments for individual farms in the covered countries. These calculation models compare use of slurry acidification with an alternative way to field spread slurry, namely incorporation of the slurry within 12 hours after spreading with band laying system.

Field trials and other research carried out in the project has not given any clear picture related to impacts on yields, soil microbial activity, soil pH, or corrosion of concrete; some countries have experiences higher yields for certain crops, others none or lower yields, and effects are not consistent across the Region.

According international research (University of Adelaide, Undated), any fertilisation has an acidifying impact on soils. In line with that, research within our project has not proven any significant effect on soil pH due to use of acidified slurry.

1.2: Air quality

Ammonia emissions stems 94% from farming and contributes to the entire air pollution. The negative effects of ammonia emissions are multiple as it affects the level of particles and ozone and contributes to acid rain and eutrophication of waters through atmospheric depositions. Ammonia emissions deteriorate human health, nature and environment. International policies related to ammonia emission and air quality in general is organised by United Nations Economic Commission for Europe (UNECE) on basis of the Convention on long-range transboundary air pollution (LRTAP) from 1979. The Convention is supported by HELCOM and EU, who since the Gothenburg Protocol from 1999 has integrated the LRTAP Convention and amendments into EU law. HELCOM connect atmospheric and waterborne nutrient loads to the Baltic Sea and has set country-wise targets for its total reduction, including for RU and BY.

While the ammonia emissions dropped by 33% from 1990 to 2005 for the eight EU Member States in the Baltic Sea Region, the development since then has been negative and moved away from the ceilings. The countries in the Region increased their ammonia emissions with averagely app. 3% from 2014 to 2016. While the emissions shall be decreased with 12% for the Baltic Sea Region countries in average from 2016 to 2020, and 26% in average until 2030, only Lithuania has currently emissions below the defined ceilings.

The hazard of ammonia emissions depends on their contribution to the entire air pollution from other sectors, such as transport and energy, and the situation is especially alarming in Germany, Poland and Denmark, for whom the European Science Foundation has estimated societal health costs of ammonia emissions to be 22, 12 and 10 € per kg ammonia emission, respectively (Sutton et al., 2011).

Ammonia and SOx emission sources and costs

Sulphuric oxides, especially sulphur dioxide (SO_2), stems mainly from combustion and the major sources includes heat and power plants. SOx is unwanted because it in moist air contribute to the formation of sulfuric acid, which returns to soils and waters with the precipitation and represents a thread against biotopes for flora and fauna. While SOx is a polluter of the air, its main constituent, sulphur (S) is in the same time one of the five most important crop nutrients. The current much reduced SOx emissions has made fertilising of crops with sulphur essential for the harvest yields, crop productivity and economic returns of crop farming, compared to the situation 30-40 years ago, where even crops with a high S need received sufficient amounts of S through atmospheric deposition.

Similarly, ammonia (NH_3) is a strong and unwanted polluter while its main constituent, nitrogen (N) is the most important macronutrient for crops. NH_3 contributes to acid deposition and eutrophication. The subsequent impacts of acid deposition can be significant, including adverse effects on aquatic ecosystems in rivers and lakes, and damage to forests, crops and other vegetation. Eutrophication can lead to severe reductions in water quality with subsequent impacts including decreased biodiversity, changes in species composition and dominance, and toxicity effects. NH_3 also contributes to the formation of secondary particulate aerosols, an important air pollutant due to its adverse impacts on human health.

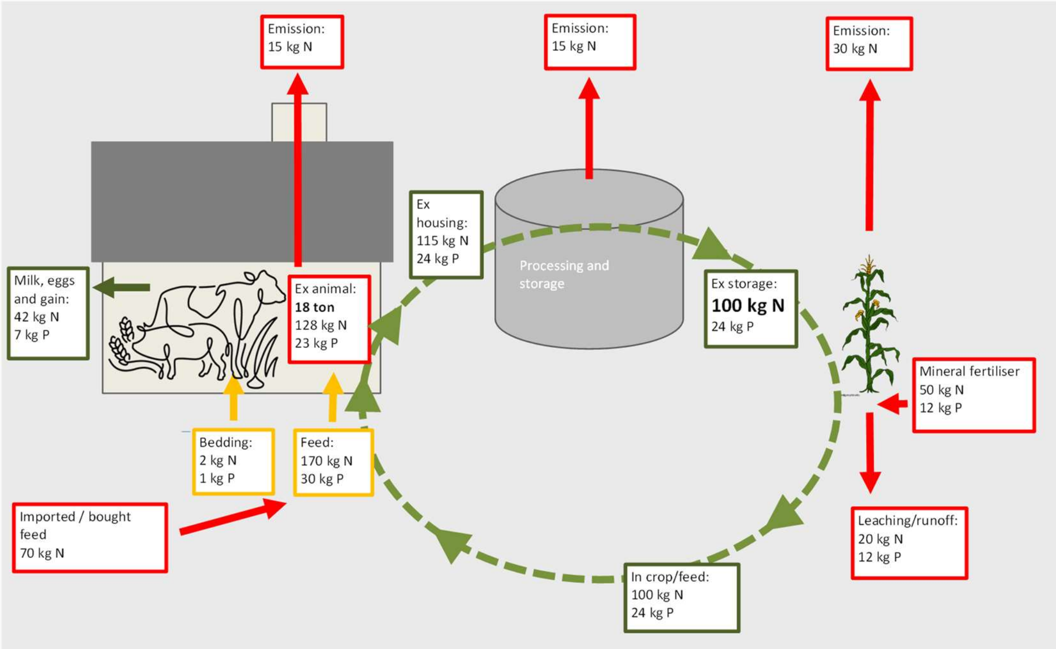

Figure 1: Manure handling at livestock farms is one of the main sources of ammonia emissions, and it can be divided into emissions from stables, manure stores and field spreading. Farms that respects good agricultural practices will normally loose more than half of the nitrogen – in this example 80 of 128 kg N, mainly due to ammonia emissions. This is far from circular economy, and it represents a big economic loss besides a high environmental burden.

It has been estimated (European Science Foundation, 2011) that the social health costs of ammonia emissions are 2-22 € per kg N for the countries in the Baltic Sea region, highest for Germany with 22 €/kg and lowest for Estonia with 2 €/kg. Similarly, EEA (2016) has estimated premature deaths associated with the 2013 levels of air pollution with PM2.5 (particulate matter with a diameter of 2.5 micrometres (µm)), NO_2 and O_3, which for instance in Poland's case is 51,030 premature deaths.

Political goals and initiatives

Having recognised the harmful effects of air pollution and acid rain, 32 countries in the Pan-European region, signed the "1979 Convention on long-range transboundary air pollution" (LRTAP), which entered into force in 1983. All eight EU Member States in the Baltic Sea Region are now parties to the Convention after it was ratified by the Baltic countries, latest Estonia in 2000. The effect of national commitments to the LRTAP led to a 17.9% ammonia emission reduction in EU-28 in the years 1990-95.

The 1999 Gothenburg Protocol to the LRTAP was ratified by the European Union on behalf of its Member States, who in 2001 issued the National Emission Ceilings Directive (NEC Directive), which strengthened the importance of the issue due to more direct possibilities for enforcement of the politically decided targets. Following this, the ammonia emission reduction targets for EU Member States has since 1999 been coordinated under the LRTAP Convention.

LRTAP decided on its thirtieth session in 2012 to adopt historic amendments to the Convention's 1999 Gothenburg Protocol and include national emission reduction commitments for 2020.

The latest development is that EU has issued a new Directive on the reduction of national emissions of certain atmospheric pollutants (2016/2284/EC), which came into force by 31 December 2016. The directive has replaced the NEC Directive, which was repealed by 1 July 2018. The new Directive holds EU Member State commitments for ammonia emission by 2030. Only three Baltic Sea Region countries, namely PL, DE and SE have committed themselves to lower 2030 ceilings compared to 2020 ceilings.

Table 2: Figures on adjusted ammonia emissions in the years 2014, 2015 and 2016, as well as ceilings for 2020 and 2030 for the eight EU Member States in the Baltic Sea Region as well as national totals for Russia and Belarus. The table also shows the distance to the ceilings, calculated as the percentage of needed emission reductions from 2016 to 2020 and 2030. (Main source: https://cdr.eionet.europa.eu/)

Country	2014	2015	2016	2020	2030	2020	2030
	Adjusted emissions, Kt			Defined ceilings, Kt		2016 distance to ceiling, % of ceiling value	
BY*	141.17	142.64	136.06	126**	126	-8	-8
DA	66.16	66.84	67.12	63.25	63.25	-6	-6
DE	601.47	609.68	601.50	593.83	443.81	-1	-36
EE	12.07	12.60	11.92	10.62	10.62	-12	-12
FI	31.65	30.09	29.72	29.88	29.88	1	1
LV	16.64	16.39	16.25	14.75	14.75	-10	-10
LT	34.60	34.72	34.03	34.12	34.12	0	0
PL	269.86	267.31	267.11	296.58	248.65	10	-7
RU*	840.12	882.37	900.25	-	-		
SE	54.41	54.3	53.1	49.25	48.09	-8	-10
TOTAL	1,228	1,235	1,217	1,218	1,019	-	-

** Source: http://www.ceip.at/ms/ceip_home1/ceip_home/webdab_emepdatabase/reported_emissiondata/, national totals.*
*** Source: Based on UNECE (2012).*

National legislation to implement the Industrial Emissions Directive (2010/75/EU) has a large role concerning limitation of ammonia emissions from farming. The Directive explicitly require EU Member States to take measures to reduce ammonia emissions on livestock holdings that have more than 40,000 places for chickens, 2,000 places for production of pigs (over 30 kg) or 750 places for sows. Joint Research Centre is coordinating the identification and description of Best Available Techniques (BATs) for reduction of the ammonia emissions, and the European Commission has in that connection decided to make slurry acidification a BAT for the entire EU (EU, 2017). It is in the interest of the Member States to reach their political commitments in the most cost-effective way, meaning by use of BATs, such as slurry acidification.

EU sanctions

It is clear from Table 2 that five EU Member States in the Region has 2016 emissions above their 2020-ceilings.

It should in this connection be kept in mind that an important objective in relation to reach of EU legally defined ceilings is to avoid infringement procedures leading to penalties for non-compliance.

In principle, the Commission can open an infringement procedure against a Member State that fails to limit its annual anthropogenic emissions of ammonia in accordance with the national emission reduction commitments applicable from 2020 as stipulated in Article 4(1) and Annex II of Directive 2016/2284[6]. The same applies to all EU legislation.

If the Member State, despite the Court's judgement, still fails to comply with its obligations, the Commission can refer the case back to the Court proposing the imposition of financial penalties[7].

As the calculation depends on several factors, such as the seriousness of the infringement, the impact of the infringement on general and particular interests, its duration and the Member State’s GDP, it is not possible to give an indication of the size of possible financial penalties. However, it can as an example be mentioned that one of the factors for calculation of penalties, the so-called “lump-sum” for Germany is defined to be M€ 11.8.

It should also be mentioned that the EU Commission checks the quality of the data reported by Member States about pollutants inventories and projections as required

[6] For detail on the stages of an infringement procedure please consult the following web-page: https://ec.europa.eu/info/law/law-making-process/applying-eu-law/infringement-procedure_en.

[7] Information on the method used to calculate the amount of the penalty payments can be found at: http://ec.europa.eu/atwork/applying-eu-law/infringements-proceedings/financial-sanctions/index_en.htm.

in art. 10 of Directive 2016/2284, and also monitors the national ammonia emission models annually.

Hydrogen sulphide (H_2S)

Hydrogen sulphide is a dangerous / hazardous gas that (alike methane) is produced by bacteria in the slurry. This means that the production of the gas is a continuous process. Some gas slips away, but the main part is captured in the slurry structures as small bubbles, that are released when the slurry is agitated. This means that the longer the slurry has been stored before agitation, the higher is the hydrogen gas release when agitated. It has a great importance how the slurry system is designed, and if the slurry is floating out of the stable by gravity forces to a pumping pit outside the barn, then the main hydrogen sulphide part is released in the pumping pit. This is the reason why many countries, including Denmark, does not allow pumping of slurry inside stables, and have requirements to the maximal size of slurry channels under the stables; the bigger they are the higher amount of hydrogen sulphide could be released inside the stable.

