Environmental assessment of slurry acidification technologies

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Interreg
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Preface

Baltic Slurry Acidification is a flagship project in the action plan for EU strategy for the Baltic Sea Region (BSR). The project was carried out between 2016-2019 with a budget of 5.2 million euros, of which 4 million euros is funded by the EU Regional Development Fund through the Interreg Baltic Sea Region Program. The general aims of the project were to reduce ammonia emissions from animal production and create a more competitive and sustainable farming sector by promoting the implementation of slurry acidification techniques (SATs) throughout the Baltic Sea Region. This report falls under Work Package 5 – Environmental and economic implications of slurry acidification. This report presents an environmental assessment of slurry acidification technologies for the Baltic Sea Region. RISE and ECRI have been largely responsible for the work behind this report however much of the background data used in the calculation has been delivered by other project partners in the respective countries.

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Content

Summary

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. Livestock slurry is the main source of ammonia nitrogen emissions in the Baltic Sea Region, which through atmospheric deposition results in a significant amount of nitrogen entering to the Baltic Sea. Slurry acidification techniques have been tested and implemented in Denmark and the three main types of slurry acidification techniques available on the market are:

1. In-house acidification of livestock slurry
2. In-storage acidification of stored livestock slurry
3. In-field acidification of livestock slurry during field spreading.

The use of slurry acidification techniques benefits farmers by increasing the nitrogen use efficiency of their organic fertilisers and thereby decreasing their dependency on mineral nitrogen.

The main objective of whole Baltic Slurry Acidification project is to promote the implementation of slurry acidification techniques throughout the Baltic Sea Region to reduce airborne eutrophication and create a more competitive and sustainable farming sector. The project will further clarify technological aspects and potential risks of eutrophication, acidification and climate change by analysing the environmental and economic implications, conduct market analysis and suggest policy recommendations that could help dissemination of SAT technology in the Baltic Sea region.

In work package 5 (WP5), environmental and economic impacts of SATs, the aim is to increase knowledge concerning the environmental and economic impacts of slurry acidification to help build end user confidence in the systems and to help justify the risks involved with investing in these technologies. This report is the environmental performance evaluation of slurry acidification. In an environmental systems analysis four scenarios were evaluated; one reference scenario and three acidification scenarios.

1. Reference scenario (*Reference*) is manure handling with no acidification. Manure in housing is evacuated to pre-tank for short-time storage. From pre-tank slurry is pumped to outdoor storage for long time storage. Using tractor and tank wagon slurry is transported from storage to field where it is applied on soil.
2. Acidification in the animal housing (*Housing)*. Slurry is evacuated from the animal housing to the pre-tank where it is acidified. Part of the slurry is recycled back into the housing to decrease emissions in the housing. When the pre-tank is full the slurry is pumped to the outdoor storage.
3. Acidification at the outdoor storage (*Storage*). slurry is evacuated from the housing to the pre-tank where it is acidified. When the pre-tank is full the slurry is pumped to the outdoor storage
4. Acidification when spreading slurry (*Spreading)*. Acid is added when the slurry is spread to crops. Acidification equipment is mounted on the tractor.

Ammonia emissions dominates the nitrogen losses from slurry handling and all slurry acidification technologies reduces ammonia emissions. The earlier in the handling chain the slurry is acidified the more effect will it have on reducing ammonia emissions.

The use of slurry acidification techniques resulted in changed air emissions of nitrogen emitted as ammonia, nitrous oxide, nitric oxide and nitrogen gas. Emissions of methane were reduced using slurry acidification in housing and outdoor storage. Acidification when spreading only impacted global warming marginally through direct and indirect nitrous oxide emissions as methane emissions occur at storage and in housing.

Emissions of nitrous oxide is less affected when using slurry acidification, or at least the information in literature on nitrous oxide emissions when using acidification techniques are inconclusive. The scenarios using slurry acidification techniques had increased emissions of nitrous oxide mainly because ammonia emission decreased leaving more nitrogen in slurry and therefore increasing the potential risk of nitrous oxide formation.

The reduced emissions of nitrogen when using slurry acidification resulted in more nitrogen remaining in slurry when spread. Thereby increasing the nitrogen efficiency defined as ammonia nitrogen available for plants after initial losses when spread. The increase in nitrogen efficiency is around 60-70 % for non-acidified slurry and increase to 75-90 %. The increased nitrogen efficiency can be interpreted as potential to reduce the use of supplementary mineral fertilisers or achieving a better ratio between phosphorus and nitrogen in slurry. The environmental effects of saved mineral fertiliser nitrogen were small compared to the impact from direct emissions from slurry handling.

Acidification and eutrophication are two environmental impact categories that to a large extent is influenced by ammonia emissions. The lowered ammonia emission using slurry acidification technologies is favourable for reducing potential eutrophication and acidification from airborne emissions. Acidification techniques reduce methane emissions as pH is lowered the contribution to global warming potentials is reduced. Also, as ammonia emissions are lower when acidifying slurry, indirect formation of nitrous oxide is reduced and thereby reducing slurry contribution to global warming

Using sulphuric acid increase the amount of sulphur in slurry from approximately 0.3 kg sulphur per tonne slurry spread to ca 1.3 kg sulphur per tonne slurry spread. The effect of increased sulphur content is unknown regarding emission of hydrogen sulphide (H2S) and sulphuric oxides (SOx). No usable data exist on sulphur emission from slurry handling. There are studies that show an initial burst of hydrogen sulphide when stirring and mixing at storage. As information on sulphur emissions are insufficient no effect of increased sulphur content were calculated more than increased amount and concentration in slurry. There is a need for investigating the effect of increased sulphur content in slurry regarding emissions and potential environmental impact.

The conclusion is that acidification of slurry lowers emissions of ammonia and methane thereby decreasing the environmental impact regarding global warming and potential terrestrial eutrophication and acidification caused by airborne emissions. Higher nitrogen efficiency is beneficial for crops and have the potential to reduce the use of mineral fertilisers. Sulphur concentration increases with a factor 3-4 and the effect on emissions and environmental impact is unknown but a potential risk.

The following conclusions are drawn from the environmental systems analysis;

- there are decreased emissions of primarily ammonia when acidifying slurry
- methane emissions decrease when acidification is done in housing or at storage
- less ammonia is lost lead to more nitrogen left in slurry resulting in higher efficiency of nitrogen
- potential to reduce mineral fertiliser use if utilised properly
- environmental impact decreases when acidifying slurry for impact categories eutrophication, acidification and climate impact
- effects depend on the assumption that ratios for changed impact is according to results from Danish trials
- differences between different countries depend on initial emissions as the effect from acidification is assumed to be the same wherever it is performed
- uncertainty regarding emissions of nitrous oxide due to lack of data concerning direct nitrous oxide emissions
- potential risk for increased indirect emissions of nitrous oxides caused by reduced ammonia emissions resulting in more nitrogen in slurry
- need for evaluating regarding costs, emissions and environmental impact, acidification as slurry handling technology compared to other measures to reduce emissions as example roofed storage, soil injection, cooling of slurry etc

1 Background

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 to mitigate eutrophication of the Baltic sea. Livestock slurry is the main source of ammonia nitrogen emissions in the Baltic Sea Region. Ammonia through atmospheric deposition results in a significant amount of nitrogen entering to the Baltic Sea. Slurry acidification techniques can be used to reduce the ammonia losses from the handling of slurry in livestock housing, slurry storages and from spreading of slurry on fields. Slurry acidification techniques have been tested and implemented in Denmark and the three main types of SATs available on the market are:

1. In-house acidification of livestock slurry
2. In-storage acidification of stored livestock slurry
3. In-field acidification of livestock slurry during field spreading.

The use of SATs benefits farmers by increasing the nitrogen use efficiency of their organic fertilisers and thereby decreasing their dependency on mineral nitrogen.

1.1 Project objectives

The main objective of Baltic Slurry Acidification project is to promote the implementation of slurry acidification techniques throughout the Baltic Sea Region to reduce airborne eutrophication and create a more competitive and sustainable farming sector. Core activities focus on establishing pilot slurry acidification installations and field trials in countries around the Baltic Sea that will be used to disseminate knowledge to target groups via field walks and demonstrations to provide local experiences to help build end user confidence in these technologies. The project will further clarify technological aspects and potential risks of acidification, analyse the environmental and economic implications, conduct market analysis and suggest policy recommendations that could help dissemination of SAT technology in the Baltic Sea region.

As a part of the whole Baltic slurry acidification environmental analysis is done for the performance of slurry acidification techniques. The environmental analysis is done in work package 5 (WP5), environmental and economic impacts of slurry acidification technologies. The aim is to increase knowledge concerning the environmental and economic impacts of slurry acidification to help build end user confidence and to help justify the risks involved with investing in these technologies. This report concerns the environmental impact from using slurry acidification techniques in comparison to conventional use of non-acidified slurry.

1.2 Environmental impacts assessment methodology

The environmental impact analysis uses methodology from life cycle assessment. Life cycle assessment is a standardised method for analysing the environmental impact for products and services using a wide range of impact categories.

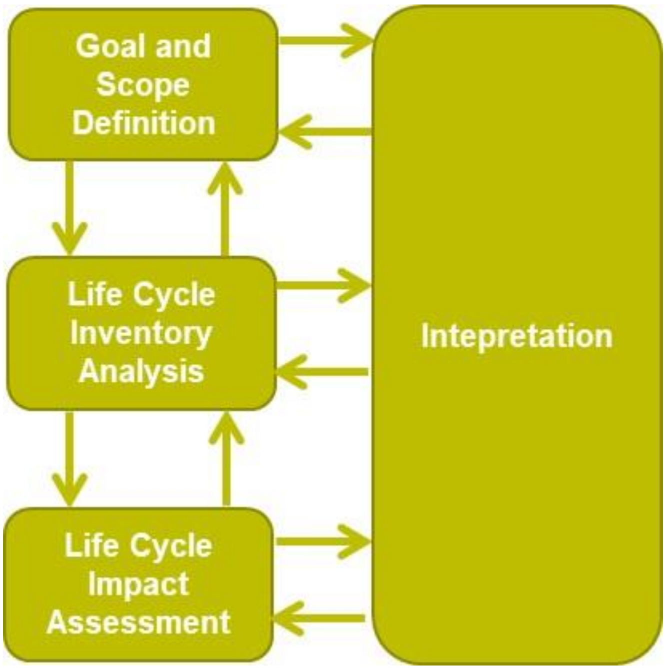


Figure 1. Life cycle assessment modelling approach and stages during a life cycle assessment.