In-house acidification is in two ways reducing the risks with hydrogen sulphide:

- The low pH is in itself reducing the activity of the hydrogen sulphide producing bacteria, which have a growth range of pH 5.5 to 8.5[8];
- The often recirculation of the slurry in case of in-house acidification would lead to smaller amounts of hydrogen sulphate to be accumulated in the slurry, compared to similar slurry systems without in-house acidification, and in-house acidification systems are designed with pumping/agitation happening outside the stable in a pumping pit.

Thus, there will be higher release of hydrogen sulphide, when slurry is moved or agitated, whether acidified or not. The VERA Verification Statement behind the approval of JH Agros in-house acidification system for pigs (VERA, 2016) states in line with this: "An increased hydrogen sulphide concentration was observed when the daily flushing of the manure took place during treatment of the manure. The higher H_2S levels lasted less than 1 hour per day. To prevent any risks for the user, the stirring of the slurry is done outside the animal house in the process tank which is equipped with decals warning against H_2S."

The concentrations of hydrogen sulphide during recirculation of slurry in case of in-house acidification was measured by the Danish Pig Research Centre. The trial report[9] shows that in-house acidification caused 67% lower hydrogen sulphide concentration in the stables, which is a highly significant difference ($P<0,001$), and a difference that

[8] http://www.filtronics.com/literature/technical/electromedia-systems/hydrogen-sulfide.pdf
[9] http://svineproduktion.dk/publikationer/kilder/lu_medd/2016/1078

appeared despite it could be expected that the higher S-content in the slurry would give better basis for the hydrogen sulphide formation. However, the measurements were only point measurements, and more research is needed to fully clarify the impact of slurry acidification on hydrogen sulphide concentrations in stables.

Smell

Pedersen and Albrechtsen (2016) found a statistically significant smell reduction effect of 32% with in-house acidification. However, the results are alone based on point measurements, and more research is needed to fully clarify the impact of slurry acidification on smell. A smell reduction effect of slurry acidification has not been documented via official tests, such as via VERA verifications, and various field tests have shown varying results. Although the tendency is clear for a smell reduction effect of slurry acidification, the situations and mechanisms causing the smell reductions has not been described and probably the management of the slurry acidification system has an impact on the effect.

1.3: Water quality

Aiming to have a Baltic Sea unaffected by eutrophication, HELCOM Contracting Parties – Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden, agreed in 2007 within the Baltic Sea Action Plan on applying a Nutrient Reduction Scheme. HELCOM Nutrient Reduction Scheme is a regional approach to sharing the burden of nutrient reductions to achieve good environmental status the of the Baltic Sea. It was estimated in 2007 that for achieving this goal, the maximum allowable annual nutrient pollution inputs (MAI) into the Baltic Sea would be 21,000 tonnes of phosphorus and about 600,000 tonnes of nitrogen. Annual reductions of some 15,000 tonnes of phosphorus and 135,000 tonnes of nitrogen would be required to achieve the plan's crucial "clear water" objective. In 2013, the HELCOM Copenhagen Ministerial Meeting adopted the revised HELCOM nutrient reduction scheme.

One of the main components of the nutrient reduction scheme is the Country-Allocated Reduction Targets (CART), indicating the target for HELCOM countries' reduction of atmospheric and waterborne nutrient inputs of total nitrogen and phosphorous, compared to a reference period from 1997 to 2003. The 2013 HELCOM Ministerial Meeting also stressed that the achievement of good environmental status for the Baltic Sea also relies on additional reduction efforts by non-Contracting Parties.

The updated CART (2013) are calculated for waterborne and airborne inputs of nitrogen and for countries and specific sub-basins. That is why it might be extra reduction for one basin which cannot be directly accounted within progress for the whole country due to missing reduction to another basin. Moreover, there are no strict amount which should be reduced via air or via water, and the country can decide how to reduce the total load.

Ammonia emissions have a significant effect on airborne eutrophication of the aquatic environment, with 40-65% of the emitted nitrogen returns as atmospheric depositions (Det Økologiske Råd, 2001). In the case of slurry acidification, ammonia emission of 1,000 tonnes corresponds to 823 tonnes of nitrogen, whereof 40-65% later appears as atmospheric depositions, equal to 330 - 541 tonnes. Some of this fall on cultivated fields, where the crop norms in some cases takes this into account, but the majority may be assumed to fall over sea, lakes and streams, or on non-cultivated areas, which form the largest part of the territories of the Baltic Sea region countries. The background load is typically in the range of 8 - 15 kg N per ha, highest in residential areas. A significant part of the nitrogen "drops" down close to the source. Depending on vegetation and terrain, approx. 20-60% of ammonia emissions falls down within 1-2 km from the source as so-called “dry deposition”. On the other hand, ammonia bound to dust particles will in the atmosphere typically be transported over long distances, and much of this fall down as “wet deposition” over the sea. Concretely for HELCOM members, the airborne deposition of N is estimated using the EMEP / MSC-W model and is based, inter alia on data for ammonia emissions in the member countries (Bartnicki & Benedictow, 2016).

Table 3: 2007 and 2013 CARTs on nitrogen for HELCOM and non-HELCOM countries, as well as progress towards CARTs for 2014.

Country	2007	2013	2014	
	Country-Allocated Reduction Targets for all sub-basins, Kt/a		Extra reduction (total input) compared to ceilings for Baltic Sea basins since 1997-2003, Kt/a	Missing reduction (total input) to fulfil ceilings for Baltic Sea basins since 1997-2003, Kt/a
DA	17.21	2.89	10.17	0
DE	5.6	7.17 +0.5*	3.36	7.28
EE	0.9	1.8	0.90	1.08
FI	1.2	2.43 +0.6*	0.33	1.72
LV	2.56	1.67	7.22	5.40
LT	11.7	8.97	0.04	18.51
PL	62.4	43.61**	0.10	27.54
SE	20.78	9.24	15.97	1.87
RU	6.97	10.380*	0	24.72
Transboundary Common pool*** (including BY)	3.78	3.32 1.98	0 0	11.11 7.40

** Reduction requirements stemming from*

- *German contribution to the river Odra inputs, based on ongoing modelling approaches with MONERIS;*
- *Finnish contribution to inputs from river Neva catchment (via Vuoksi river);*
- *these figures include Russian contribution to inputs through Daugava, Nemunas and Pregol*

*** At this point in time Poland accepts the Polish Country Allocated Reduction Targets as indicative due to the ongoing national consultations, and confirms their efforts to finalize these consultations as soon as possible*

**** Non-HELCOM countries*

Per the latest results of HELCOM assessments (Table 3) the following conclusions can be made:

- Denmark is the only country that have fulfilled nitrogen ceilings to all HELCOM sub-basins.
- Finland and Sweden met their nitrogen ceilings to all HELCOM basins except to the Baltic Proper and the Gulf of Finland where missing reduction is less than 10% of the input ceilings for these countries.
- Russia and Belarus exceeded their ceilings to all sub-basins.

Reductions in the airborne deposition of nitrogen due to reduced ammonia emissions is not recognised in Denmark in relation to the objective of the Food and Agriculture Package to reduce nitrogen emissions to the aquatic environment by approx. 6,000 tons in the period 2016-2021. This being despite Denmark is a full member of HELCOM, who according the above recognises airborne eutrophication equally with other forms of nitrogen discharges to the aquatic environment.

1.4: Climate change

Greenhouse gas emissions (GHG emissions) are recorded in so-called GHG emission inventories submitted to the United Nations Framework Convention on Climate Change (UNFCCC) and form the official data for international climate policies.

Farming, forestry and fishing were responsible for 12% of GHG emissions in EU-28 in 2015 (Eurostat, 2017). Nitrous oxide (N2O) and methane (CH4) are the major greenhouse gases from the farming sector. They amount to approximately 43 percent and 55 percent of total emissions. The carbon dioxide emissions (CO2) represent only approx. 2 percent.

The greenhouse gas emission policy framework is complex and includes GHG accounts, GHG inventories, an Emissions Trading System (EU ETS), and overall policy objectives that has been converted to decisions about so-called "effort-sharing", which are national commitments to reach the overall policy targets. National Renewable Energy Action Plans (NREAPs) plays important roles as instruments for reach of the overall and the effort-sharing targets.

The general policy objectives for GHG emission are reductions of 20% from 1990 to 2020, and 40% from 1990 to 2030 for EU as a whole[10].

Table 4 presents GHG figures concerning the eight EU Member States in the Baltic Sea Region. Generally, the 2020 effort-sharing targets are highest for the four oldest EU Member States in the Region. Germany is the only country in the Baltic Sea Region that is behind the expected GHG emission reduction, thus having a clear need to strengthen its efforts in that respect, while the other seven EU Member States in the Region are on track or have so far achieved higher GHG emission reductions than expected. Seven of the eight EU Member States in the Baltic Sea Region, meaning all of them except Lithuania, needs to reduce GHG emissions until 2030.

Table 4: Figures on actual Greenhouse Gas Emissions for 1990, 2005 and 2015, as well as decided effort sharing for 2020 and 2030 for the eight EU Member States in the Baltic Sea Region. Calculated ceilings, that are above actual 2015-emissions, are underlined.

Country	1990*	2005*	2015*	2020**	2030**
	Actual emissions, $MtCO_{2e}$			Effort-sharing decision, % in relation to 2005-emissions / ceiling, calculated as $MtCO_{2e}$***	
DA	72	69	51	-20 / 55	-39 / 42
DE	1,263	1,015	927	-14 / 873	-38 / 629
EE	41	19	18	11 / 21	-13 / 17
FI	72	71	58	-16 / 60	-39 / 43
LA	26	12	12	17 / 14	-6 / 11
LT	48	23	20	15 / 26	-9 / 21
PL	487	400	388	14 / 456	-7 / 372
SE	73	69	56	-17 / 57	-40 / 41
TOTAL	2,082	1,677	1,530	-	-

* Source: http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics_-_emission_inventories

** Source: https://ec.europa.eu/clima/policies/effort_en

*** Own calculations.

[10] https://ec.europa.eu/clima/citizens/eu_en

Thus, in relation to climate change, the EU Member States in the Region are obliged to reduce greenhouse gas emissions with 354 $MtCO_{2e}$ until 2030, equal to about 23% compared to 2015 levels.

Methane (CH_4)

Slurry acidification has a positive impact on GHG emission reductions, inter alia since methanogenesis in the slurry is inhibited by pH's deviating from its optimum at 7.0 (Hilhorst et al., 2002). Methane is formed during storage of slurry and increases with the duration of the storage period as well as the temperature during storage. The effect is significant, and Petersen et al. (2011) has found an effect of acidification of 67-87% and Summer (2016) an effect of the same order of magnitude. The effect of slurry acidification on methane emissions is especially important in the case of digestate, which has a higher temperature when leaving the digester tanks, as well as a higher pH value, both being factors that promote methanogenesis. In addition, digestate is being in the methanogenesis-process when pumped from digester tanks to storage tanks.

Overall, the effect of in-house acidification is estimated to be a greenhouse gas emission reduction of approx. 16 kg CO_{2eq} / ton for cattle (including a share of 72% from methane) and 44 kg CO_{2eq} / ton for pig (including a share of 88% from methane) according Olesen et al. (2018).

Laughing gas (N_2O)

Use of SATs can decrease greenhouse gas emissions from livestock production by reducing nitrous oxide emissions that are indirectly related to ammonia emissions (IPCC, 2006). However, the effect on laughing gas emission reduction is relatively small and not so well documented as e.g. the effect on ammonia emissions. The effect is estimated by Tommy Dalgaard from Aarhus University to be 0.7% in case all Danish cattle slurry is in-house acidified, and 0.4% if all slurry is in-house acidified (Dalgaard, 2017).

1.5: Other impacts

Use of high levels of sulphuric acid per tonnes of slurry, such as the case for in-house acidification or acidification of digestates, would in combination with high doses of acidified slurry per ha result in a high S application rate per ha, well above the S fertilising need of crops, normally within the range of 15-50 kg per ha. This would result in leaching of S to the aquatic environment. The effects of sulphate leaching for the soil processes and for the recipient has been the subject of several studies, such as those mentioned by Olesen et al. (2018). So far, the conclusions are that the subject need further studies in order to clarify possible risks for negative impacts of elevated sulphate concentrations in soils and recipients.

2: Method and organisation

The main aim of this report is to give policy makers the best possible basis for decisions about implementation of slurry acidification in their country in the Baltic Sea Region. Thus, the report presents compiled results and recommendations of policy nature of the entire Baltic Slurry Acidification project, including the highlighting of strength, opportunities, weaknesses and threats of the use of slurry acidification technologies in the Baltic Sea Region and the individual countries of the Region. The report is also providing documented evidence of possible barriers and enablers for disseminated use of slurry acidification in the individual Baltic Sea Region countries.

The report is based on background information in the form of synthesized outputs, analyses and conclusions of activities 6.1 and 6.2 concerning market feasibility and legislation as well as those of other work packages, such as WP2 concerning technical feasibility, WP3 concerning the installation of slurry acidification equipment, WP4 concerning practical observations from the performance of field research with slurry acidification, and WP5 concerning estimated environmental and economic impacts of the up-scaling of the use of slurry acidification.

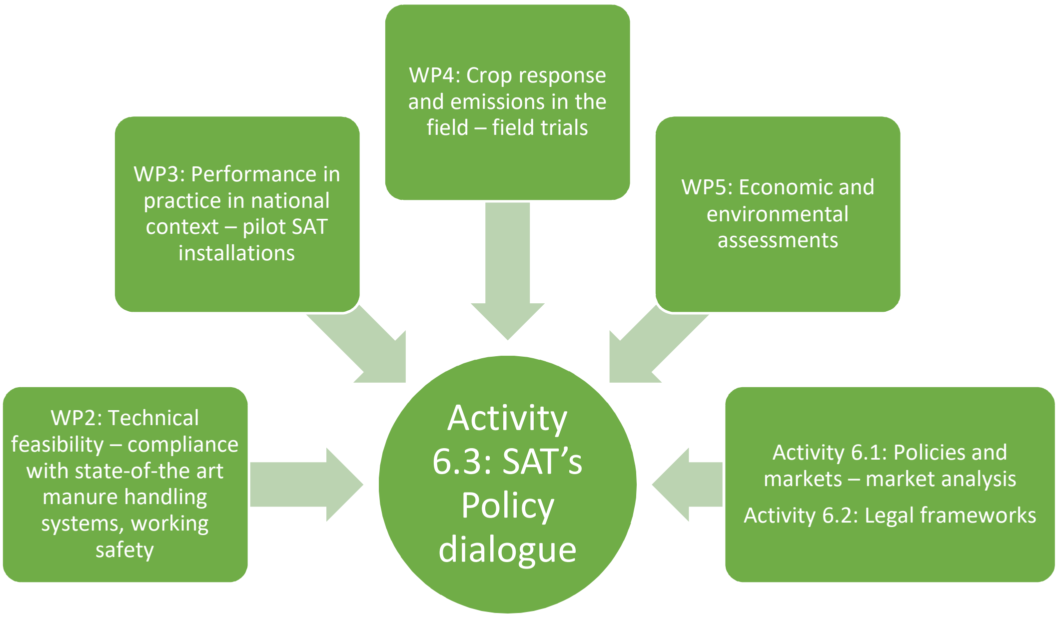

Figure 2: The report is based on background information of synthesized results and recommendations across the entire project and is thus considering all relevant technical, economic and legal aspects of slurry acidification.

The policy recommendations are specified for each of the EU Member States in the Baltic Sea Region and take into consideration the situation in the specific country. There can be several scenarios, such as good technical feasibility and no legal barriers, but a small market; a good economic feasibility and a large market, but severe legal barrier; etc.

2.1: Method

The SWOT matrix has been used for analysing and presenting the various project results and policy recommendations.

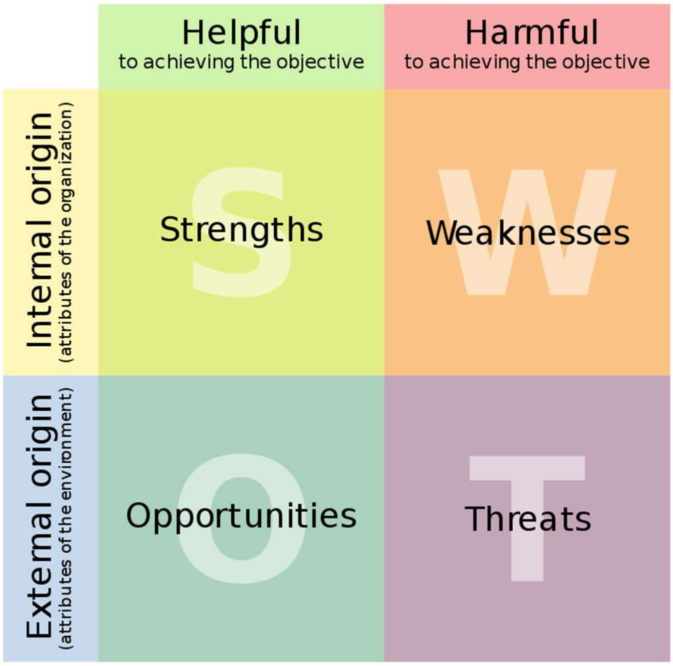

Figure 3: The SWOT matrix is used for analysing the background information and presenting policy recommendations.

Whereas a SWOT analysis often is used in relation to strategic planning for organisations, the perspective is in this case the countries of the Baltic Sea Region. This means that an external factor (attribute to the environment) is related to the extra-country context, such as internationally determined policy goals for air quality or nitrogen loads to the Baltic Sea, including atmospheric deposition of nitrogen. An internal factor (attribute of the organisation) is related to the situation within the country in question, such as national legislation or support schemes, or the national market economic situation that determine the impact of slurry acidification on the farms' economy.

The SWOT matrix relates to the objective. We have thus clarified the quantified target/ceiling for each country in relation to the social impacts of slurry acidification, which are defined in the introduction section as

- Air quality / ammonia emission
- Water quality / atmospheric N deposition
- Climate impact / greenhouse gas emissions

Another, inherited objective is food security and the profitability and competitiveness of the agro-food sector. Therefore, the economic impacts of slurry acidification on the farm production are key components of the report.

2.2: Organisation

This report has been prepared on basis of i) an initial identification of relevant reports, followed by ii) work package leaders' analysis of them according the SWOT matrix, and iii) country representatives' cooperation on formulation and/or editing of national recommendations across the work packages. The organisation is visualised in Figure 3.

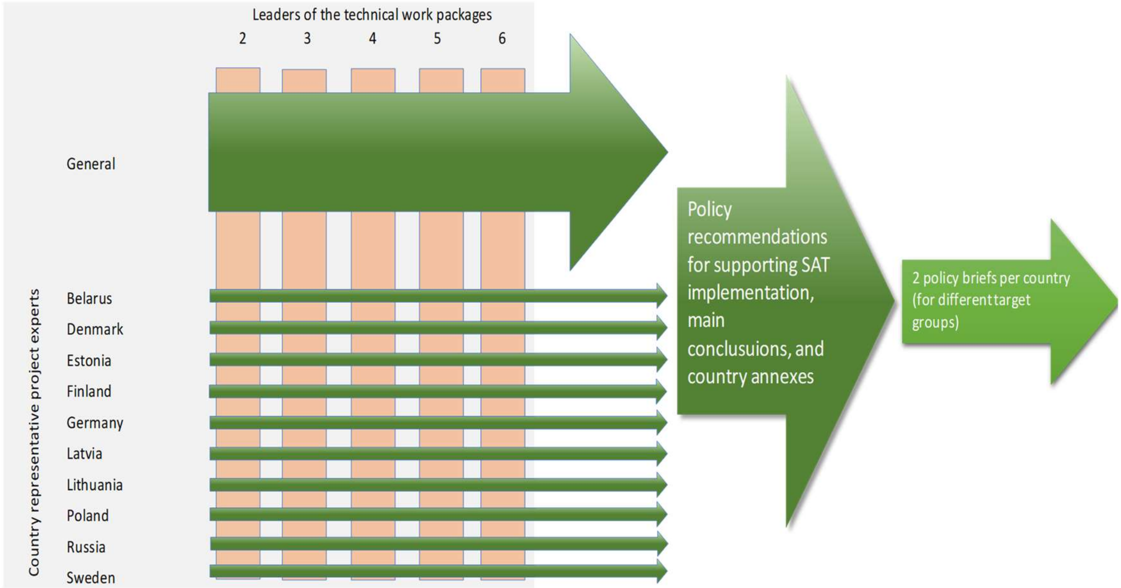

Figure 3: Organisation of the preparation of this report and related policy briefs with main messages.

3: Summary of policy recommendations for individual Baltic Sea Region countries

Policy recommendations for implementing the use of SATs in a given country should be based on clear advantages, which is the reason for going through the strengths, weaknesses, opportunities and threats before presenting the actual policy recommendations.

3.1: Strengths

Strengths are according SWOT terminology helpful, internal issues in relation to reach the objectives that are listed up in section 1.

The following tables lists the strengths for the different countries and for the whole Baltic Sea Region.

Table 5: Strengths related to SATs use for clear waters and clean air for the different countries and for the whole Baltic Sea Region.

Country	Weighed potential for slurry acidification, million tonnes of slurry*	Other strengths
BY	14.3	-
DA**	14 (25)	SATs are developed in Denmark, where they are well-known and used on beforehand, which is an advantage in case of upscaling. Suppliers' commercially offered equipment is officially recognised as BATs that livestock farms can use for obtaining environmental permits.
DE	159.5	-
EE	1.6	-
FI	3.9	-
LA	0.9	-
LT	1.5	-
PL	21.6	-

Country	Weighed potential for slurry acidification, million tonnes of slurry*	Other strengths
RU[11]	3.3	-
SE	13.4	-
TOTAL	234.0	Experience and commercial solutions are available in the Region.

** The weight potential considers a number of important market-related factors, such as the availability of contractors, and the role of ammonia emissions in environmental permitting.*

*** For Denmark, we are alone considering an increased use of 14 million tonnes of slurry, which in combination with the present use brings the total use to a level of app. 17 million tonnes, or app. half of the entire Danish slurry production.*

For all EU Member States in the Region (the issue was not analysed for Belarus and Russia), legislation and standards, as well as infrastructure is in place for handling of sulphuric acid, including regulations for road transport and storage of sulphuric acid.

3.2: Weaknesses

Weaknesses are according the SWOT matrix harmful, internal issues in relation to reach the objectives that are listed in section 1.

The following tables lists the weaknesses for the different countries and for the whole Baltic Sea Region.

Table 6: Weaknesses related to SATs use for clear waters and clean air for the different countries and for the whole Baltic Sea Region.

Country	Installations needed*				Corresponding investment need, M€	Corresponding annual costs for depreciation, interest and maintenance, M€
	In-house	In-store	In-field	In total		
BY	307	161	240	708	91.1	13.2
DA	280	150	220	650	83.4**	12.1**
DE	3,435	1,794	2,655	7,884	1,016.2	147.3

[11] 5 regions in the North-Western part of Russia.

Country	Installations needed*				Corresponding investment need, M€	Corresponding annual costs for depreciation, interest and maintenance, M€
	In-house	In-store	In-field	In total		
EE	34	18	27	79	10.1	1.5
FI	83	44	65	192	24.7	3.6
LA	18	10	14	42	5.4	0.8
LT	32	17	25	74	9.5	1.4
PL	456	243	360	1,059	135.8	19.7
RU[12]	70	37	54	161	20.7	3.0
SE	289	151	225	665	85.6	12.4
TOTAL	5,004	2,625	3,885	11,514	1,482.4	215.0

* *The distribution on SAT types assumes a market share division as in Denmark, weight potential considers a number of important market-related factors, such as the availability of contractors, and the role of ammonia emissions in environmental permitting.*

** *For the Danish case is alone calculated with acidifying half of the Danish slurry production and assumed that one third of the slurry acidification capacity already exists.*

33: Opportunities

Opportunities are according the SWOT matrix beneficial issues with relation to demands coming from outside, i.e. for reach the objectives that are listed in section 1.

The following tables lists the opportunities for the different countries and for the whole Baltic Sea Region.

[12] 5 regions in the North-Western part of Russia.

Table 7: Opportunities related to SATs use for clear waters and clean air for the different countries and for the whole Baltic Sea Region.