Life cycle assessment is an iterative process moving through different steps(Figure 1). The first step is the definition of goal and scope. The goal and scope are all included processes within defined system boundaries. Life Cycle Inventory Analysis, in which associated emissions are assigned to each process. The Life Cycle Impact Assessment, emissions are converted to units fitting into the respective impact category, for example kg CO_2-equivalents for Global Warming Potential. Interpretation of the results, where sensitivity analysis is made of identified parameters and variables.

In project Baltic Slurry Acidification, the environmental impact analysis will use the life cycle assessment methodology in a simplified form. No specialised software tool will be used; calculations will be performed using Excel spreadsheet. From the life cycle assessment standard, methodology for inventory analysis and impact analysis will be adapted to project goal and scope. In the Baltic slurry acidification project only, airborne emissions contributing to global warming, Eutrophication and acidification will be assessed.

1.3 System boundaries

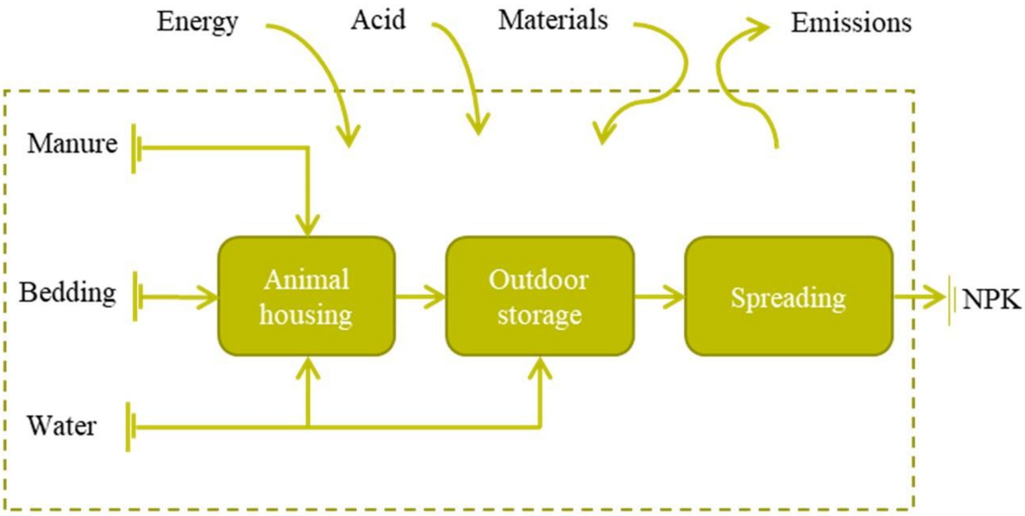


Figure 2. General description of slurry handling systems studied.

All systems start at slurry excreted from animal and end after initial losses when slurry is applied on arable land (Figure 2). Emissions from slurry management occur in the animal housing prior to evacuation of slurry, in the outdoor storage and when spreading slurry. The system includes emissions from input materials and energy used. The energy and materials used are generation of electricity, production and use of diesel, sulphuric acid, mineral fertiliser nitrogen and lime. Electricity used in the studied countries is national electricity mixes. The studied scenarios are only studying slurry from dairy cattle and fattening pigs. Only acidification of slurry using sulphuric acid (H_2SO_4) is studied. The need of supplementary or saved mineral fertiliser nitrogen is assessed. The difference is calculated as plant available ammonium nitrogen when using non-acidified and acidified slurry.

Emission in soil after initial emission from spreading are excluded, therefore no emissions and environmental impact is calculated from leakage of nutrients and formation of airborne emissions occurring after initial losses when spreading slurry. The reason for this is that after spreading, processes in soil and plant influence the emissions in field. Therefore, it's not possible to attribute or allocate emissions from soil processes and leakage to the slurry spread. From slurry handling, housing, storage and spreading, only air emissions of nitrogen and carbon is calculated. It is assumed that leakage of nitrogen phosphorus and potassium and carbon during slurry handling is negligible and therefore not included.

1.4 Environmental impacts analysis

Studied environmental impact categories are global warming potential using the 100 year timeframe, potential eutrophication (EP) and acidification (AP) from airborne emissions. Methodology for calculating these impact categories are taken from IPCC

(2013) for global warming and Hischier et al. (2010) for eutrophication and acidification (Table 1). Relevant emissions are weighted into environmental impact categories as global warming potential that calculates the effect of greenhouse gas emissions using weighting factors from IPCC (2013). Potential terrestrial and aquatic eutrophication and acidification are calculated using weighting factors from Hischier et al. (2010).

Table 1. Weighting factors for environmental impact categories; eutrophication potentials, EP, acidification potentials, AP and global warming potentials, GWP_{100}.

	Eutrophication ($kg\ PO_4^{-}eq\ kg^{-1}$)	Acidification ($kg\ SO_2$-eq. kg^{-1})	Global warming ($kg\ CO_2$-eq. kg^{-1})
N to air	0.42		
NOx to air	0.13	0.5	
NH_3 to air	0.35	1.6	
SO_2 to air		1.2	
CO_2 renewable to air			0
CO_2 fossil to air			1
CH_4 renewable to air[A]			34
CH_4 fossil to air[A]			34
N_2O to air[A]			298

[A] Including climate change feedbacks (IPCC, 2013)

1.4.1 Global warming potentials

Global warming is the increase in the earth's average temperature that causes changes in the climate. Global warming is caused primarily from emissions of carbon dioxide, methane and nitrous oxide to the atmosphere. The gases stop solar radiation reflected from earth surface to radiate out into the space. This causes a greenhouse effect when solar heat is trapped inside the earth atmosphere. Global warming potentials is standardised over specific time intervals of 20, 100 and 500 years and is expressed as carbon dioxide equivalents (CO2-eq). This means that the contribution from different greenhouse gases to global warming are all expressed in terms of kg CO2-eq. Most commonly used is the 100 years exposure time expressed as GWP100. In this project GWP100 for the gases carbon dioxide, methane and nitrous oxide will be quantified as GWP100 (Table 1) using weighting factors from IPCC (2013). GWP is a global impact category meaning that an emission of greenhouse gases impact whole earth wherever it is emitted. Weighting factors for methane and nitrous oxide include climate change feedbacks. Climate change feedbacks means that climate change causes changes in the climate. These changes affect the climate change further as they feed back to the climate change. These feedbacks can be positive, increasing climate change or negative decreasing climate change (IPCC, 2013).

1.4.2 Potential eutrophication

Eutrophication caused by emissions of nutrients as nitrogen and phosphorus to terrestrial and aquatic environment. The emissions of nutrients cause excess growth of plant biomass and due to the high load, it can result in oxygen depletion. Eutrophication potential (EP) used is taken from the Ecoinvent database and using a generic impact category CML 2001 eutrophication potential expressed as phosphate equivalents (kg PO4-eq) (Hischier et al., 2010) in Table 1. In this study terrestrial eutrophication is quantified.

1.4.3 Potential acidification

The acidification potential is used to describe the potential for different substances ability to form H^{+}-ions. They are calculated against and set against the reference substance sulphur dioxide (SO2) and are expressed as sulphur dioxide equivalents (SO2-eq) in Table 1 (Hischier et al., 2010).

1.5 Saved mineral fertiliser

Saved mineral fertiliser is calculated as the difference in ammonium nitrogen between the reference scenario and the acidification scenarios. The plant available ammonium nitrogen is the amount available for plants after initial losses when spreading slurry. Higher amounts of ammonium nitrogen in the acidification scenarios compared to the reference scenario is assumed as saved mineral fertilisers. Lower amounts in the acidification scenarios compared to reference scenario leads to a need of supplementary mineral fertiliser. Mineralisation of organic nitrogen during first year after spreading and long-term effects of mineralisation of organic nitrogen is not included.

- $NH4N_{ref}$ is the amount of NH4-N available for plants in non-acidified slurry
- $NH4N_{AC}$ is the amount of NH4-N available for plants from acidified slurry

The saved mineral fertiliser (SMF) is calculated using equation
$SMF = NH4N_{ref} - NH4N_{AC}$ where $NH4N_{ref}$ and $NH4N_{AC}$ is the amount of ammonium nitrogen available for plants.

1.6 Units for presenting results

In life cycle assessment a functional unit is chosen that is representative for the goal of the study. The functional unit is the base that all results are presented according to. In current study there are an interest to show the potential of acidification technologies on a national level and to show the potential of saving emissions as technology compared to conventional handling of slurry. For the scenarios the results will be presented as **kg per year** or **kg per tonne slurry spread**. Results per year show the total impact on national, regional or local level depending on the part of all slurry using acidification technology. This can be related to total emissions and national level goals for reducing NH3 emissions etc. Results per ton slurry show the potential compared to non-acidified slurry on a farm level showing the potential for decreasing emissions and environmental impact. When presenting the impact from different countries studied the results are shown as relative results compared to national emissions for non-acidified slurry. These results are shown as percentual change compared to reference, being non-acidified slurry.

2 Studied Scenarios

In total four scenarios are evaluated; one reference scenario and three acidification scenarios.

1. Reference scenario (*Reference*) is manure handling with no acidification. slurry in housing is evacuated to pre-tank for short-time storage. From pre-tank slurry is pumped to outdoor storage for long time storage. Using tractor and tank wagon slurry is transported from storage to field where it is applied on soil.
2. Acidification in the animal housing (*Housing)*. Slurry is evacuated from the animal housing to the pre-tank where it is acidified. Part of the slurry is recycled back into the housing to decrease emissions in the housing. When the pre-tank is full the slurry is pumped to the outdoor storage.
3. Acidification at the outdoor storage (*Storage*). slurry is mucked from the housing to the pre-tank where it is acidified. When the pre-tank is full the slurry is pumped to the outdoor storage
4. Acidification when spreading slurry (*Spreading)*. Acid is added when the slurry is spread to crops. Acidification equipment is mounted on the tractor.

All scenarios are calculated as a base scenario with average data, min and max scenarios with the lowest and highest value for reduction when acidifying. The scenarios are calculated for pig and cattle slurry and the combined effect of all slurry, both pig and cattle as slurry. Pig slurry composition is slurry from fattening pigs and cattle slurry composition is represented by slurry from dairy cattle. All scenarios are calculated for the countries Denmark, Estonia, Finland and Sweden. An additional scenario for Sweden where best available technology (BAT) is compared to acidification. BAT is no changes in housing, roof over outdoor storage and soil injection when spreading.

2.1 Reference scenario

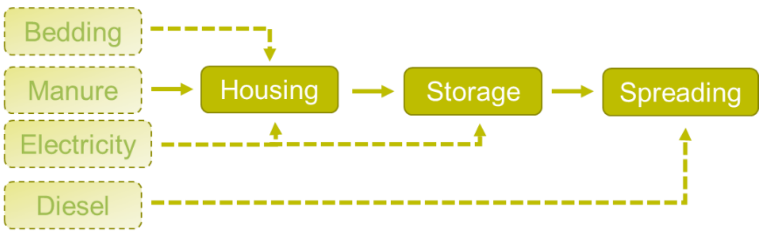


Figure 3. The reference scenario for handling slurry where there is no acidification of slurry.

The reference scenario describes slurry management from animal housing to spreading on arable land. The slurry management includes evacuation of slurry from housing to pre-tank. slurry pumped from the pre-tank to the outdoor storage. slurry pumped from outdoor storage to tank wagon that is pulled by tractor and slurry spread on arable land. From housing slurry is evacuated using scrapers to the pre-tank. The slurry is stored there for 1-4 days before pumped to outdoor storage. Outdoors, slurry is stored in concrete storage. The outdoor storage is filled and emptied from the bottom to reduce emissions. Outdoor storage is set as open storages with a natural crust form at the top. Spreading is assumed as an average technology, a combination of broadcast and hose spreaders and soil injection.

Energy for handling slurry is electricity and diesel. From the animal housing, slurry is evacuated using scrapers etc. that in ducts move slurry to the pre tank situated in the housing. Slurry is stored for a short time, only a few days before it is pumped to outdoor storage. The scrapers and the pump use electricity. In the outdoor storage slurry is stored for a longer period before transported and used as fertiliser. Electricity is used when stirring and mixing slurry prior to emptying the outdoor storage. The storage is emptied using an electric pump. Slurry is transported to field for application using tank wagon and tractor. The same tractor and tank wagon are used during spreading.

2.2 Acidification in housing

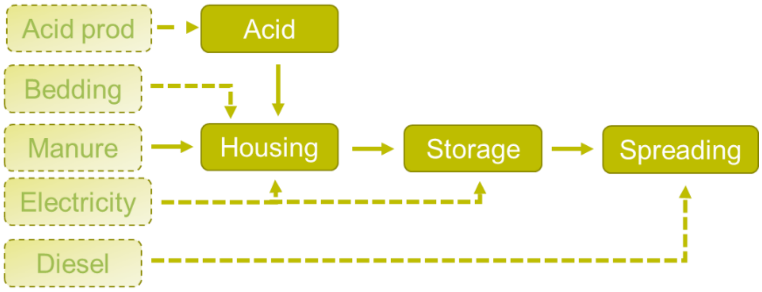


Figure 4. Showing the scenario for handling slurry where acidification is done inside the animal housing.

The scenario with acidification in housing is the same as the reference scenario with the addition of the acidification equipment. When acidifying slurry in the animal housing a tank holding the acid is placed outside and acid is added to the pre-tank on daily basis. Part of the acidified slurry is recycled back to the animal housing acidifying slurry in the duct underneath the slats before the pre-tank.

2.3 Acidification at storage

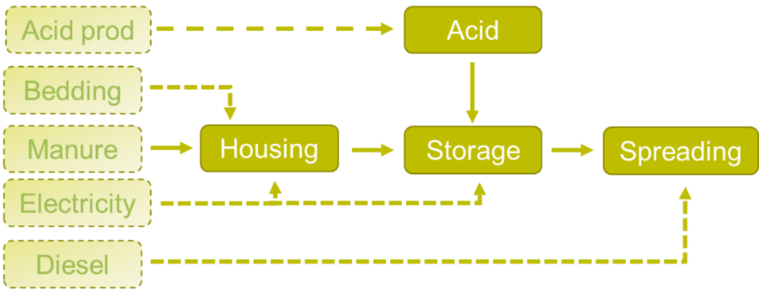


Figure 5. Showing the scenario for handling slurry where acidification is done at the outdoor slurry storage.

The scenario for Acidification at storage is the same as the reference scenario with the addition that sulphuric acid is added at the pre-tank. Acidified slurry is pumped to outdoor storage and kept at a lower pH than non-acidified slurry. Slurry is pumped to the outdoor storage where it is stored prior to application when emptying the storage slurry is stirred and mixed. At the same time acid is added to lower pH.

2.4 Acidification when spreading

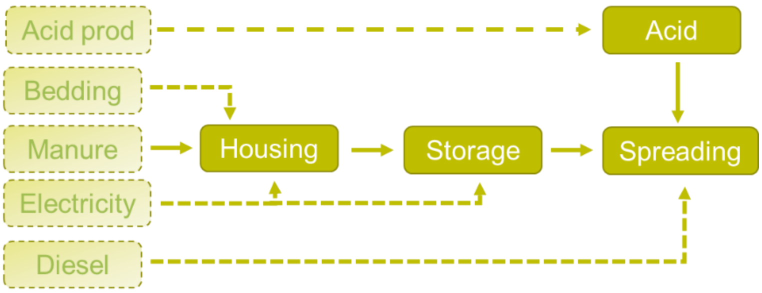


Figure 6. Showing the scenario for handling slurry where acidification is done when spreading slurry.

The scenario is the same as the reference scenario. The difference is that slurry is acidified when spreading. Equipment for adding acid to slurry during spreading is carried at the front of the tractor. pH is measured continuously, and the acid is injected into the slurry just before application on arable land.

2.5 Sensitivity and scenario analysis

Information regarding decreased emissions of nitrogen when acidifying slurry varies. Reduce emissions for slurry acidification compared to conventional slurry handling are calculated for a min and max scenario to complement the base scenario that uses average data. One scenario analysis is done. For Sweden the use of other BAT technologies as roof covered outdoor storage and spreading slurry using soil injection is compared to acidification of slurry

3 Material and energy inventory

Material and energy are the inventory of materials, such as composition of slurry from pig and cattle, composition of bedding material (assumed being straw), energy as electricity and diesel used at various stages of the slurry handling. It also includes inventory for production and use of sulphuric acid, equipment used for adding acid to slurry and production and use of lime.

3.1 Amount and composition of slurry and bedding material

The slurry composition is described by different variables (Table 2) and uses average data for the animal slurry used. Composition of pig and cattle slurry for Denmark, Estonia and Finland use slurry composition from Hamelin et al. (2013). Sweden uses composition adapted from Hamelin et al. (21013). Inventory data for slurry compositions are presented in Appendix 1.

Table 2. Composition of slurry and bedding material, parameter logged, acronym and unit

Parameter	Acronym	Unit
Wet weight	WW	kg
Dry Matter	DM	kg/tonne
% DM		%
Volatile Solids	VS	kg/tonne
% VS of DM		% of DM
Total nitrogen	Ntot	kg/tonne
Ammonium nitrogen	NH_4-N	kg/tonne
Total phosphorus	Ptot	kg/tonne
Total potassium	Ktot	kg/tonne
Total Sulphur	Stot	kg/tonne
Total organic carbon	Ctot	kg/tonne

Energy use

The energy use when handling slurry varies to a large extent (Hörndahl, 2008, Neuman, 2009). The energy use depends on many factors such as housing system, placement of storage, equipment used when handling slurry etc. In housing and storage both electricity and diesel are used. Spreading is performed using diesel as fuel (Table 3). Energy data for studied countries are presented in Appendix 1.

Table 3. Energy use when handling slurry.

Energy use	Electricity	Diesel
Housing		
Evacuation of slurry	X	X
Addition of H_2SO_4	X	
Recycling of slurry after acidification	X	
Pumping slurry from pre-tank to storage	X	
Storage		
Spreading		
Stirring and mixing	X	
Emptying of storage	X	
Transport to and from field		X
Spreading		X
Spreading slurry		X
Addition of H_2SO_4		X
Spreading of lime		X

Energy use in animal housing: The energy use allocated to slurry handling is evacuation of slurry from housing to pre-tank and pumping slurry from pre-tank to outdoor storage. For acidification scenario housing addition of acid from acid storage and recycling of acidified slurry back to housing is added to the energy demand. For acidification scenario pumping of acid to pre-tank is added to the energy demand for the housing systems for evacuating slurry uses electricity or diesel or a combination of both. Additional energy as electricity is added when applying sulphuric acid.

Outdoor storage: No energy use is allocated to the actual outdoor storage all energy use is either taking part in the animal housing pumping from pre-tank and adding acid in pre-tank or allocated to the spreading.

Spreading: Energy when spreading slurry includes stirring and mixing before emptying storage, pumping of slurry from storage to tank wagon. Transport to and from field and spreading slurry in field. Electricity is assumed as energy when mixing, stirring and pumping slurry and diesel is used when transporting and spreading of slurry. When acidifying in field a 3 % increase of diesel consumption is assumed when spreading. Spreading of slurry is performed using 18 m^3 tank wagon. If spreading using soil injection instead of broad or band spreader the energy use increases 4-9 kWh per working width of spreader assuming an average increased energy demand of 6.5 kW per m work width.

Additional energy to add sulfuric acid to slurry. The extra energy needed is assumed is assumed as an 10 % increase where acidification is done. For acidification in housing and storage electricity use is assumed to be equal to 10 % extra electricity needed for pumping from pre-tank to outdoor storage. For acidification when spreading the fuel consumption when spreading is increased with 10 %.

Energy use is electricity or diesel used depending on solution for energy use. Electricity is expressed as **kWh/ ton slurry** and diesel as **litre diesel/ tonne slurry or kWh_{diesel}/ tonne slurry**. Tonnes of slurry are the amount of slurry at various stages in the handling chain.

Environmental effects as climate change, potential eutrophication and acidification from production, distribution and use of electricity and diesel is shown in Table 4.

Table 4. Environmental impact categories Global warming (g CO_2-eq/kWh_{el} & kg CO_2-eq/m^3 fuel), Eutrophication (g PO_4-eq/kWh_{el} & kg PO_4-eq/m^3_{fuel}) and acidification (g SO_2-eq/kWh_{el} & kg SO_2-eq /m^3_{fuel}) for diesel including production. distribution and use.

Energy carrier	Global warming	Eutrophication	Acidification	
Danish electricity mix	343	0.0401	0.2067	Danish energy agency (2017)
Estonian electricity mix	762	0.022	0.1184	n.a
Finnish electricity mix	250	0.0096	0.0516	n.a
Swedish electricity mix	36	0.0051	0.0233	Gode et al. (2011)
Diesel	2 728	2.0149	9.1127	Gode et al (2011)

3.2 Emissions from slurry management

Emission from slurry handling are all air emissions. There are nitrogen emissions of ammonia (NH3-N), nitrous oxide (N2O-N), nitric oxides (NO-N) and nitrogen (N2). Carbon is emitted as methane (CH4-C), Carbon dioxide (CO2-C). Carbon is either biogenic carbon from slurry or fossil from energy as diesel and electricity. Indirect nitrous oxide is formed when ammonia and nitric oxide land on ground and the conditions are such that nitrous oxide can be formed.