Country	Reduced ammonia emissions, Kt	Healthcare sector savings, M€	Reduced atmospheric deposition of nitrogen, ton	Reduced greenhouse gas emission, tonnes of CO_{2e}
BY	10.2	-	3,432 – 5,577	85,524
DA*	10.0	58	3,360 – 5,460	85,803
DE	113.9	2,105	38,280 – 62,205	1,052,615
EE	1.1	2.9	384 - 624	10,419
FI	2.8	7.0	936-1,521	25,434
LV	0.6	2.2	216 - 351	5,516
LT	1.1	1.8	360 - 585	9,806
PL	15.4	155.5	5,184 – 8,424	139,736
RU[13]	2.4	-	792 - 1,287	21,451
SE	9.6	56	3,216 – 5.226	88,561
TOTAL	167.1	2,416	56,160 – 91,260	1,524,863

*** For the Danish case is alone calculated with acidifying half of the Danish slurry production.*

3.4: Threats

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

[13] 5 regions in the North-Western part of Russia.

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

The use of S as fertiliser should due to concerns for water quality be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019). Due to the relations between the plant nutrients N, P and S in slurries, the amount of S applied with acidified slurry would seldom exceed the mentioned recommended maximal application if the application of acidified slurry is in line with regulations for fertilising with N and P. Special attention should be given to the issue in case of acidified slurry based on in-house acidification, where the use of sulphuric acid is high in combination with low values of N and P in the acidified slurry.

3.5: Policy recommendations

Summarising and monetising the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in Baltic Sea Region countries, the calculation is as follows:

Table 8: Annual value of realising the use of SATs for the weighed slurry potential. All figures in M€.

Country	Avoided EU penalty related to ammonia, M€	Savings in the healthcare sector, M€	Value of reduced greenhouse gas emission, M€	Annual costs of investments in SAT installations, M€	Net value, M€	Additional, estimated value of N abatement, M€*
BY	NA	(102**)	1.9	-13.2	-11.3	9
DA***	1.7	58	1.9	-12.1	45.6	9
DE	11.8	2,105.4	23.1	-147.3	1,993.0	100

Country	Avoided EU penalty related to ammonia, M€	Savings in the healthcare sector, M€	Value of reduced greenhouse gas emission, M€	Annual costs of investments in SAT installations, M€	Net value, M€	Additional, estimated value of N abatement, M€*
EE	0.4	2.0	0.2	-1.5	2.0	0.7
FI	0	7.0	0.6	-3.6	4.0	2.5
LV	0	2.2	0.1	-0.8	1.5	0.6
LT	0	1.8	0.2	-1.4	0.6	0.9
PL	0	155.5	3.1	-19.7	138.9	13.6
RU[14]	NA	(5.9****)	0.5	-3.0	-2.5	2.1
SE	2.7	56.3	1.9	-12.4	48.5	8.4
TOTAL	16.6	2,388.2 (+107.9)	33.4	212.7	2,220.3	147

** The estimated reduced airborne deposition would further have a considerable value for the society according Hautakangas et al. (2014) and Sutton et al. (2011). The abatement costs is varying, dependent on sector and other pre-conditions, and we have here assumed it to be only € 2 per kg N.*

*** Savings in the healthcare sector was not assessed for Belarus by Sutton et al. (2011), and we have assumed the value to be the same as for the neighbour country Poland, but the figure is not included in the net value for Belarus of using SATs and is therefore placed in brackets.*

**** For Denmark, all figures are based on Foged (2017), assuming half of the Danish slurry production is acidified, which is about 17 million tonnes of slurry, whereas the weighed potential for Denmark is 25 million tonnes of slurry. The Net value includes additionally an estimated operational cost of M€ 3.9 per year.*

***** Savings in the healthcare sector was not assessed for Russia by Sutton et al. (2011), and we have assumed the value to be the same as for the neighbour country Finland, but the figure is not included in the net value for Russia of using SATs and is therefore placed in brackets.*

Thus, the effect of implementing the potential for use of SATs in the Baltic Sea Region countries is a positive economic effect for the societies of in total € 2.2 billion per year,

[14] 5 regions in the North-Western part of Russia.

to which come and estimated value of N abatement related to the aquatic environment of M€ 147 per year, and positive healthcare sector effects in Russia and Belarus.

Four of the EU Member States in the Region, DA, EE, FI and LV, would by implementing the use of SATs avoid EU penalties, as they would either with certainty meet their defined ammonia emission ceiling by 2020, or be brought so close to the ceiling that the use of SATs in combination with other, minor measures would make it realistic for these countries to avoid penalties for non-compliance with the ceilings.

Our recommendation is therefore to the eight EU Member States in the Region to implement the use of SATs, whereas the immediate recommendation is to establish official expert work groups to consider the impacts of this, and the way to do it. Hence, we recognise that our analyses as presented in this report are made without consideration to the specificities of the legal and institutional context in the individual countries.

For the five north-western regions in Russia as well as for Belarus, we do not immediately have sufficient basis for recommending the implementation of SATs use. The policy context in these countries are different from that of EU, and the value of SATs use is unclear.

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Annex 1: Policy recommendations relating to BY/Belarus

Annex 1.1: Strengths

Neumann et al. (2017):

- Belarus' potential for use of slurry acidification is based on production of 45.6 million tons slurry and other liquid manures and digestates. However, the pre-conditions for slurry acidification are not good in Belarus, for instance due to a relatively low role of ammonia emissions in the regulation of farming and protection of sensitive areas against atmospheric depositions of ammonia. Thus, a more realistic, weighed potential for slurry acidification is 14.3 million tonnes.

Annex 1.2: Weaknesses

Neumann et al. (2017) and chapter 2:

- Treatment of the weighed potential would require 708 slurry acidification installations, including 307, 161 and 240 installations for in-house, in-storage and in-field slurry acidification, respectively.
- Required investments in SAT installations is estimated to M€ 91.1, and the corresponding annual costs for depreciation and interest payment of the investments, and for their maintenance would cost M€ 13.2.
- Net operational costs for the farmer users comprise in the main the costs for sulphuric acid, and the savings on purchase of nitrogen and sulphur mineral fertilisers. Although marginal, there could also be additional costs for labour, fuel and electricity. Theoretically, there could also be additional costs for liming, but it is unclear whether fertilising with acidified slurry gives a higher demand for liming than fertilisation by use of mineral fertilisers, which is acidifying soils (University of Adelaide. Undated). All in all, taking the mentioned parameters into account, the net operational costs of using slurry acidification are for Belarus farms in general minimal, whereas the economic feasibility of individual farms' use of slurry acidification may be either positive or negative, dependent on the exact pre-conditions.

Zelčs (2018):

- There is no demand for solid cover on slurry tanks in Belarus, wherefore the use of in-house acidification could not give Belarus farmers any savings for investments in such.

- There is currently no demand for injection of slurry in Belarus, wherefore an alternative use of slurry acidification would not give any savings in costs for slurry injection.
- No financial incentives are provided for Belarus investors in slurry acidification technology, neither generally for investments in ammonia emission reduction technology.

Annex 1.3: Opportunities

Chapter 1 and assumptions mentioned in chapter 2:

- Acidification of the weighed slurry potential of 14.3 million tons means that Belarus would reduce ammonia emissions with 10.2 Kt, which is equal to the reduction needed for Belarus to reach its ammonia emission ceiling in 2020 according UNECE (2012).
- The aquatic environment is annually saved for between 3,432 and 5,577 tonnes of atmospheric nitrogen deposition, which would be an important contribution for fulfilment of the Belarus HELCOM CART (Table 3).
- There is also a potential reduction of greenhouse gas emissions of 85,524 tonnes CO_{2e}.
- Farmers use of slurry acidification technologies could be secured via financial incentives, enforced via regulation, or based on a combination of financial incentives and regulation.

Annex 1.4: Threats

The use of S as fertiliser should due to concerns for water quality, firstly the organoleptic quality (WHO, 2004), be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019).

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

Annex 1.5: Policy recommendations

When we summarise and monetise the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in Belarus, the calculation is as follows:

Issue	Impact	Value, M€ per year
Reduced ammonia emissions	10.2 Kt, which is sufficient for reaching the defined ceiling for 2020.	0
Savings in the health sector	Unclear, is not informed for Belarus by Sutton et al. (2011)	-
Reduced atmospheric N deposition	3,432 – 5,577 tonnes, which is probably not sufficient in relation to HELCOM CART	0
Reduced greenhouse gas emissions	85,800 tonnes CO_{2e} of a value of € 21.9 per tonnes (https://markets.businessinsider.com/commodities/co2-emissionsrechte)	1.9
Investments in SAT installations	Depreciation, maintenance and interest payment	-13.2
Net value		-11.3

On this basis, we cannot recommend Belarus to implement the use of SATs. However, the benefit for the health sector would be M€ 102 per year in case the savings would be similar to the neighbour country, Poland, i.e. 12 € per kg N in ammonia emissions.

Likewise, it has of course a value that the aquatic environment is saved for atmospheric depositions of nitrogen, and if this is set to € 2 per kg N, this value would be in the level of M€ 9 per year. Therefore, Belarus might consider implementing the use of SATs despite the above calculation.

Annex 2: Policy recommendations relating to DA/Denmark

Annex 2.1: Strengths

Neumann et al. (2017):

- Slurry acidification technologies (SATs) have been developed in Denmark and are approved by the Danish Environmental Protection Agency as Best Available Techniques (BAT) that Danish farms can utilise to reduce ammonia losses by up to 64%[15]. Thus, the knowledge to and experience with the technology is good in Denmark, as well as the entire infrastructure for a wider disseminated use of SATs.
- Denmark has a high potential for slurry acidification and could acidify up to 32 million tons slurry. The feasibility for utilising this potential for slurry acidification, based on subjective evaluation of nine important parameters concluded that slurry acidification has a more realistic, weighed potential of 25 million tonnes of slurry in Denmark. Parameters that especially favours the use of slurry acidification in Denmark are for instance a high role of ammonia emissions in the environmental permitting, a high number of farms that must have environmental permits, and a high number of agricultural contractors.

Zelčs (2018):

Danish legislation favours the use of slurry acidification:

- In-house acidification, and in some cases also in-storage acidification can replace rigid/solid cover on slurry tanks, which in general is required for slurry tanks situated closed than 300 metres from neighbours or sensitive nature, according §22 of "Bekendtgørelse nr. 865 af 23-06-2017 - Husdyrgødningsbekendtgørelsen"[16] (Cabinet Order No. 865 of 23 June 2017 – "The Cabinet Order on Livestock Manure").
- Danish farms operate under strict limitations of N fertilisation via maximally allowed application norms, hindering them to purchase and use more N mineral fertiliser than they are entitled to according a calculated farm N-quota, deducted N in the manure from own livestock. Regulations are based

[15] http://eng.mst.dk/trade/agriculture/environmental-technologies-for-livestock-holdings/list-of-environmental-technologies/

[16] https://www.retsinformation.dk/Forms/R0710.aspx?id=192157#id16e03b59-5946-49ed-86b7-fd2c89aa9d62

on "Lov om jordbrugets anvendelse af gødning og om plantedække, jf. lovbekendtgørelse nr. 433 af 3. maj 2017"[17] (In English: Law on use of fertilisers and on demands to plant cover). The limitations were tighter from 1999 to 2016, where a politically decided reduction of N-fertiliser norms was imposed in addition to the requirements / limitations listed under point 3 of Annex III of the Nitrates Directive[18].

- No Danish legislation poses barriers for use of slurry acidification technologies.

Annex 2.2: Weaknesses

Foged (2017b):

- An analysis in 2017 of selected types of farms indicates that the net cost of using slurry acidification amounts to € 0.4 – 1.5 per tons of slurry, with in-field acidification of pig slurry as the cheapest and in-house acidification of cattle slurry the most expensive due to higher investment costs. Acidification of digestate based on cattle slurry costs € 3.0 and 2.3 per ton for respectively in-tank and in-field acidification due to the high sulfuric acid consumption and is not included in the scenario for acidification of half of Danish slurry production.
- The mentioned net costs of using slurry acidification are calculated under consideration to both economic gains and advantages, as well as losses and costs. The economic gains include savings on consumption of N and S fertilisers, reduced costs for spreading in cases where slurry acidification can replace slurry injection, and reduced investment costs in cases where in-house acidification removes demands for investments in solid cover on slurry tanks. The costs include investments in the slurry acidification installations and equipment, costs for the consumption of sulphuric acid, and costs for extra liming to neutralise the effect of the sulphuric acid.
- The use of SATs has gone down since the fertiliser norms were changed in 2016, and the use of slurry acidification was already in 2017 reduced to less than half of the capacity for acidification of about 20% of the Danish slurry production. The reduced use of slurry acidification in Denmark is assumed to have a close connection to the changed market conditions with easier access to purchase of mineral fertiliser nitrogen in amounts needed by the crops.

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[17] https://www.retsinformation.dk/pdfPrint.aspx?id=188833
[18] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31991L0676

- In a macro-economic perspective, the aggregate additional costs for acidifying half of Danish slurry production are approx. € 16 million annually for the almost 14 million. tons of slurry to be acidified further. The costs include depreciation, interest payment and maintenance of an investment over the next 2-3 years of app. € 83.4 million in tripling the number of installations for slurry acidification and annual operating losses of approx. € 3.9 million.
- Danish policy targets for reduction of N-emissions to water courses does not consider atmospheric depositions stemming from ammonia emissions, but alone leaching and runoff.

Neumann et al.- (2017):

- Parameters, that especially have the potential to limit the use of slurry acidification in Denmark comprise ambitious political goals for anaerobic digestion of manure that may be difficult to integrate with slurry acidification.

Zelčs (2018):

- No financial incentives are provided for Danish investors in slurry acidification technology, neither generally for investments in ammonia emission reduction technology. However, a leaked Government document from June 2018 gives reason to believe subsidies for SATs will be introduced shortly.

Annex 2.3: Opportunities

Foged (2017b):

- Acidification of half of Danish slurry production means that Denmark would reach the politically determined goal of reducing ammonia emissions by 2020 to 63.25 kt. The healthcare sector will save app. M€ 58 yearly and the aquatic environment is saved annually for between 3,360 and 5,460 tonnes of airborne nitrogen deposition. There is also a reduction of greenhouse gas emissions of 85,803 tonnes CO_{2e}, equivalent to about 1 % of the Danish greenhouse gas reduction target from 2015 to 2030.
- To reach the EU defined ammonia emission ceiling for 2020, Denmark would have to reduce ammonia emissions from the 2016 level with 6% as explained in Table 2. Considering the use of SATs have declined sharply as a result of changed fertilisation rules since 2016, and increased ammonia emissions during the latest reported years, it is doubtful that Denmark otherwise would be able to comply with the ceiling of 63.25 kT in 2020.

Section 1:

- Acidifying half of the Danish slurry production would avoid costly, tedious and lengthy infringement procedures that due to missing reach of the ammonia emission ceiling unavoidably would lead to large EU penalties, whereof the financial penalty "lump sum" factor alone is M€ 1,737.

- The Danish Government has launched a so-called "Clean air vision", backed by the entire clean-tech sector. The vision comprises five main objectives, namely:
    1. Cooperate on Danish exports of clean air solutions.
    2. Showcase Denmark for innovative clean air solutions.
    3. Work for effective implementation and enforcement of international regulation of air pollution - in Denmark, in the EU and globally.
    4. Create better coherence between research, development and innovation.
    5. Communicate about Danish clean-tech strengths.

  Thus, a wider disseminated use of slurry acidification technologies in Denmark is an opportunity for supporting at least aims no. 2, 3 and 4 of the "Clean air vison".

Annex 2.4: Threats

The use of S as fertiliser should due to concerns for water quality, firstly the organoleptic quality (WHO, 2004), be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019).

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

Annex 2.5: Policy recommendations

When we summarise and monetise the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in Denmark, the calculation is as follows:

Issue	Impact	Total value, M€ per year
Reduced ammonia emissions	10.0 Kt, which is sufficient for reaching the defined ceiling for 2020 and for avoiding EU penalties.	1.7
Savings in the health sector	€ 10 per kg N in ammonia emissions Sutton et al. (2011)	58
Reduced atmospheric deposition	3,360 – 5,460 tonnes – Denmark has already reached HELCOM CART but has an additional Danish goal of reducing N losses to waters with app. 6,000 tonnes	0
Reduce greenhouse gas emissions	85,803 tonnes CO_{2e} of a value of € 21.9 per tonnes (https://markets.businessinsider.com/commodities/co2-emissionsrechte)	1.9
Investments in SAT installations	Depreciation and interest payment of the investments, and for their maintenance	-12.1
Operational costs of SATs		-3.9
Net value		45.6

On this basis of a very high net value, we can clearly recommend Denmark to implement the scenario for acidification of half of the Danish slurry production, which is equal to almost 14 million tonnes slurry more that the current acidification of about 3.3 million tonnes of slurry, so the total slurry acidification would reach more than 17 million tonnes of slurry.

The estimated reduced airborne deposition would further have a considerable value for the society according Hautakangas et al. (2014) and Sutton et al. (2011). In case the abatement cost is set to € 2 per kg N, the value for the society would be in the level of M€ 9.

It is therefore suggested to discuss among policy makers, how a wider disseminated use of slurry acidification technologies could be realised, and in this way contribute to the realisation of the "Clean air vision" (Environment Protection Agency, Denmark, undated), especially with respect to its aims:

2. Showcase Denmark for innovative clean air solutions.
3. Work for effective implementation and enforcement of international regulation of air pollution - in Denmark, in the EU and globally.
4. Create better coherence between research, development and innovation.

Annex 3: Policy recommendations relating to DE/Germany

Annex 3.1: Strengths

Neumann et al. (2017):

- Germany has a high potential for use of slurry acidification and could acidify up to 191 million tons slurry and other liquid manures and digestates, whereas a more realistic, weighed potential is 159.5 million tonnes of slurry, which would require 3,435, 1,794 and 2,655 installations, respectively for in-house, in-storage and in-field slurry acidification.

Fors et al. (2018):

- Germany has legislation and standards, as well as infrastructure in place for handling of sulphuric acid, including regulations for road transport and storage of sulphuric acid.

Neumann et al., 2018:

- Field trials in Germany 2017 have shown significantly higher dry matter yields on permanent grassland in the acidified treatments in comparison to the non-acidified treatments at all nitrogen levels. Additionally, ammonia emissions were significantly reduced in the acidified treatments.

Annex 3.2: Weaknesses

Neumann et al. (2017) and chapter 2:

- Required investments in SAT installations are in the level of € 1 billion, and the corresponding annual costs for depreciation and interest payment of the investments, and for their maintenance would cost M€ 147.
- Net operational costs for the farmer users comprise in the main the costs for sulphuric acid, and the savings on purchase of nitrogen and sulphur mineral fertilisers. Although marginal, there could also be additional costs for labour, fuel and electricity. Theoretically, there could also be additional costs for liming, but it is unclear whether fertilising with acidified slurry gives a higher demand for liming than fertilisation by use of mineral fertilisers, which is acidifying soils (University of Adelaide. Undated). All in all, taking the mentioned parameters into account, the net operational costs of using slurry acidification are for German farms in general minimal, whereas the economic feasibility of individual farms' use of slurry acidification may be either positive or negative, dependent on the exact pre-conditions.

Zelčs (2018):

- There is currently no general demand for solid cover on slurry tanks in Germany, wherefore the use of in-house acidification could not give German farmers any savings for investments in such.
- There is currently no general demand for injection of slurry in Germany, wherefore an alternative use of slurry acidification would not give any savings in costs for slurry injection.
- A regulation is, probably unintendedly, being interpreted as prohibiting in-house and in-storage acidification, or rather the storage of slurry with chemicals added, and the interpretation of the regulation must be considered before these technologies can be applied (reference).

Fors et al. (2018):

- According German Road Traffic Regulations (StVO), a longer distance than 3.5 metres between the steering wheel centre and the front edge of the front tank is not permitted. This hampers the possibility for use of in-field acidification equipment with a front tank mounted on the tractor.

Annex 3.3: Opportunities

Chapter 1 and assumptions mentioned in chapter 2:

- Acidification of the weighed slurry potential of 159.5 million tons means that Germany would reduce ammonia emissions with 113.9 Kt, which would be a very valuable contribution to reach the policy objective of 594 Kt in 2020, a target that Germany was 1% above in 2016.
- In addition, the healthcare sector will save app. € 2.1 billion annually due to improved air quality.
- The aquatic environment is annually saved for between 38 and 62 million tonnes of atmospheric nitrogen deposition, which probably is more than enough for fulfilment of the German HELCOM CART (see Table 3), dependent on the distribution of the depositions on sub-basins.
- There is also a potential reduction of greenhouse gas emissions of 1,052,615 tonnes CO_{2e}, which would help Germany to fulfil its commitments in relation to climate change.

Annex 3.4: Threats

The use of S as fertiliser should due to concerns for water quality, firstly the organoleptic quality (WHO, 2004), be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019).

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

Annex 3.5: Policy recommendations

When we summarise and monetise the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in Germany, the calculation is as follows:

Issue	Impact	Total value, M€ per year
Reduced ammonia emissions	113.9 Kt, which is sufficient for reaching the defined ceiling for 2020 and for avoiding EU penalties.	11.8
Savings in the health sector	€ 22 per kg N in ammonia emissions Sutton et al. (2011)	2,105.4
Reduced atmospheric deposition	38,280 – 62,205 tonnes – which would probably be sufficient for reach of HELCOM CART obligations	0

Reduce greenhouse gas emissions	1,052,615 tonnes CO_{2e} of a value of € 21.9 per tonnes (https://markets.businessinsider.com/commodities/co2-emissionsrechte)	23.1
Investments in SAT installations	Depreciation and interest payment of the investments, and for their maintenance	-147.3
Net value		1,993.0

On this basis of a very high net value, we can clearly recommend Germany to acidify the weighed slurry potential of 159.5 million tonnes of slurry.

The estimated reduced airborne deposition would further have a considerable value for the society according Hautakangas et al. (2014) and Sutton et al. (2011). In case the abatement cost is set to € 2 per kg N, the value for the society would be in the level of M€ 100 per year.

Considering the above, it is recommended to establish an expert working group with representation from relevant authorities and knowledge institutions in order to clarify

1. the potential impacts of slurry acidification for the livestock sector and the society, based on outputs, conclusions and recommendations of the Baltic Slurry Acidification-project as well as other documentation; and
2. possible ways of amending regulations, standards and subsidy programmes for ensuring an envisaged use of slurry acidification, including an evaluation of the relevance of banning storage of acidified slurry and cost-efficient ways to deal with the StVO limit of 3.50 metres distance between the steering wheel centre and the front edge of the front tank.

Annex 4: Policy recommendations relating to EE/Estonia

Annex 4.1: Strengths

Neumann et al. (2017)[19]:

- Estonias production of slurry and other liquid manures and digestates is 2.17 million tons per year, whereas a more realistic, weighed potential for slurry acidification is 1.6 million tonnes of slurry.

Fors et al. (2018):

- Estonia has legislation and standards, as well as infrastructure in place for handling of sulphuric acid, including regulations for road transport and storage of sulphuric acid.

Rodhe et al. (2017):

- Estonian farmers are aware of the value of avoiding ammonia emission from slurry and other liquid manures, and it is therefore a common practice to inject slurry in order to optimise the nitrogen fertilisation through slurry to especially crops like grassland, cereals and maize, although there is no legal demand for it. Thus, app. 60% of Estonian slurries and other liquid manure is injected. Alternative use of slurry acidification would give possibility to obtain the same effect by cheaper bandspreading.

Annex 4.2: Weaknesses

Neumann et al. (2017) and chapter 2:

- It would require 34, 18 and 27 installations, respectively for in-house, in-storage and in-field slurry acidification to acidify the weighed potential.

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[19] The figures are updated on basis of a new survey that was made after conclusions of Neumann et al. (2017). The new survey shows a substantial higher slurry production in Estonia, namely 2.17 million tonnes, and the weighed potential for slurry acidification is therefore raised from 1.1 to 1.6 million tonnes slurry for Estonia. The data were collected by ECRI senior researcher Raivo Vettik in spring 2017 from farms which belong in group- intensive rearing of cattle and pigs according the Industrial Emissions Directive. The farms were picked from webpage: https://www.envir.ee/et/kompleksloakohustusega-kaitised-kompleksload-kontrollprotokollid.