3.2.1 Ammonia emissions

Ammonia is emitted at all stages in the slurry handling chain. Emissions from animal housing and when spreading slurry is where the losses of ammonia is largest. Emissions of ammonia is percentage of either total nitrogen content (Ntot) in slurry or percentage of ammonium nitrogen. The emission factors are calculated or estimated values. How emission factors are obtained is described further in Appendix 1 for studied countries. Ammonia emissions from housing, storage and spreading is calculated using formulas below.

- $NH3\text{-}N_{house}=Ntot*EF_{NH3Nhouse}$
- $NH3\text{-}N_{storage}=Ntot*EF_{NH3Nstorage}$
- $NH3\text{-}N_{spread}=Ntot*EF_{NH3Nspread}$

3.2.2 Nitrous oxide emissions

Emissions of nitrous oxide is calculated as a percentage of total ammonia nitrogen TAN (NH4-N). The emission factors $EF_{N2Ohouse}$, $EF_{N2Ostore}$ and $EF_{N2Ospread}$,

- $N2O\text{-}N_{house}=Ntot*EF_{N2ONhouse}$
- $N2O\text{-}N_{storage}=Ntot*EF_{N2ONstorage}$
- $N2O\text{-}N_{spread}=Ntot*EF_{N2ONspread}$

3.2.3 Nitric oxide and Nitrogen losses

Emission factors for nitric oxide (NO) do exist for slurry management (EEA, 2009). Nitric oxide is formed through nitrification in the surface layer of stored slurry or in slurry aerated to reduce odour or to promote composting. EEA (2009) have estimated emission factors for nitric oxides and nitrogen (Table 5). Emission factors are used for calculating nitrogen emissions at Tier 2 level (EEA, 2009).

Table 5. Emission factors for NO and N_2 formation in stored liquid slurry expressed in proportion to TAN

	Emission factor	Proportion of TAN
$EF_{NO\text{-}N}$	NO	0.0001
EF_{N2}	N_2	0.0030

TAN = Total Ammonia Nitrogen

- $NO\text{-}N=TAN*EF_{NO\text{-}N}$
- $N_2=TAN*EF_{N2}$

3.2.4 Methane and carbon dioxide formation and losses

Methane: Slurry evacuation is performed at different intervals, from 1-2 times per day to longer periods. When slurry is frequently evacuated, methane emissions from slurry in housing negligible compared to enteric fermentation. For storage, emissions are calculated using IPCC (2006) Tier 2 method;

CH_4 [kg] = VS [kg] * B_0 * 0.67 [kg CH_4 per m^3 CH_4] * MCF.

When spreading the conditions are aerobic and therefore soil methane formation is negligible. The maximum potential methane formation (B_0) is the amount of CH4 that can be formed when VS is degraded at anaerobic conditions and the methane conversion factors (MCF) gives the part of B_0 transformed into CH4 during storage (Table 6).

Table 6. Potential methane formation (B_0) and the methane conversion factors (MCF) for liquid slurry from dairy cattle and fattening pigs (SEPA, 2016).

	Dairy cattle	Fattening pigs	Unit
B_0	0.24	0.45	m^3 CH_4/ kg VS
MCF_{liquid}	3.50	3.50	% of B_0

Carbon dioxide CO_2 is formed at the same time as methane in housing and storage. Ratio between CO_2 and CH_4 can be estimated using equation from Buswell et al. (1952);

$C_nH_aO_bN_c$ + [n-0.25a-0.5b+1.75c]*H_2O → [0.5n+0.125a-0.25b-0.375c]*CH_4 + [0.5n-0.125a+0.25b-0.625c]*CO_2 + cNH_4+$cHCO_3^-$.

Knowing the composition of carbohydrates. VFA. fat. proteins and lignin theoretical amounts of carbon dioxide and methane can be calculated (Table 7). The distribution between carbon dioxide and methane is thereby known. Using IPCC Tier 2 equation for methane formation in slurry storages and the distribution between carbon dioxide and methane from Buswell et al. (1952) an estimate of carbon dioxide formed can be calculated to **1.83 kg of CO_2 is formed per kg CH_4**.

Table 7. Distribution of carbon sources (% of VS) in VS from cattle and fattening pig.

	Chemical formula	Dairy cattle	Fattening pigs
Carbohydrate	$C_6O_{10}H_5$	42.5	58.0
Fat	$C_{57}H_{104}O_6$	16.2	7.7
Protein	$C_5H_7NO_2$	27.0	16.8
VFA	$C_2H_4O_2$	8.5	4.0
Lignin	$C_{46}H_{38}O_{16}$	5.8	13.5

3.2.5 Indirect formation of nitrous oxides

Nitrous oxide is formed indirectly when ammonia and nitrogen oxide is formed. The assumption is that part of the ammonia and nitric oxide emitted will end in such way that nitrous oxide is formed. According to IPCC (2006) 1 % of ammonia and nitric oxide respectively emitted end in positions were conditions is favourable for nitrous oxide formation.

4 Manufacture of sulphuric acid and mineral fertilisers

Emissions and energy use for manufacture of sulphuric acid are collected from the Ecoinvent database (Althaus et al., 2007). Emissions and energy used for manufacture of mineral fertilisers are collected from (Brentrup & Palliere, 2008 & Williams et al., 2010). The emissions are used to calculate environmental impact categories GWP. EP and AP for sulphuric acid and mineral fertilisers from cradle to factory gate (Table 8).

Table 8. Environmental impact categories global warming (kg CO_2-eq/ kg), eutrophication (kg PO_4-eq/ kg) and acidification (kg SO_2-eq/ kg) from manufacture of sulphuric acid and mineral fertilisers.

	Global warming	Eutrophication	Acidification
Sulfuric acid	7.62e-2	8.52e-4	4.14e-4
Nitrogen (AN)			
European average	6.20	5.00e-4	4.70e-3
BAT	2.74	5.00e-4	4.70e-3
Nitrogen (Urea)			
European average	1.59	5.40e-4	5.30e-3
BAT	1.13	5.40e-4	5.30e-3
Nitrogen (CAN)			
European average	6.30	5.50e-4	5.30e-3
BAT	2.83	5.50e-4	5.30e-3
Nitrogen (AS)	3.00	5.20e-4	5.30e-3
Phosphorus (TSP)	1.66	7.40e-4	8.10e-3
Phosphorus (SSP)	0.60	5-70e-4	6.60e-3
Potassium (MOP)	0.60	3.00e-4	7.20e-3

Amount of sulphuric acid varies with slurry properties and were in the acidification is done. The aim is pH value ranging from 5.5-6.4 (Petersen et al., 2016, Nyord et al., 2010). Nyord et al. (2010) used 1,9-2,9 litre 96 % H2SO4 acidifying pig and cattle slurry during spreading with Biocovers SyreN system. Acidification in housing with Infarm system used 3.3 litre per ton slurry. Petersen et al. (2016) used 5.1 kg per pig in spring period and 5.6 kg per pig in the summer and autumn period when acidifying in housing, this correspond to 9.8 and 10.7 kg acid per tonne slurry. Sørensen & Eriksen (2009) used 5.0 kg of sulphuric acid per tonne slurry to reach pH 5.5 (Table 9). No data was found for systems were acidification take part early in the outdoor storage. It is assumed that acidification in storage uses the same amount of acid as inhouse acidification.

Table 9. Amount of sulphuric acid used at acidification of slurry.

Time of application	amount of H_2SO_4		
	Min	base	Max
Acidification in housing	3.3	3.3	10.7
Acidification at storage	n.a.	n.a.	n.a.
Acidification when spreading	1,9	n.a.	2.9

5 Emission reduction factors for acidification

Petersen et al. (2014) tested acidification of pig slurry in housing and storage. Slurry were stored for 83 days. pH was lowered to 5.5 and 6.5 and ammonia losses were 84 % for the inhouse acidification and 49 % for the storage acidification trials. Petersen et al. (2016) studied the effects of inhouse acidification of slurry for finishing pigs during three production periods, spring, summer and autumn. Acidified slurry had lower ammonia emissions than untreated slurry. Ammonia emissions decreased with 66.2 % in spring, 44.3 % in summer and 70.7 % in autumn. ten Hoeve et al (2016) used a life cycle perspective on slurry acidification they collected data for ammonia emissions from acidification. They calculated reduction of ammonia for inhouse acidification and field acidification. Ammonia emissions when acidifying in house lowered emissions in housing with 50-86%, at storage with 65-92% and when spreading with 54-82%. Acidification when spreading reduced ammonia emissions with 54-82 % compared to emissions from non-acidified slurry. Methane emissions were only measured during the spring production period and showed a 50.3 % decrease. Kai et al. (2008) tested acidification in housing using the Infarm A/S system. Comparing emissions from housing, storage and field application compared to Danish standard values for emissions of untreated slurry the reductions of ammonia were lowered 70-90 %.

In a review article by Fanguiero et al. (2015) emissions reduction when acidifying slurry were collected from different sources. Emissions of ammonia, nitrous oxide methane, carbon dioxide and hydrogen sulphide were presented. Inhouse acidification reduced ammonia emissions 50%-70%, storage acidification with 50%-88% and field application lowered ammonia emissions with 40-80% for pig slurry and 15-80 % for cattle slurry.

Methane emissions from slurry management mainly occurs during storage. As slurry acidification impact on methanogenesis, CH4 emissions are likely to be lowered when using long-term acidification but not short-term (Fanguiero et al., 2015). Acidification of slurry can lower methane emissions between 50-99 % during storage (Petersen et al, 2014, Petersen et al., 2016). In review by Fangueiro et al., (2015) Methane emissions during storage were lowered in a range of 67-87 % using sulphuric acid. Berg and Pazsiczki (2006) reported 40% mean decrease of CH4. Carbon dioxide showed lowered emissions with 1.1 % in spring, 5.2% for summer and 2.9% for autumn compared to non-acidified slurry. Their conclusion is that acidification might reduce methane formation in housings. The reason being that most methane emissions in housing probably were caused by enteric fermentation (Petersen et al., 2016).

The effect of nitrous oxide emissions when acidifying slurry is inconclusive. Nitrous oxide emissions mainly occur at storage and field application. The nitrous oxide formation in housing is considered negligible. No effect on nitrous oxide emissions are shown when acidifying slurry. Acidifying at spreading can increase with 23 % when happen when using sulphuric acid (Fanguiero et al., 2015). Petersen et al. (2016) reported that nitrous oxide emissions were slightly lower for acidified slurry during storage. Although these trials were without crust and therefore N2O is negligible according to emission factors from IPCC (2006). According to IPCC (2006) nitrous oxide formation during storage with a crust is 0,05 kg N2O-N/ kg N in slurry and zero when there is no crust.