- Required investments in SAT installations are in the level of € 10.1 million, and the corresponding annual costs for depreciation and interest payment of the investments, and for their maintenance would cost € 1.5 million.
- Net operational costs for the farmer users comprise in the main the costs for sulphuric acid, and the savings on purchase of nitrogen and sulphur mineral fertilisers. Although marginal, there could also be additional costs for labour, fuel and electricity. Theoretically, there could also be additional costs for liming, but it is unclear whether fertilising with acidified slurry gives a higher demand for liming than fertilisation by use of mineral fertilisers, which is acidifying soils (University of Adelaide. Undated). All in all, taking the mentioned parameters into account, the net operational costs of using slurry acidification for Estonian farms are in general minimal, whereas the economic feasibility of individual farms' use of slurry acidification may be either positive or negative, dependent on the exact pre-conditions.

Kučinskienė et al. (2019):

- Field trials in Estonia with acidified slurry has not shown any substantial impact on crop yields or in other ways had clear effect on the soil fertility.

Zelčs (2018):

- There is no demand for solid cover on slurry tanks in Estonia, wherefore the use of in-house acidification could not give Estonian farmers any savings for investments in such.

Annex 4.3: Opportunities

Chapter 1 and assumptions mentioned in chapter 2:

- Acidification of the weighed slurry potential of 1.6 million tons means that Estonia would reduce ammonia emissions with 1.1 Kt, which would be a very valuable contribution to reach the policy objective of 10.6 Kt in 2020, a target that Estonia was app. 12% above in 2016.
- In addition, the healthcare sector will save app. M€ 2.9 annually due to improved air quality.
- The aquatic environment is annually saved for between 384 and 624 tonnes of atmospheric nitrogen deposition, which would be a valuable contribution for fulfilment of the Estonian HELCOM CART of 1,080 tonnes (see Table 3).
- There is also a potential reduction of greenhouse gas emissions of 10,419 tonnes CO_{2e}, which would help Estonia to fulfil its 2030 commitments in relation to climate change.
- Farmers use of slurry acidification technologies could be secured via financial incentives, enforced via regulation, or based on a combination of financial

incentives and regulation. Considering the outlined societal benefits, compared with the required investments and net operational costs,

Annex 4.4: Threats

The use of S as fertiliser should due to concerns for water quality, firstly the organoleptic quality (WHO, 2004), be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019).

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

The reputation of slurry acidification can drop if

- Excessive sulphur is found to be harmful for soil or water.
- Safety requirements are not followed strictly, and some accident happens in connection the acid
- The technical support to SAT is not satisfactory, because the number of SAT producers is few and the enterprises are small.

Annex 4.5: Policy recommendations

Summarising and monetising the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in Estonia, the calculation is as follows:

Issue	Impact	Total value, M€ per year
Reduced ammonia emissions	1.1 Kt, which is almost sufficient for reaching the defined ceiling for 2020 and we therefore anticipate Estonia could avoid EU penalties.	0.4
Savings in the health sector	€ 3 per kg N in ammonia emissions Sutton et al. (2011)	2.9
Reduced atmospheric deposition	384 – 624 tonnes – which would be a valuable contribution to reach HELCOM CART obligations	0
Reduce greenhouse gas emissions	10,419 tonnes CO_{2e} of a value of € 21.9 per tonnes (https://markets.businessinsider.com/commodities/co2-emissionsrechte)	0.2
Investments in SAT installations	Depreciation and interest payment of the investments, and for their maintenance	-1.5
Net value		2.0

On this basis of a positive net value, we can recommend Estonia to acidify the weighed slurry potential of 1.6 million tonnes of slurry.

The estimated reduced airborne deposition would further have a considerable value for the society according Hautakangas et al. (2014) and Sutton et al. (2011). In case the abatement cost is set to € 2 per kg N, the value for the society would be in the level of M€ 1.0 per year.

Considering the urgent and high need for Estonia to reduce ammonia emissions and the cost efficiency and positive side effects of slurry acidification, including for the healthcare sector and for the reduction of airborne depositions of nitrogen, it is recommended to establish an expert working group with representation from relevant authorities and knowledge institutions in order to clarify

1. the potential impacts of slurry acidification for the livestock sector and the society, based on outputs, conclusions and recommendations of the Baltic Slurry Acidification-project as well as other documentation; and
2. possible ways of amending regulations, standards and subsidy programmes for ensuring an envisaged use of slurry acidification.

Annex 5: Policy recommendations relating to FI/Finland

Annex 5.1: Strengths

Slurry systems are fairly common in Finnish livestock farming. It is assessed that Finland could acidify up to 6 million tons slurry and other liquid manures and digestates, whereas a more realistic, weighed potential is 3.9 million tonnes of slurry (Neumann et al., 2017).

Finland also has a strong agro-environmental legislation and a widely adopted system of subsidies for additional environmental measures in the agro-environment-climate compensation schemes. Fertilisation plans have to comprise the soluble nutrient content of manures (Zelčs, 2018).

Furthermore, Finland has legislation and standards, as well as infrastructure in place for handling of sulphuric acid, including regulations for road transport and storage of sulphuric acid (Fors et al. (2018).

Annex 5.2: Weaknesses

The investment costs and the challenge to minimize the operational cost for the farmer are seen as the main weaknesses. From Neumann et al. (2017) and chapter 2 in this report, we summarize, that

- It would require 83, 44 and 65 installations, respectively for in-house, in-storage and in-field slurry acidification to fulfil the weighed potential.
- Required investments in SAT installations are in the level of € 24.7 million, and the corresponding annual costs for depreciation and interest payment of the investments, and for their maintenance would cost M€ 3.6.
- Net operational costs for the farmer users comprise in the main the costs for sulphuric acid, and the savings on purchase of nitrogen and sulphur mineral fertilisers. Although marginal, there could also be additional costs for labour, fuel and electricity. Theoretically, there could also be additional costs for liming, but it is unclear whether fertilising with acidified slurry gives a higher demand for liming than fertilisation by use of mineral fertilisers, which is acidifying soils (University of Adelaide. Undated). All in all, taking the mentioned parameters into account, the net operational costs of using slurry acidification for farms are in general minimal, whereas the economic feasibility of individual farms' use of slurry acidification may be either positive or negative, dependent on the exact pre-conditions.

The field trials performed in the project in Finland with acidified slurry have not shown statistically significant[20]. The impact on soil fertility has not been studied. (Kučinskienė, 2018).

A minor weakness is also that on the national level, there is no requirement for a solid cover on manure storages. This requirement, if substituted with in-house acidification system (which would reduce ammonia emissions also from storage), would give the farmer savings in the avoided investment cost for the solid cover. Requirement for solid cover could, however, be included in environmental permit conditions by local and regional authorities (Zelčs, 2018).

Annex 5.3: Opportunities

There are clear environmental and health benefits from slurry acidification in Finland, as summarized in chapters 1 and 2 in this report:

- Acidification of the weighed slurry potential of 3.9 million tons means that Finland would reduce ammonia emissions with 2.8 Kt, whereas Finland already meet its policy objective of 31 Kt in 2020.
- The healthcare sector will save app. € 7 million annually due to improved air quality.
- The aquatic environment is annually saved for between 936 and 1,521 tonnes of atmospheric nitrogen deposition, which would be a good contribution to fulfil the Finnish HELCOM CART of 1,720 tonnes (see Table 3).
- There is also a potential reduction of greenhouse gas emissions of 25,434 tonnes CO_{2e}, which would help Finland to fulfil its commitments in relation to climate change effort-sharing for 2030.

Zelčs (2018): Furthermore, the history and wide coverage of the agro-environment compensation system in Finland provides opportunities to support SATs. Subsidies for slurry injection is currently provided to reduce ammonia emissions (and phosphorus losses to waters), and it would thus be relatively easy to widen the scope of this subsidy, so it would also encompass spreading of acidified slurry with e.g. band laying system, which would be considerably cheaper for the farmers.

[20] It must be noted, however, that the two years the field tests were done represented two extremes in terms of weather conditions: 2017 was very wet whereas 2018 was very dry and warm. Also released legacy nitrogen may have contributed to the high yield in 2017 and thus overshadowed the effect of acidification"

Annex 5.4: Threats

The use of S as fertiliser should due to concerns for water quality, firstly the organoleptic quality (WHO, 2004), be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019).

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

Annex 5.5: Policy recommendations

Summarising and monetising the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in Finland, the calculation is as follows:

Issue	Impact	Total value, M€ per year
Reduced ammonia emissions	2.8 Kt, whereas Finland already complies with its ceiling for 2020 and therefore anyway could avoid EU penalties.	-
Savings in the health sector	€ 3 per kg N in ammonia emissions according Sutton et al. (2011).	7.0

Reduced atmospheric deposition	936 – 1,521 tonnes – which would be a valuable contribution to reach HELCOM CART obligations.	0
Reduce greenhouse gas emissions	25,434 tonnes CO_{2e} of a value of € 21.9 per tonnes. (https://markets.businessinsider.com/commodities/co2-emissionsrechte)	0.6
Investments in SAT installations	Depreciation and interest payment of the investments, and for their maintenance.	-3.6
Net value		4.0

On this basis of a positive net value, we can recommend Finland to investigate acidification up to the weighed slurry potential of 3.9 million tonnes of slurry.

The estimated reduced airborne deposition would further have a considerable value for the society according Hautakangas et al. (2014) and Sutton et al. (2011). In case the abatement cost is set to € 2 per kg N, the value for the society would be in the level of M€ 2.5 per year.

Finland has a need to reduce nitrogen pollution to the Baltic Sea and greenhouse gases. Considering this and the cost efficiency and positive side effects of slurry acidification, including for the healthcare sector, it is recommended to establish an expert working group with representation from relevant authorities and knowledge institutions in order to clarify

1. the potential impacts of slurry acidification for the livestock sector and the society, based on outputs, conclusions and recommendations of the Baltic Slurry Acidification-project as well as other documentation;
2. possible ways of amending regulations, standards and subsidy programmes for ensuring an envisaged use of slurry acidification; and
3. the market situation with respect to equipment suppliers, contractors as well as the markets (availability, price) for sulphuric acid in comparison with other available and potential acids, including organic acids.

Annex 6: Policy recommendations relating to LV/Latvia

Annex 6.1: Strengths

Neumann et al. (2017):

- Latvia could acidify up to 2.1 million tons slurry and other liquid manures and digestates, whereas a more realistic, weighed potential is 0.9 million tonnes of slurry.

Fors et al. (2018):

- Latvia has legislation and standards, as well as infrastructure in place for handling of sulphuric acid, including regulations for road transport and storage of sulphuric acid.

Annex 6.2: Weaknesses

Neumann et al. (2017) and chapter 2:

- It would require 18, 10 and 14 installations, respectively for in-house, in-storage and in-field slurry acidification to fulfil the potential.
- Required investments in SAT installations are in the level of € 5.4 million, and the corresponding annual costs for depreciation and interest payment of the investments, and for their maintenance would cost M€ 0.8.
- Net operational costs for the farmer users comprise in the main the costs for sulphuric acid, and the savings on purchase of nitrogen and sulphur mineral fertilisers. Although marginal, there could also be additional costs for labour, fuel and electricity. Theoretically, there could also be additional costs for liming, but it is unclear whether fertilising with acidified slurry gives a higher demand for liming than fertilisation by use of mineral fertilisers, which is acidifying soils (University of Adelaide. Undated). All in all, taking the mentioned parameters into account, the net operational costs of using slurry acidification are for Latvian farms in general minimal, whereas the economic feasibility of individual farms' use of slurry acidification may be either positive or negative, dependent on the exact pre-conditions.

Kučinskienė et al. (2019):

- Field trials in Latvia with acidified slurry has not shown any substantial impact on crop yields or in other ways had clear effect on the soil fertility.

Zelčs (2018):

- There is currently no demand for solid cover on slurry tanks in Latvia, wherefore the use of in-house acidification could not give Latvian farmers any savings for investments in such.
- There is currently no demand for injection of slurry in Latvia, wherefore an alternative use of slurry acidification would not give any savings in costs for slurry injection.

Annex 6.3: Opportunities

Chapter 1 and assumptions mentioned in chapter 2:

- Acidification of the weighed slurry potential of 0.9 million tons means that Latvia would reduce ammonia emissions with 0.6 Kt, which would be a very valuable contribution to reach the policy objective of 14.75 Kt in 2020, a target that Latvia was 10% above in 2016.
- In addition, the healthcare sector will save app. € 2.2 million annually due to improved air quality.
- The aquatic environment is annually saved for between 216 and 351 tonnes of atmospheric nitrogen deposition, which would be a valuable contribution for fulfilment of the Latvian HELCOM CART of 5,400 tonnes (see Table 3).
- There is also a potential reduction of greenhouse gas emissions of 5,516 tonnes CO_{2e}, which would help Latvia to fulfil its commitments in relation to climate change effort-sharing for 2030.