Hydrogen sulphide is produced at anaerobic conditions when organic sulphur is mineralised. Hydrogen sulphide formation is influenced by the concentration in liquid phase, temperature and pH. Few references and data exist on hydrogen sulphide emission from animal and manure management Maasikmets et al. (2015). No clear information on emissions of hydrogen sulphide emissions when acidifying slurry were found. Therefore, no sulphur emissions were calculated. Only the increased amount of sulphur in slurry after acidification is calculated.

Nitrogen oxides and nitrogen are assumed to have the same reduction factors as ammonia. These emissions are generally uncertain and low compared to ammonia emissions. Factors in Table 10 show how much of initial emission of non-acidified slurry remain depending on were in the handling chain acidification is done.

Table 10. Emissions factors for slurry, percentage of emissions from non-acidified slurry, when acidifying slurry using sulphuric acid in housing, at storage or when spreading showing Min (base) Max.

	Housing	Storage	Spreading
	min (base) max	min (base) max	min (base) max
Acidification in housing			
Ammonia (NH_3)	40 (30) 3	40 (13) 8	40 (34) 21
Nitrous oxide (N_2O)	100 (100) 100	100 (100) 100	100 (100) 100
Nitrogen oxide NOx as NO	40 (30) 3	40 (13) 8	40 (34) 21
Nitrogen (N_2)	40 (30) 3	40 (13) 8	40 (34) 21
Methane (CH_4)	40 (40) 3	50 (11) 1[A]	100 (100) 100
Acidification at storage			
Ammonia (NH_3)	100 (100) 100	60 (25) 19	40 (34) 21
Nitrous oxide (N_2O)	100 (100) 100	100 (100) 100	100 (100) 100
Nitrogen oxide NOx as NO	100 (100) 100	60 (25) 19	40 (34) 21
Nitrogen (N_2)	100 (100) 100	60 (25) 19	40 (34) 21
Methane (CH_4)	100 (100) 100	20 (20) 20[B]	100 (100) 100[C]
Acidification in field			

Ammonia (NH_3)	100 (100) 100	100 (100) 100	38 (30) 21
Nitrous oxide (N_2O)	100 (100) 100	100 (100) 100	100 (100) 100
Nitrogen oxide NOx as NO	100 (100) 100	100 (100) 100	38 (30) 21
Nitrogen (N_2)	100 (100) 100	100 (100) 100	38 (100) 21
Methane (CH_4)	100 (100) 100	100 (100) 100	100 (100) 100

[A] For cattle slurry: 30 (13) 100

[B] For cattle slurry use 77 (77) 20

[C] For cattle slurry use 77 (77) 100

6 Results

6.1 Emissions from slurry handling

Emissions from slurry handling occur over the whole handling chain from housing to spreading. All the emissions that are considered in the systems analysis are air emissions. This because when handling slurry, it's assumed that there is no leakage within the system boundaries and therefore, no water emissions are considered. The emissions presented are nitrogen and carbon emissions. Nitrogen emissions are dominated by ammonia. Other nitrogen emissions as nitrous oxide, nitric oxide and nitrogen gas. Carbon emissions are methane and carbon dioxide. Carbon dioxide is emitted as organic carbon from slurry and fossil carbon dioxide is emitted from use of energy as diesel and electricity.

6.1.1 Ammonia emissions

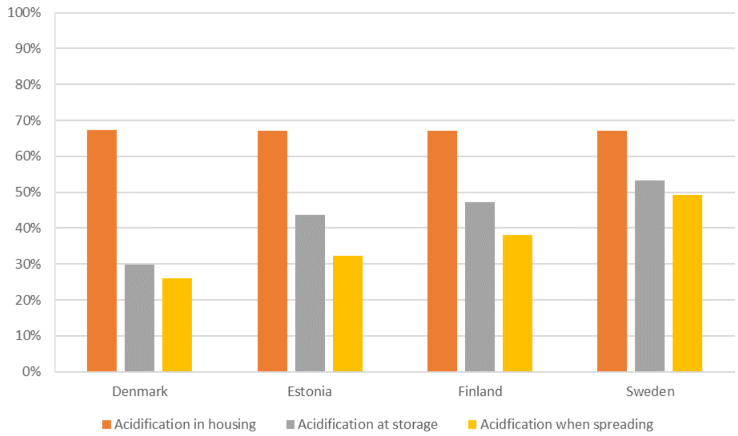


Figure 7. Decrease of total ammonia emissions from slurry when acidifying slurry in housing, storage or when spreading compared to reference, no acidification.

Ammonia is emitted at all stages of the slurry handling from animal housing to spreading. Figure 7 show how much ammonia emissions are lowered when using acidification techniques compared to non-acidified slurry. It's more effective to acidify early in the handling chain than further on (Figure 7 & Table 11) as the largest emissions of ammonia are from housing and spreading Acidification in housing show the largest overall decrease of ammonia emissions compared to non-acidified slurry.

Table 11. Total emissions of ammonia from slurry handling with or without acidification as a function of the total amount of pig and cattle slurry spread annually.

	Housing	Storage	Spreading	Total	
Denmark					
Reference	0.62	0.086	0.42	1.13	kg NH_3/ tonne slurry spread
AC in housing	0.19	0.086	0.17	0.37	kg NH_3/ tonne slurry spread
AC at storage	0.62	0.014	0.15	0.79	kg NH_3/ tonne slurry spread
AC when spreading	0.62	0.021	0.13	0.83	kg NH_3/ tonne slurry spread
Estonia					
Reference	0.31	0.16	0.40	0.87	kg NH_3/ tonne slurry spread
AC in housing	0.09	0.041	0.15	0.29	kg NH_3/ tonne slurry spread
AC at storage	0.31	0.040	0.14	0.49	kg NH_3/ tonne slurry spread
AC when spreading	0.31	0.16	0.12	0.59	kg NH_3/ tonne slurry spread
Finland					
Reference	0.26	0.17	0.43	0.86	kg NH_3/ tonne slurry spread
AC in housing	0.06	0.025	0.13	0.21	kg NH_3/ tonne slurry spread
AC at storage	0.26	0.043	0.15	0.45	kg NH_3/ tonne slurry spread
AC when spreading	0.26	0.17	0.13	0.56	kg NH_3/ tonne slurry spread
Sweden					
Reference	0.14	0.07	0.48	0.68	kg NH_3/ tonne slurry spread
AC in housing	0.04	0.009	0.18	0.23	kg NH_3/ tonne slurry spread
AC at storage	0.14	0.017	0.17	0.32	kg NH_3/ tonne slurry spread
AC when spreading	0.14	0.07	0.14	0.35	kg NH_3/ tonne slurry spread

6.1.2 Methane emissions

Methane is formed at anaerobic conditions from the degradation of organic material in slurry. It's formed in the outdoor storage with minor part formed in animal housing. Distribution between methane formed in housing or storage varies between countries depending on how long time manure is kept in housing before evacuated. When spreading conditions is mostly aerobic and methane formation is assumed to be zero.

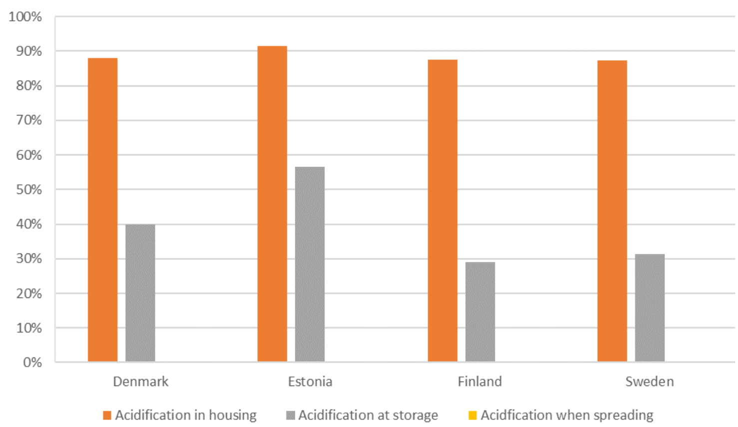


Figure 8. Decrease of total methane emissions from slurry when acidifying slurry in housing, storage or when spreading compared to reference, no acidification.

Acidification in housing show the highest reduction of methane emitted as methane is formed both in housing and during storage. The distribution between housing and storage regarding methane emissions (Appendix 1) and the percentual reduction of methane when acidifying in housing and storage impact the size of emissions (Table 10).

Table 12. Total emissions of methane from slurry handling with or without acidification.

	Housing	Storage	Spreading	Total	
Denmark					
Reference	0.11	0.34	0	0.46	kg CH_4/ tonnes slurry spread
AC in housing	0.014	0.34	0	0.055	kg CH_4/ tonnes slurry spread
AC at storage	0.11	0.041	0	0.28	kg CH_4/ tonnes slurry spread
AC when spreading	0.11	0.16	0	0.46	kg CH_4/ tonnes slurry spread
Estonia					
Reference	0.11	0.32	0	0.43	kg CH_4/ tonnes slurry spread
AC in housing	0.013	0.023	0	0.037	kg CH_4/ tonnes slurry spread
AC at storage	0.11	0.080	0	0.19	kg CH_4/ tonnes slurry spread
AC when spreading	0.11	0.32	0	0.43	kg CH_4/ tonnes slurry spread
Finland					
Reference	0.095	0.28	0	0.38	kg CH_4/ tonnes slurry spread
AC in housing	0.0087	0.026	0	0.035	kg CH_4/ tonnes slurry spread
AC at storage	0.095	0.14	0	0.24	kg CH_4/ tonnes slurry spread
AC when spreading	0.095	0.28	0	0.38	kg CH_4/ tonnes slurry spread
Sweden					
Reference	0.016	0.31	0	0.33	kg CH_4/ tonnes slurry spread
AC in housing	0.0021	0.040	0	0.042	kg CH_4/ tonnes slurry spread
AC at storage	0.016	0.21	0	0.23	kg CH_4/ tonnes slurry spread
AC when spreading	0.016	0.31	0	0.33	kg CH_4/ tonnes slurry spread

6.1.3 Nitrous oxide emissions

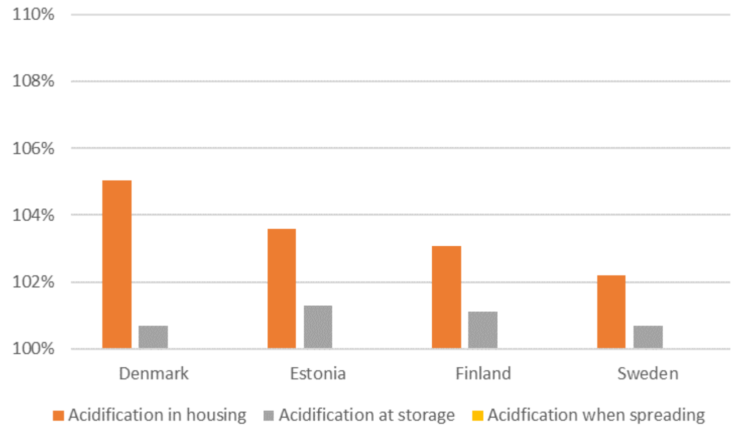


Figure 9. Increased of total nitrous oxide emissions from slurry when acidifying slurry in housing, storage or when spreading compared to reference, no acidification.

Nitrous oxide emissions increases compared to reference scenario (Figure 9). More nitrogen is left in slurry when acidifying and the potential for nitrous oxide formation increases as a function of available nitrogen. There is no change in direct nitrous oxide formation when acidifying when spreading. The amount of nitrogen spread is the same as in in the reference scenario, therefore the nitrous oxide formation is not affected.

Table 13. Total direct emissions of direct nitrous oxide from slurry handling with or without acidification.

	Housing	Storage	Spreading	Total	
Denmark					
Reference	0.0080	0.019	0.025	0.052	kg N_2O/ tonnes slurry spread
AC in housing	0.0080	0.019	0.028	0.055	kg N_2O/ tonnes slurry spread
AC at storage	0.0080	0.019	0.026	0.052	kg N_2O/ tonnes slurry spread
AC when spreading	0.0080	0.019	0.025	0.052	kg N_2O/ tonnes slurry spread
Estonia					
Reference	0.0073	0.017	0.024	0.048	kg N_2O/ tonnes slurry spread
AC in housing	0.0073	0.017	0.026	0.050	kg N_2O/ tonnes slurry spread
AC at storage	0.0073	0.017	0.025	0.049	kg N_2O/ tonnes slurry spread
AC when spreading	0.0073	0.017	0.024	0.048	kg N_2O/ tonnes slurry spread
Finland					
Reference	0.0070	0.016	0.023	0.047	kg N_2O/ tonnes slurry spread
AC in housing	0.0055	0.013	0.020	0.038	kg N_2O/ tonnes slurry spread
AC at storage	0.0070	0.016	0.024	0.047	kg N_2O/ tonnes slurry spread
AC when spreading	0.0070	0.016	0.023	0.047	kg N_2O/ tonnes slurry spread
Sweden					

	Hous-ing	Stor-age	Spread-ing	Total	
Reference	0.0055	0.013	0.019	0.038	kg N_2O/ tonnes slurry spread
AC in housing	0.0055	0.013	0.020	0.039	kg N_2O/ tonnes slurry spread
AC at storage	0.0055	0.013	0.020	0.038	kg N_2O/ tonnes slurry spread
AC when spread-ing	0.0055	0.013	0.019	0.038	kg N_2O/ tonnes slurry spread

6.1.4 Other emissions of nitrogen

Nitrogen is also emitted as nitric oxide and nitrogen gas. These emissions are small compared to ammonia and nitrous oxide emissions. The total emissions of nitric oxides and nitrogen varies between 1.0-1.6 % of the total nitrogen emissions. Nitrogen as nitrogen gas is inert and doesn't contribute to environmental impact. Nitric oxide emissions can land unfavourably and cause indirect nitrous oxide formation as ammonia. It's assumed that 1 % (IPCC, 2006) of the ammonia and nitric oxide land on ground in such way that nitrous oxide is formed when ammonia and nitrogen oxide is degraded.

6.2 Environmental impact

Three environmental impact categories are presented as result from the system study. These are potential terrestrial eutrophication, potential acidification and climate change as global warming potentials. Environmental impact can be presented for the whole system, that's including emissions from generation and use of energy and materials as lime, sulphuric acid. Environmental impact can also be presented as the impact from slurry emissions only.

6.2.1 Base scenarios

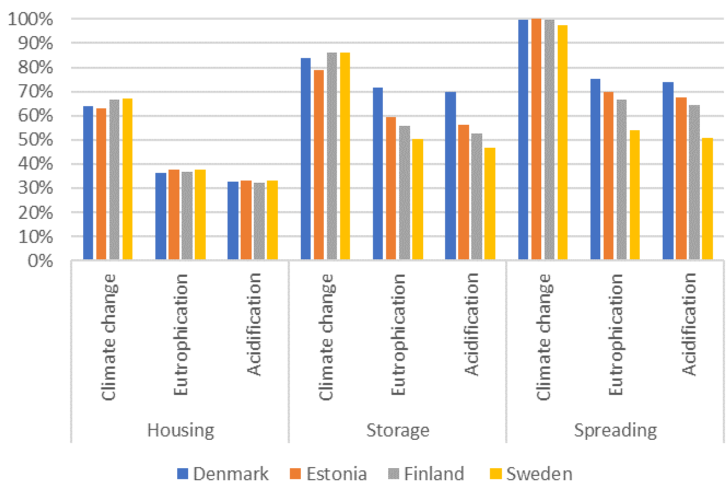
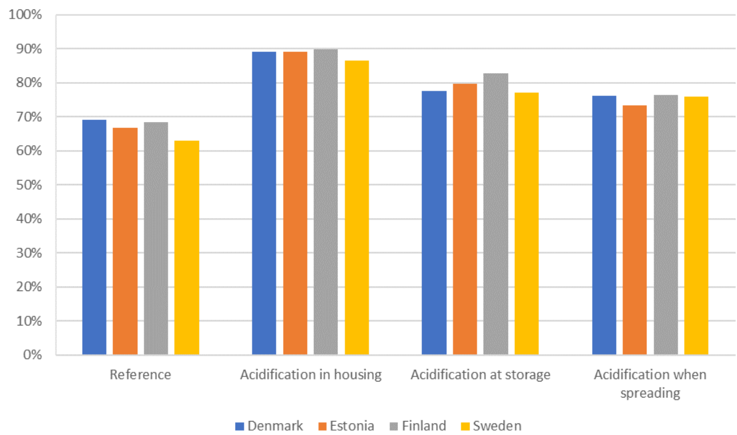


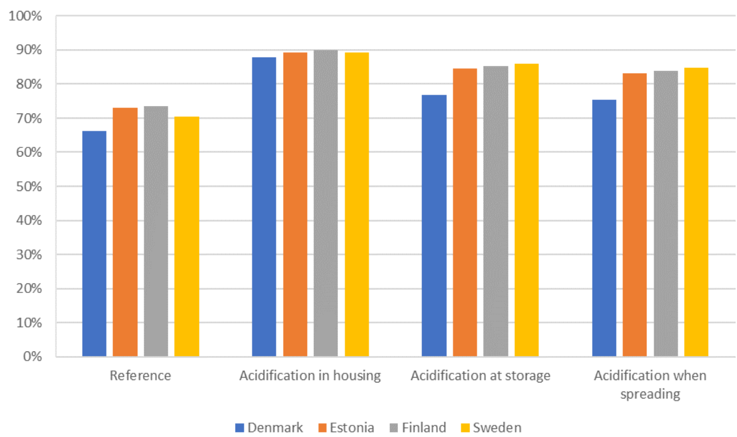
Figure 10, Changes in environmental impact climate, change, potential eutrophication and potential acidification when acidifying slurry expressed as percentage of non-acidified slurry

Figure 10 show the changed environmental impact from the slurry as percentage of non-acidified slurry. Environmental impact from handling slurry is dominated by the actual emissions from the slurry. Emissions from use of energy, production of acid etc. is small compared to the impact from slurry

Acidifying early in the slurry handling chain is more effective than acidifying further on the handling chain. Emissions of climate gases are methane, nitrous oxide and fossil carbon dioxide from use of energy and manufacture of acid. Nitrogen oxide and ammonia contributes to global warming through indirect nitrous oxide formation.

6.3 Plant available ammonia nitrogen





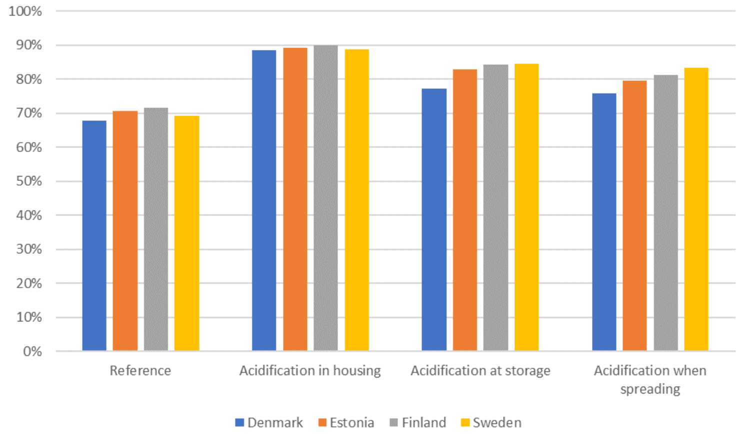


Figure 11. Part nitrogen as ammonia (NH_4) available to plants after spreading of slurry depending on technology used to acidify slurry. Diagrams from left to right is pig slurry, cattle slurry and pig & cattle slurry

Nitrogen efficiency is the amount of ammonia nitrogen that are available for plant uptake after losses in the slurry handling chain. Mineralisation or organic nitrogen in slurry and mineralisation of nitrogen in soil pool is not included, only ammonia nitrogen in slurry. As shown in Figure 11 acidification increases the amount of ammonia nitrogen in slurry.

Available ammonia nitrogen is around 65% to 70 % when handling slurry without acidification. In-farm systems where acidification is done in the animal housing saves the most ammonium nitrogen. It increases ammonia nitrogen availability to just below 90 %, acidification at storage or when spreading slurry show similar ammonium efficiency (Figure 11). There are small differences in available ammonia nitrogen if acidification is done early in storage or when in field when spreading.

Increased ammonium content in slurry can lead to lowered need of supplementary mineral fertilisers when fertilising crops. In Table 14 the potential to save mineral fertiliser nitrogen are shown.

Table 14. Amount of potential saved nitrogen mineral fertiliser (tonne/ year) for countries Denmark, Estonia, Finland and Sweden when acidifying slurry in housing, storage or when spreading.

	Denmark	Estonia	Finland	Sweden
Pig slurry				
AC in housing	-10 738	-400	-698	-1 602
AC at storage	-4 524	-230	-473	-958
AC when spreading	-3 732	-119	-265	-874
Cattle slurry				
AC in housing	-10 377	-503	-2 097	-6 874
AC at storage	-5 032	-356	-1 479	-5 671
AC when spreading	-4 435	-314	-1 304	-5 249
Pig and cattle slurry				
AC in housing	-21 115	-903	-2 795	-8 476

	Denmark	Estonia	Finland	Sweden
AC at storage	-9 556	-585	-1 951	-6 629
AC when spreading	-8 167	-433	-1 569	-6 122

If the use of mineral fertiliser nitrogen decreases the emissions from manufacturing nitrogen decrease. It is mainly global warming that is affected when manufacturing N-fertiliser. In Table 15 the effect of including saved mineral fertilisers are shown as the percentual decrease of the total global warming. Including less use of mineral fertiliser nitrogen lowers global warming with 1% to 15 %.