Annex 6.4: Threats

The use of S as fertiliser should due to concerns for water quality, firstly the organoleptic quality (WHO, 2004), be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019).

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

Annex 6.5: Policy recommendations

Summarising and monetising the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in Latvia, the calculation is as follows:

Issue	Impact	Total value, M€ per year
Reduced ammonia emissions	0.6 Kt, which is not sufficient for reaching the defined ceiling for 2020 and we therefore anticipate that Latvia could not avoid EU penalties.	-
Savings in the health sector	€ 4 per kg N in ammonia emissions Sutton et al. (2011)	2.2
Reduced atmospheric deposition	216 – 351 tonnes – which would be a valuable contribution to reach HELCOM CART obligations	0
Reduce greenhouse gas emissions	5,516 tonnes CO_{2e} of a value of € 21.9 per tonnes (https://markets.businessinsider.com/commodities/co2-emissionsrechte)	0.1
Investments in SAT installations	Depreciation and interest payment of the investments, and for their maintenance	-0.8
Net value		1.5

On this basis of a positive net value, we can recommend Latvia to acidify the weighed slurry potential of 0.9 million tonnes of slurry.

The estimated reduced airborne deposition would further have a considerable value for the society according Hautakangas et al. (2014) and Sutton et al. (2011). In case the abatement cost is set to € 2 per kg N, the value for the society would be in the level of M€ 0.6 per year.

Use of slurry acidification in Latvian farming would reduce ammonia emissions, greenhouse gas emissions and Latvian contribution to nitrogen eutrophication of the Baltic Sea and thus have several positive effects in relation to defined policy targets. It would furthermore reduce costs for the healthcare sector. It is on this background recommended to establish an expert working group with representation from relevant authorities and knowledge institutions in order to clarify

1. the potential impacts of slurry acidification for the livestock sector and the society, based on outputs, conclusions and recommendations of the Baltic Slurry Acidification-project as well as other documentation; and
2. possible ways of amending regulations, standards and subsidy programmes for ensuring an envisaged use of slurry acidification.

Annex 7: Policy recommendations relating to LT/Lithuania

Annex 7.1: Strengths

Neumann et al. (2017):

- Lithuania has a potential for use of slurry acidification and could acidify up to 8 million tons slurry and other liquid manures and digestates, whereas a more realistic, weighed potential is 1.5 million tonnes of slurry.

Fors et al. (2018):

- Lithuania has legislation and standards, as well as infrastructure in place for handling of sulphuric acid, including regulations for road transport and storage of sulphuric acid.

Annex 7.2: Weaknesses

Neumann et al. (2017) and chapter 2:

- It would require 32, 17 and 25 installations, respectively for in-house, in-storage and in-field slurry acidification to fulfil the potential.
- Required investments in SAT installations are in the level of € 9.5 million, and the corresponding annual costs for depreciation and interest payment of the investments, and for their maintenance would cost M€ 1.4.
- Net operational costs for the farmer users comprise in the main the costs for sulphuric acid, and the savings on purchase of nitrogen and sulphur mineral fertilisers. Although marginal, there could also be additional costs for labour, fuel and electricity. Theoretically, there could also be additional costs for liming, but it is unclear whether fertilising with acidified slurry gives a higher demand for liming than fertilisation by use of mineral fertilisers, which is acidifying soils (University of Adelaide. Undated). All in all, taking the mentioned parameters into account, the net operational costs of using slurry acidification are for Lithuanian farms in general minimal, whereas the economic feasibility of individual farms' use of slurry acidification may be either positive or negative, dependent on the exact pre-conditions.

Report 4:

- Lithuanian University of Health Sciences have in field trials in 2018 measured 16% higher yields in barley, and 13% higher yields from grassland, but spring wheat had 6% lower yields, and almost no effect were seen on corn and oats. Soil pH measured after harvest showed a tendency of being lower at both plots given acidified slurry and plots given other fertilisers, compared to soil analyses before trials started. However, soil pH differences were not statistically significant. It is necessary to carry out more trials for more years before any firm conclusions can be made about the impact of slurry acidification on crop yields and soil fertility, especially about the impacts on soil pH.

Zelčs (2018):

- There is no demand for solid cover on slurry tanks in Lithuania, wherefore the use of in-house acidification could not give Lithuanian farmers any savings for investments in such.
- There is currently no demand for injection of slurry in Lithuania, wherefore an alternative use of slurry acidification would not give any savings in costs for slurry injection.

Annex 7.3: Opportunities

Chapter 1 and assumptions mentioned in chapter 2:

- Acidification of the weighed slurry potential of 1.5 million tons means that Lithuania would reduce ammonia emissions with 1.1 Kt.
- In addition, the healthcare sector will save app. € 1.8 million annually due to improved air quality.
- The aquatic environment is annually saved for between 360 and 585 tonnes of atmospheric nitrogen deposition. This would be an important contribution to fulfil the rather large Lithuanian HELCOM CART of 18,510 tonnes nitrogen (see Table 3).
- There is also a potential reduction of greenhouse gas emissions of 9,806 tonnes CO_{2e}, whereas the current emission level already is below ceilings for both 2020 and 2030.

Annex 7.4: Threats

The use of S as fertiliser should due to concerns for water quality, firstly the organoleptic quality (WHO, 2004), be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019).

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

Annex 7.5: Policy recommendations

Summarising and monetising the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in Lithuania, the calculation is as follows:

Issue	Impact	Total value, M€ per year
Reduced ammonia emissions	1.1 Kt. Lithuania is already under the defined ceiling for 2020 and wold not be able to save EU penalties.	-
Savings in the health sector	€ 2 per kg N in ammonia emissions Sutton et al. (2011)	1.8
Reduced atmospheric deposition	360 – 585 tonnes – which would be a valuable contribution to reach HELCOM CART obligations	0
Reduce greenhouse gas emissions	9,806 tonnes CO_{2e} of a value of € 21.9 per tonnes (https://markets.businessinsider.com/commodities/co2-emissionsrechte)	0,2

Investments in SAT installations	Depreciation and interest payment of the investments, and for their maintenance	-1.4
Net value		0.6

On this basis of a positive net value, we can recommend Lithuania to acidify the weighed slurry potential of 1.5 million tonnes of slurry.

The estimated reduced airborne deposition would further have a considerable value for the society according Hautakangas et al. (2014) and Sutton et al. (2011). In case the abatement cost is set to € 2 per kg N, the value for the society would be in the level of M€ 0.9 per year.

Use of slurry acidification in Lithuanian farming would reduce ammonia emissions, greenhouse gas emissions and Lithuanian contribution to nitrogen eutrophication of the Baltic Sea and thus have several positive effects in relation to defined policy targets. It would furthermore reduce costs for the healthcare sector. It is on this background recommended to establish an expert working group with representation from relevant authorities and knowledge institutions in order to clarify

1. the potential impacts of slurry acidification for the livestock sector and the society, based on outputs, conclusions and recommendations of the Baltic Slurry Acidification-project as well as other documentation; and
2. possible ways of amending regulations, standards and subsidy programmes for ensuring an envisaged use of slurry acidification.

Annex 8: Policy recommendations relating to PL/Poland

Annex 8.1: Strengths

Neumann et al. (2017):

- Poland has a high potential for use of slurry acidification and could acidify up to 35 million tons slurry and other liquid manures and digestates, whereas a more realistic, weighed potential is 21.6 million tonnes of slurry.

Fors et al. (2018):

- Poland has legislation and standards, as well as infrastructure in place for handling of sulphuric acid, including regulations for road transport and storage of sulphuric acid.

Annex 8.2: Weaknesses

Neumann et al. (2017) and chapter 2:

- It would require 456, 243 and 360 installations, respectively for in-house, in-storage and in-field slurry acidification to fulfil the potential.
- Required investments in SAT installations are in the level of € 135.8 million, and the corresponding annual costs for depreciation and interest payment of the investments, and for their maintenance would cost M€ 19.7.
- Net operational costs for the farmer users comprise in the main the costs for sulphuric acid, and the savings on purchase of nitrogen and sulphur mineral fertilisers. Although marginal, there could also be additional costs for labour, fuel and electricity. Theoretically, there could also be additional costs for liming, but it is unclear whether fertilising with acidified slurry gives a higher demand for liming than fertilisation by use of mineral fertilisers, which is acidifying soils (University of Adelaide. Undated). All in all, taking the mentioned parameters into account, the net operational costs of using slurry acidification are for Polish farms in general minimal, whereas the economic feasibility of individual farms' use of slurry acidification may be either positive or negative, dependent on the exact pre-conditions.

Kučinskienė (2018):

- Field trials carried out in Poland in 2017 and 2018 with different crops has in general shown positive effects on crop yields. The field trials also showed that fertilising with acidified slurry, compared to non-acidified slurry or mineral fertilisers, did not affect the microbial activity of the soils, resulted in higher soil pH and resulted in substantial reduced ammonia emissions. However, the weather was atypical in both 2017 and 2018 and more field trials are needed to make more solid conclusions.

Zelčs (2018):

- There is no demand for solid cover on slurry tanks in Poland, wherefore the use of in-house acidification could not give Polish farmers any savings for investments in such.
- There is currently no demand for injection of slurry in Poland, wherefore an alternative use of slurry acidification would not give any savings in costs for slurry injection.

Annex 8.3: Opportunities

Chapter 1 and assumptions mentioned in chapter 2:

- Acidification of the weighed slurry potential of 21.6 million tons means that Poland would reduce ammonia emissions with 15.4 Kt.
- In addition, the healthcare sector will save app. € 155.5 million annually due to improved air quality.
- The aquatic environment is annually saved for between 5,184 and 8,424 tonnes of atmospheric nitrogen deposition, which is a good and valuable contribution for fulfilment of the Polish HELCOM CART of 27,540 tonnes nitrogen (see Table 3).
- There is also a potential reduction of greenhouse gas emissions of 139,736 tonnes CO_{2e}, which would help Poland to fulfil its 2030 commitments in relation to climate change.

Annex 8.4: Threats

The use of S as fertiliser should due to concerns for water quality, firstly the organoleptic quality (WHO, 2004), be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019).

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

Annex 8.5: Policy recommendations

Summarising and monetising the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in Poland, the calculation is as follows:

Issue	Impact	Total value, M€ per year
Reduced ammonia emissions	15.4 Kt. Poland has already complied with the defined ceiling for 2020 and would in all cases avoid EU penalties.	-
Savings in the health sector	€ 12 per kg N in ammonia emissions Sutton et al. (2011)	155.5
Reduced atmospheric deposition	5,184 – 8,424 tonnes – which would be a valuable contribution to reach HELCOM CART obligations	0
Reduce greenhouse gas emissions	139,736 tonnes CO_{2e} of a value of € 21.9 per tonnes (https://markets.businessinsider.com/commodities/co2-emissionsrechte)	3.1
Investments in SAT installations	Depreciation and interest payment of the investments, and for their maintenance	-19.7
Net value		138.9

The indicated, positive effect on crop yields has not been taken into consideration in the estimated net value.

On the basis of a very positive net value, we can recommend Poland to acidify the weighed slurry potential of 21.6 million tonnes of slurry.

The estimated reduced airborne deposition would further have a considerable value for the society according Hautakangas et al. (2014) and Sutton et al. (2011). In case the abatement cost is set to € 2 per kg N, the value for the society would be in the level of M€ 13.6 per year.

Use of slurry acidification in Polish farming would reduce ammonia emissions, greenhouse gas emissions and Polish contribution to nitrogen eutrophication of the Baltic Sea and thus have several positive effects in relation to defined policy targets. It would furthermore reduce costs for the healthcare sector. It is on this background recommended to establish an expert working group with representation from relevant authorities and knowledge institutions in order to clarify

1. the potential impacts of slurry acidification for the livestock sector and the society, based on outputs, conclusions and recommendations of the Baltic Slurry Acidification-project as well as other documentation; and
2. possible ways of amending regulations, standards and subsidy programmes for ensuring an envisaged use of slurry acidification.

Annex 9: Policy recommendations relating to RU/Russia[21]

Annex 9.1: Strengths

Neumann et al. (2017):

- Russia has a potential for use of slurry acidification and could acidify up to 7.4 million tons slurry and other liquid manures, whereas a more realistic, weighed potential is 3.3 million tonnes of slurry.

Annex 9.2: Weaknesses

Neumann et al. (2017) and chapter 2:

- It would require 70, 37 and 54 installations, respectively for in-house, in-storage and in-field slurry acidification to fulfil the potential.
- Required investments in SAT installations are in the level of € 20.7 million, and the corresponding annual costs for depreciation and interest payment of the investments, and for their maintenance would cost M€ 3.
- Net operational costs for the farmer users comprise in the main the costs for sulphuric acid, and the savings on purchase of nitrogen and sulphur mineral fertilisers. Although marginal, there could also be additional costs for labour, fuel and electricity. Theoretically, there could also be additional costs for liming, but it is unclear whether fertilising with acidified slurry gives a higher demand for liming than fertilisation by use of mineral fertilisers, which is acidifying soils (University of Adelaide. Undated). All in all, taking the mentioned parameters into account, the net operational costs of using slurry acidification are for Russian farms in general minimal, whereas the economic feasibility of individual farms' use of slurry acidification may be either positive or negative, dependent on the exact pre-conditions.
- National legislation doesn't regulate ammonia emissions.

[21] With Russia means here 5 Russian regions, fully of mostly located within the Baltic Sea drainage area.

Zelčs (2018):

- There is no demand for solid cover on slurry tanks in Russia, wherefore the use of in-house acidification could not give Russian farmers any savings for investments in such. However, since a BAT approach will be introduced for regulation of large pig farms in 2019, the situation could change, and it is expected that they will be required to have cover on slurry tanks in the future.
- There is currently no demand for injection of slurry in Russia, wherefore an alternative use of slurry acidification would not give any savings in costs for slurry injection. However, slurry injection is included in the upcoming BAT reference book for pig breeding farms.
- National legislation doesn’t regulate ammonia emissions.
- Low qualification of farm workers could be an obstacle in many cases.
- There are legislation rules, limits and control of operations with acid, which can create difficulties for farmers in practical aspects of acid use (purchase, transport, storage and handling).

Annex 9.3: Opportunities

Chapter 1 and assumptions mentioned in chapter 2:

- Acidification of the weighed slurry potential of 7.4 million tons means that Russia would reduce ammonia emissions with 2.4 Kt.
- The aquatic environment is annually saved for between 792 and 1,287 tonnes of atmospheric nitrogen deposition, which would be a valuable contribution to the fulfilment of the Russian HELCOM CART of 24,720 tonnes nitrogen (see Table 3).
- There is also a potential reduction of greenhouse gas emissions of app. 21,451 tonnes CO_{2e}.
- According to the Russian Food Security Policy, it can be assumed that the national milk and beef production will increase, whereas the pig and poultry production already has reached the target level.
- SATs have a good opportunity for being officially acknowledged as cleantech for large livestock farms in Russia, who has decided to implement a BAT-system from 2019, comparable to that of EU.

Annex 9.4: Threats

The use of S as fertiliser should due to concerns for water quality, firstly the organoleptic quality (WHO, 2004), be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019).

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

Annex 9.5: Policy recommendations

Summarising and monetising the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in 5 north-western regions of Russia, the calculation is as follows:

Issue	Impact	Total value, M€ per year
Reduced ammonia emissions	2.4 Kt. Russia has no ceiling for ammonia emissions and would not have risks for penalties.	-

Savings in the health sector [22]	Sutton et al. (2011) has not estimated the value for the Russian healthcare sector	-
Reduced atmospheric deposition	792 – 1,287 tonnes – which would be a valuable contribution to reach HELCOM CART obligations	0
Reduce greenhouse gas emissions	21,451 tonnes CO_{2e} of a value of € 21.9 per tonnes (https://markets.businessinsider.com/commodities/co2-emissionsrechte)	0.5
Investments in SAT installations	Depreciation and interest payment of the investments, and for their maintenance	-3.0
Net value		-2.5[22]

On this basis, we cannot recommend the 5 Russian regions to implement the use of SATs at the moment. However, the benefit for the health sector would be M€ 5.9 per year in case the savings would be similar to the neighbour country, Finland, i.e. 3 € per kg N in ammonia emissions. Likewise, it has of course a value that the aquatic environment is saved for atmospheric depositions of nitrogen, and if this is set to € 2 per kg N, this value would be in the level of M€ 2.1 per year. Therefore, the 5 Russian regions might consider implementing the use of SATs despite the above calculation.

However, the mentioned BAT introduction in Russia will create incentives for application of environmentally friendly technologies, including SATs. It can be assumed that interest in SATs will increase starting from next year.

In order to ensure the possibility of SATs implementation in Russia and inclusion in the BAT list, it must undergo a comprehensive study under the natural and climatic conditions of Russia, as well as pass approbation at 2 industrial sites (farms) in Russia.

Present Russian conditions are not ready for recommending the implementation of SATs. It is necessary to continue analysis of SATs in practical experiments at pilot farms to provide reliable recommendations for changing conditions and making SATs organizational, technically and economically feasible. At the same time national regulation of ammonia emissions is highly required for implementation of SATs.

[22] Health care sector savings has not been estimated for Russia by Sutton et al. (2011) but using Finland as a reference country with 3 € per kg N, then savings would be M€ 5.9 per year and the total net value would be M€ 3.4 per year.

Annex 10: Policy recommendations relating to SE/Sweden

Annex 10.1: Strengths

Neumann et al. (2017):

- Sweden has a potential for acidifying up to 24 million tons slurry and other liquid manures and digestates, whereas a more realistic, weighed potential is 13.4 million tonnes of slurry.

Fors et al. (2018):

- Sweden has legislation and standards, as well as infrastructure in place for handling of sulphuric acid, including regulations for road transport and storage of sulphuric acid.

Annex 10.2: Weaknesses

Neumann et al. (2017) and chapter 2:

- It would require 289, 151 and 225 installations, respectively for in-house, in-storage and in-field slurry acidification to fulfil the potential.
- Required investments in SAT installations are in the level of € 85.6 million, and the corresponding annual costs for depreciation and interest payment of the investments, and for their maintenance would cost M€ 12.4.
- Net operational costs for the farmer users comprise in the main the costs for sulphuric acid, and the savings on purchase of nitrogen and sulphur mineral fertilisers. Although marginal, there could also be additional costs for labour, fuel and electricity. Theoretically, there could also be additional costs for liming, but it is unclear whether fertilising with acidified slurry gives a higher demand for liming than fertilisation by use of mineral fertilisers, which is acidifying soils (University of Adelaide. Undated). All in all, taking the mentioned parameters into account, the net operational costs of using slurry acidification are for Swedish farms in general minimal, whereas the economic feasibility of individual farms' use of slurry acidification may be either positive or negative, dependent on the exact pre-conditions.

Kučinskienė et al. (2019):

- Field trials in Sweden with acidified slurry has not shown any substantial impact on crop yields or in other ways had clear effect on the soil fertility.

Zelčs (2018):

- There is currently no demand for solid cover on slurry tanks in Sweden, wherefore the use of in-house acidification could not give Swedish farmers any savings for investments in such.
- There is currently no demand for injection of slurry in Sweden, wherefore an alternative use of slurry acidification would not give any savings in costs for slurry injection.
- There are Swedish animal welfare regulations requiring techniques for animal husbandry to be approved.

Annex 10.3: Opportunities

Chapter 1 and assumptions mentioned in chapter 2:

- Acidification of the weighed slurry potential of 13.4 million tons means that Sweden would reduce ammonia emissions with 9.6 Kt, which would be a very valuable contribution to reach the policy objective of 47 Kt in 2020, a target that Sweden was 28% above in 2016.
- In addition, the healthcare sector will save app. € 56.3 million annually due to improved air quality.
- The aquatic environment is annually saved for between 3,216 and 5,226 tonnes of atmospheric nitrogen deposition, which is more than enough for fulfilment of the Swedish HELCOM CART of 1,870 tonnes nitrogen (see Table 3), dependent on the distribution of the depositions on sub-basins.
- There is also a potential reduction of greenhouse gas emissions of 88,561 tonnes CO_{2e}, which would help Sweden to fulfil its 2030-commitments in relation to climate change.

Annex 10.4: Threats

The use of S as fertiliser should due to concerns for water quality, firstly the organoleptic quality (WHO, 2004), be limited to a level that corresponds to the needs of the crops, and it is generally recommended not to exceed 50 kg S per ha (Loide, 2019).

According our immediate knowledge, there are in the foreseeable future no potential, international demands that would make slurry acidification an unacceptable technology in relation to the objectives of clean air and water, a stable climate and a profitable and competitive agro-food sector. Slurry acidification can happen in organic farming with other acidifying agents than sulphuric acid, however giving higher costs for the consumption of the acidifying agent (Joubin, 2018).

We have likewise no knowledge to manure processing technologies or market forces that would cause dramatic changes to the current economic competitiveness of slurry acidification.

A threat could be a scenario of the population converting to become vegans, which with simultaneous cease of animal food exports would mean an end to livestock manure production and its ammonia emissions. However, the EU Agricultural Outlook (2017a) has through analyses of commodity markets, consumption patterns and macroeconomic assumptions for the period until 2030 predicted increased demands for both dairy and meat products on basis of the Aglink-Cosimo model. A lower demand for fresh milk and beef is awaited, whereas the demand for processed dairy products as well as poultry meat in general will increase. The livestock number is in general expected to decline, which largely is compensated for by increased productivity per animal.

Annex 10.5: Policy recommendations

Summarising and monetising the above advantages / opportunities and disadvantages / weaknesses of utilising the potential for slurry acidification in Sweden, the calculation is as follows:

Issue	Impact	Total value, M€ per year
Reduced ammonia emissions	9.6 Kt, which would be sufficient for reaching the defined ceiling for 2020 and avoiding EU penalties.	2.7
Savings in the health sector	€ 7 per kg N in ammonia emissions Sutton et al. (2011)	56.3
Reduced atmospheric deposition	3,216 – 5,226 tonnes – which is probably sufficient for reaching HELCOM CART obligations	0
Reduce greenhouse gas emissions	88,561 tonnes CO_{2e} of a value of € 21.9 per tonnes (https://markets.businessinsider.com/commodities/co2-emissionsrechte)	1.9
Investments in SAT installations	Depreciation and interest payment of the investments, and for their maintenance	-12.4
Net value		48.5

On this basis of a very positive net value, we can recommend Sweden to acidify the weighed slurry potential of 13.4 million tonnes of slurry.

The estimated reduced airborne deposition would further have a considerable value for the society according Hautakangas et al. (2014) and Sutton et al. (2011). In case the abatement cost is set to € 2 per kg N, the value for the society would be in the level of M€ 8.4 per year.

Considering the urgent and high need for Sweden to reduce ammonia emissions and the cost efficiency and positive side effects of slurry acidification, including for the healthcare sector, it is recommended to establish an expert working group with representation from relevant authorities and knowledge institutions in order to clarify

1. the potential impacts of slurry acidification for the livestock sector and the society, based on outputs, conclusions and recommendations of the Baltic Slurry Acidification-project as well as other documentation; and
2. possible ways of amending regulations, standards and subsidy programmes for ensuring an envisaged use of slurry acidification.

Interreg
Baltic Sea Region
Baltic Slurry Acidification

EUROPEAN UNION

EUROPEAN REGIONAL DEVELOPMENT FUND

www.balticslurry.eu

Summary of the project

Baltic Slurry Acidification is an agro-environmental project financed by Interreg Baltic Sea Region under the priority area Natural resources and specific objective Clear Waters. The aim of the project is to reduce nitrogen losses from livestock production by promoting the use of slurry acidification techniques in the Baltic Sea Region and thus to mitigate eutrophication of the Baltic Sea. Baltic Slurry Acidification project was implemented in the period March 2016 - February 2019.

Summary of the report

The report is intended for policy makers from ten main Baltic Sea Region countries. It summarises societal policy objectives and international commitments related to slurry acidification, as well as the business goals of farmers. Country annexes outlines the strengths, opportunities, weaknesses and threats related to use of slurry acidification in the individual countries, based on results and conclusions of project activities. The report recommends all EU Member States in the Region to establish expert groups for further analysing the impacts of slurry acidification and ways for its implementation.