Table 15. Saved Global warming potentials (GWP_{100}) as part of total GWP from replaced mineral fertiliser nitrogen production.

	Denmark	Estonia	Finland	Sweden
Pig slurry				
AC in housing	-14%	-15%	-11%	-15%
AC at storage	-5%	-6%	-7%	-8%
AC when spreading	-3%	-2%	-3%	-5%
Cattle slurry				
AC in housing	-12%	-4%	-6%	-1%
AC at storage	-5%	-3%	-4%	-1%
AC when spreading	-3%	-2%	-3%	-1%
Pig and cattle slurry				
AC in housing	-15%	-8%	-8%	-3%
AC at storage	-5%	-4%	-5%	-2%
AC when spreading	-3%	-2%	-3%	-1%

6.3.1 Increased sulphur content in acidified slurry

When acidifying slurry with sulphuric acid the concentration of sulphur in the slurry increase manifold. As information and available data concerning sulphur emissions as sulphuric oxides (SOx) or as hydrogen sulphides (H2S) is scarce it isn't possible to quantify increased emissions and environmental impact from sulphur added to the slurry with the acid. The result shown is the increased amount of sulphur in slurry presented as total amount and increased concentration in slurry.

Sulphuric acid added to slurry is 3.3 kg/ tonne when acidifying in housing 3.0 kg/ tonne slurry at storage and 2.4 kg/ tonne (Birkmose and Vestgaard, 2013). These standard values are used for all studied countries.

When using acidification technologies, the concentration in slurry increases from initially 0.24 to 0.35 kg/ tonne to 1.00 to 1.37 kg/ tonne slurry.

Table 16. Amount (tonnes spread/ year) of sulphur as S-tot in slurry (total of pig and cattle) and concentration (kg S/ tonne slurry spread) for Denmark, Estonia, Finland and Sweden.

	Denmark	Estonia	Finland	Sweden
Amount	9 380	452	1 492	6 044
Concentration	0.35	0.30	0.24	0.34
Amount	36 913	1 864	7 405	20 021
Concentration	1.37	1.24	1.20	1.12
Amount	34 379	1 734	6 864	18 746
Concentration	1.27	1.16	1.11	1.05
Amount	29 717	1 583	6 135	19 471
Concentration	1.10	1.06	1.00	1.09

6.4 Sensitivity analysis

In the sensitivity analysis changes in ammonia emissions when varying part of slurry acidified from 0%, no acidification, to 100 % all slurry acidified. Another sensitivity analysis is variation of studied environmental impact when using min and max reduction of emissions when using acidification technique. Ammonia emissions when varying part of slurry acidified is shown as percentual decrease of emissions compared to reference scenario and as reduced emissions tonnes per year. The test of min and max reduction of emissions when acidifying is presented as the percentual change of environmental impact in comparison to base scenario.

6.5 Part of slurry acidified

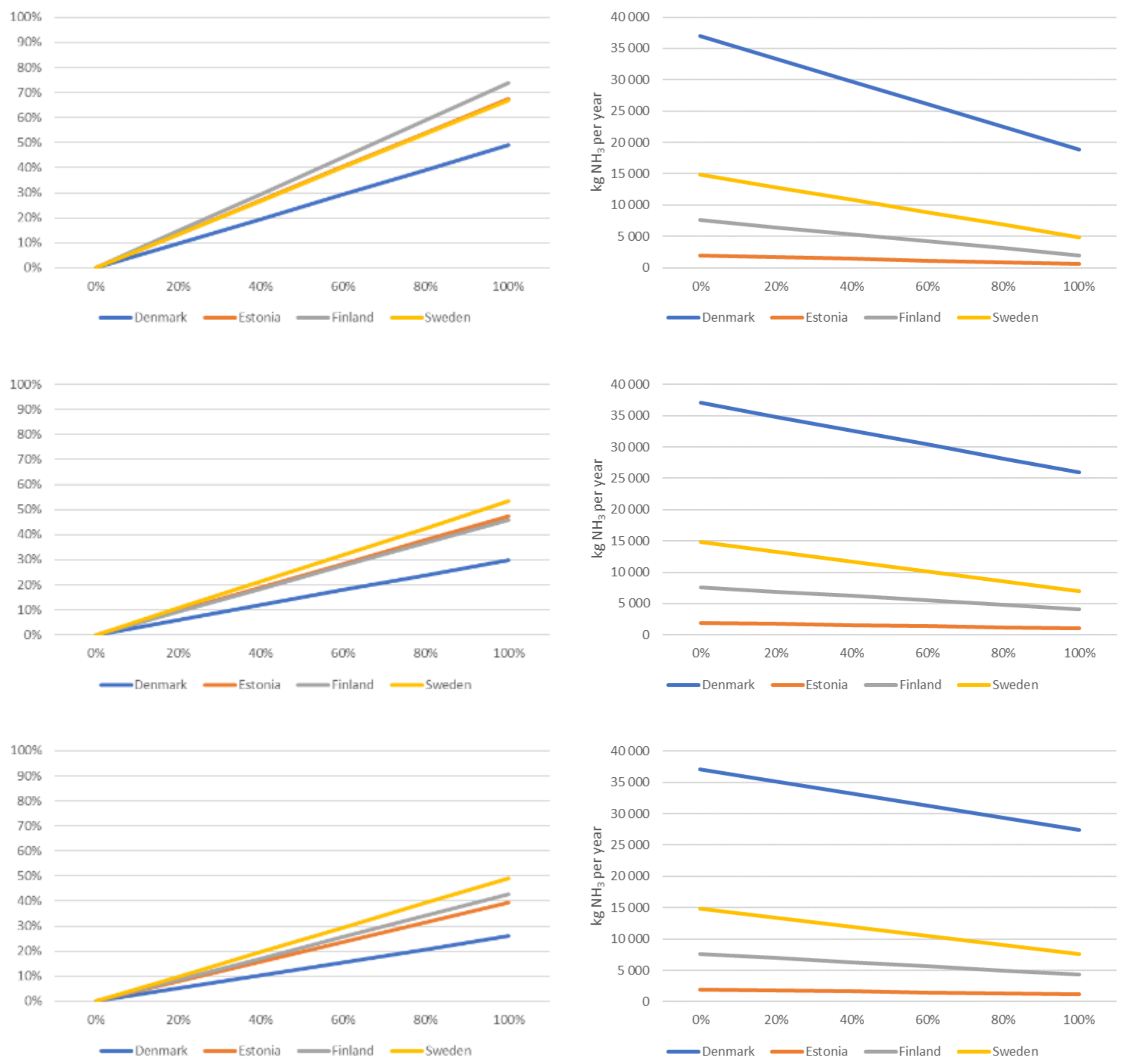


Figure 12. Change of ammonia emissions when percentage of slurry acidified varies from 0% to 100 % of total slurry spread. First column shows percentual decrease and second column tonnes

of ammonia volatilised. The rows, from left to right show acidification in housing, at storage and when spreading

The sensitivity analysis of ammonia emissions shows the changed emissions depending on how big part of slurry that are treated with slurry acidification technologies. As ammonia is volatilised over the entire handling chain the effect on ammonia emissions is larger the earlier the acidification is done. It is also important to show actual amount saved and not only percentual change of emissions. As an example, acidification in housing. For Finland Acidification in housing has the potential to decrease ammonia emissions with as much as 70 % and the corresponding number for Denmark is only 50 % considering the actual amount of slurry and total amount of ammonia 70 % lower emissions in Finland correspond to 5 600 tonnes of ammonia and 50 % lower emissions in Denmark correspond to 18 200 tonnes of ammonia. The relative effect, in percent, is higher for Finland, Estonia and Sweden compared to Denmark but the actual amount of ammonia emissions reduced is highest for Denmark.

6.5.1 Variations of environmental impact

The effect or impact on using slurry acidification varies. The literature gives a range within the emissions varies (Table 10). As emissions varies the environmental impact is affected. In Table 17 the difference in environmental impact compared to base scenario is shown. Min scenario is using the parameters with the smallest reduction of emissions when acidifying and max uses parameter values with the largest reduction.

Table 17. Changes is environmental impact when using min and max reduction parameters

	Denmark		Estonia		Finland		Sweden	
	Min	Max	Min	Max	Min	Max	Min	Max
Climate change								
AC in housing	29%	-7%	21%	-5%	25%	-7%	28%	-8%
AC at storage	0%	-12%	0%	-6%	0%	-15%	0%	-24%
AC when spreading	0%	0%	0%	0%	0%	0%	0%	0%
Eutrophication								
AC in housing	28%	-57%	28%	-44%	25	-54%	22%	-39%
AC at storage	6%	-7%	14%	-15%	6%	-9%	14%	-19%
AC when spreading	4%	-4%	7%	-8%	4%	-5%	10%	-11%
Acidification								
AC in housing	31%	-64%	32%	-50%	30%	-61%	27%	-46%
AC at storage	6%	-7%	16%	-16%	7%	-9%	16%	-21%
AC when spreading	4%	-4%	7%	-8%	4%	-5%	11%	-12%

6.6 Scenario analysis

BAT technologies other than acidification is only studied for Sweden. The reason is that there are data available for Sweden regarding emissions from storage and spreading using different solutions. There are other possibilities to reduce ammonia emissions from slurry handling than acidification as example; covered storage, more efficient spreading regarding technology, spreading time and incorporation into soil. Other technology for spreading is use of trailing hoses and soil injection. Spreading on more favourable time of year as spring can reduce emissions from slurry handling. In this project a scenario was outdoor storage is covered by roof instead of only a floating crust and all spreading is done using trailing hoses is compared to reference and acidification of slurry.

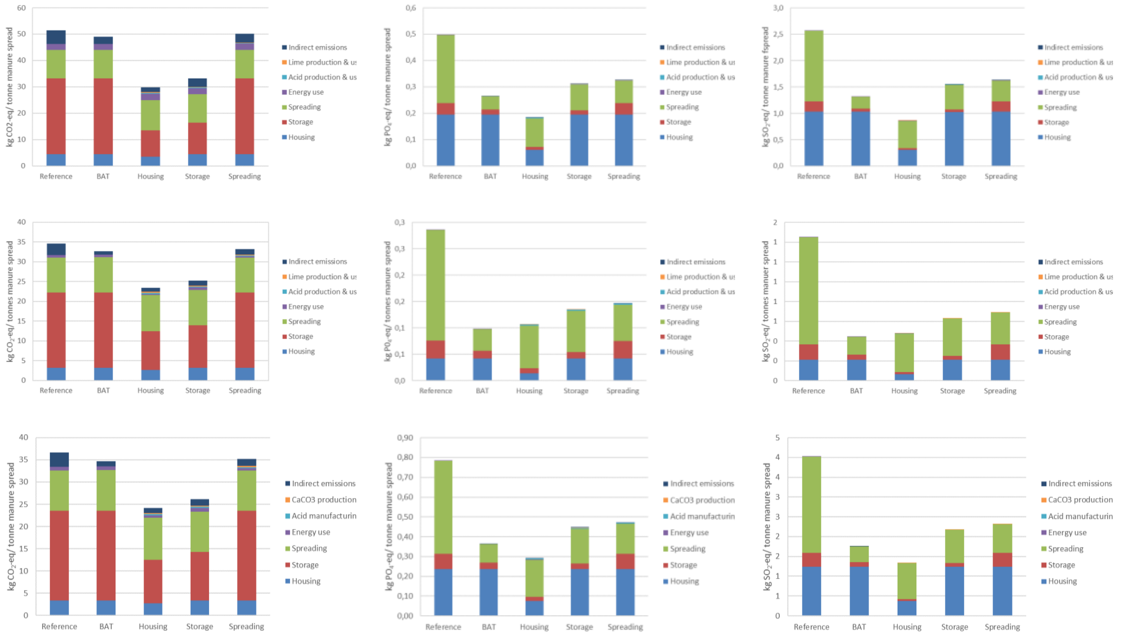


Figure 13. Environmental impact comparing non-acidified (reference), using roofed storage and spreading with trailing hoses (BAT) and acidified slurry (Housing, Storage and Spreading) for pig, cattle and total slurry in Sweden.

Global warming is influenced by emissions of methane and nitrous oxide and is only marginally changed compared to reference. Global warming is at the same magnitude as slurry acidification in housing (Figure 13). The decrease in global warming is mainly from reduced ammonia emissions resulting in less indirect nitrous oxide formation as methane emissions and direct emissions of nitrous oxide using BAT is not affected (Table 18). Emissions causing eutrophication and acidification is greatly reduced when using roof covered storage and spreading slurry using trailing hoses. Especially environmental impact from spreading is lowered. The impact for eutrophication and acidification is higher than acidification in housing but lower than acidification at storage or when spreading. For cattle slurry using roofed storage and trailing hoses gives the lowest environmental impact for eutrophication and acidification. The lowered eutrophication and acidification are mainly caused by reduced ammonia emissions.

Table 18. Total emissions from both pig, cattle and pig + cattle slurry (kg/ tonne slurry spread) contributing to environmental impact categories global warming, eutrophication and acidification

	Reference	Housing	Storage	Spreading	BAT
Ammonia					
Pig	1.36	0.46	0.82	0.86	0.69
Cattle	1.13	0.37	0.55	0.60	0.41
Pig + cattle	1.15	0.38	0.58	0.63	0.45
Nitrous oxide					
Pig	0.073	0.076	0.073	0.073	0.073
Cattle	0.077	0.079	0.077	0.077	0.077
Pig + cattle	0.076	0.079	0.077	0.076	0.077
Nitric oxides					
Pig	0.026	0.010	0.009	0.0087	0.026
Cattle	0.028	0.010	0.010	0.0093	0.028
Pig + cattle	0.028	0.010	0.010	0.0092	0.028
Methane					
Pig	0.65	0.07	0.16	0.65	0.65
Cattle	0.59	0.14	0.21	0.59	0.59
Pig + cattle	0.59	0.13	0.20	0.59	0.59
Indirect nitrous oxide					
Pig	0.018	0.006	0.011	0.011	0.009
Cattle	0.015	0.0049	0.0072	0.0078	0.0055
Pig + cattle	0.015	0.0050	0.0076	0.0082	0.0060

7 Discussion

The results show that slurry acidification decrease emissions of nitrogen and methane from pig and cattle slurry. The emission reduction is primarily based on Danish trials and are given as percentual reduction of used emissions at various stages of the slurry handling. When using the approach that changes are set as a percentage of original emissions, this tends to lead to results were systems with initially high emission factors to a larger extent reduce their emissions compared to systems with initially low emissions. As an example, in animal housing the Danish standard emission factor for ammonia losses is 16 % compared to Sweden that has 4 %. A decrease with 70-90 % will have a larger impact on Danish emissions than on Swedish.

Acidification impact nitrogen emissions primarily ammonia but probably other nitrogen compounds are also affected by acidification, In the case of nitrous oxide, a powerful green-house gas the impact is uncertain. There are few studies that considers nitrous oxide emissions from acidified slurry. Therefore, in this study it is assumed that nitrous oxide emissions are not directly affected by acidification. Changes in direct nitrous oxide formation are assumed as a function on emissions of other nitrogen compounds. Changes in ammonia emissions change the amount of nitrogen in slurry. As nitrous oxide emissions are calculated as percentage of total nitrogen or ammonium nitrogen will lead to changed nitrous oxide emissions.

Indirect formation is caused by emissions of ammonia and nitrogen oxides. The standard value according to IPCC (2006) is 1 % of ammonia and nitrogen oxide will fall to the ground in such way that nitrous oxide is formed. As acidification of slurry has a large impact on ammonia emissions this will be noted for the indirect formation of nitrous oxide.

To what extent emissions are reduced when slurry is acidified are collected from various literature sources. The change of emissions compared to non-acidified slurry are presented as a percentual change regarding base emission for studied countries. The emission factors used are based on primarily Danish studies as acidification in mainly used in Denmark. The emissions factors from Danish trials are transferred to the other studied countries without regard to country specific differences of slurry handling, such as time in housing and storage. The results are only valid considering that reduction obtained in Denmark can be transferred to other country's disregarding differences in handling. As the effects of slurry acidification is given as percentual change compared to reference of non-acidified slurry. Countries with high initial emissions will have larger change in emissions when comparing the difference between acidification in housing and acidification at storage or when spreading. As an example, Denmark have compared to Sweden high emissions from housing 16% of nitrogen versus 4% of nitrogen. As the reduction of ammonia in housing are 70 % (Kai et al., 2008). Danish emissions are lowered from 16 % to 4.8 of initial emissions. Applying this to Swedish conditions the emissions from housing are only 1.2 %. The changed standard emission from housing in Denmark are still higher than the standard emission for Sweden. This indicates that other measures such as frequent evacuation of manure from housing to sealed pre-tank or to outdoor storage has a large impact on ammonia emissions.

When acidifying with sulphuric acid the amount and concentration of sulphur in slurry increases significantly. What the effect of this increased concentration is uncertain given current knowledge. Also unknown is how lower the pH in slurry affect emissions of sulphur as sulphur oxides or hydrogen sulphide. There is an initial burst of hydrogen sulphide when stirring and mixing slurry, but the effect of the emissions is short. As the information on acidifications effect on sulphur emissions is unknown no emissions are calculated

Acidification of slurry reduce emissions of primarily ammonia and methane and thereby the environmental impact caused by them. There are other ways to reduce emissions. In animal housing frequent manuring, cooling of slurry in ducts use of filtration of exhaust ventilation air can reduce ammonia emissions. In outdoor storage, cooling of manure either by circulating water or by keeping the storage below ground or partly below ground. Covering of storage using roof or crust on the surface. To reduce emissions when spreading different technology as trailing hoses or injection can be used. The timing of the spreading has a large impact on ammonia emissions also how soon after spreading the slurry is incorporated into soil. These other measures can be used either on their own or in combination with acidification. What the actual effect is unknown as no study explicitly studied acidification in comparison with other measures to decrease emissions from slurry.

As acidification reduce ammonia and other nitrogen emissions more nitrogen as ammonium is left in slurry after spreading. The effect can differ depending how it's deemed. As phosphorus dominate over nitrogen acidified slurry can lead to better nitrogen phosphorus balance This will make acidified slurry more effective as a fertiliser. Theoretically increased amount of nitrogen leads to lowered need of supplementary nitrogen mineral fertiliser. Less mineral fertiliser nitrogen saves resources and reduce global warming.

Assessing environmental costs has difficulties associated with it. It has to do with both identification and of allocation of environmental cost. In the case of slurry acidification different outputs are the result from using the technology. There are outputs different environmental impacts as global warming, eutrophication and acidification. There are changes in emissions from handling slurry. Environmental cost accounting can include consumption of resources, energy, emitted pollutants etc. There is information available, but the methods used today for accounting financial and costs are limited in their ability to link environmental costs with financial cost accounting. Therefore, there is a need for further development of methodologies to incorporate environmental cost assessment to traditional financial accounting.

8 Conclusions

The following conclusions are drawn from the environmental systems analysis;

- there are decreased emissions of primarilysNH3 when acidifying slurry
- methane (CH4) emissions decreases when acidification is done in housing or at storage
- less NH3 lost lead to more nitrogen left in slurry resulting in higher efficiency of nitrogen
- potential to reduce mineral fertiliser use if utilised properly
- environmental impact decreases when acidifying slurry for impact categories eutrophication, acidification and climate impact
- effects depend on the assumption that ratios for changed impact is according to results from Danish trials
- differences between different countries depend on initial emissions as the effect from acidification is assumed to be the same wherever it is performed
- uncertainty regarding emissions of nitrous oxide (N2O) due to lack of data concerning direct N2O emissions
- potential risk for increased indirect emissions of nitrous oxides caused by reduced ammonia emissions resulting in more nitrogen in slurry
- need for evaluating regarding costs, emissions and environmental impact, acidification as slurry handling technology compared to other measures to reduce emissions as example roofed storage, soil injection, cooling of slurry etc

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Appendix 1. Inventories of countries

Denmark

Amount of slurry spread annually in Denmark is 27 million tonnes (Neuman, 2017). Using data from Loustarinen (2013) the ratio between pig and cattle slurry was calculated

- Pig slurry: 13 078 435 tonnes
- Cattle slurry: 13 921 565 tonnes

Slurry composition

Slurry composition changes when the slurry is moved forward in the handling chain. To the initial composition of manure from animal, bedding material and water is added. Water is added from spillage, cleaning, precipitation etc. During the handling emissions of nitrogen and carbon changes the concentration of nitrogen and carbon available in slurry. Manure compositions from Table 19 is used as initial input data. To the manure from animal bedding material used in housing and addition of water from housing and outdoor storage is added. From the initial manure composition from animal emissions during handling is subtracted and the amount and composition of the manure is calculated for each step in the slurry handling chain. Ending in the amount of slurry spread each year.

Table 19. Slurry composition for slurry from animal (Hamelin et al, 2013)

	Pig slurry	Cattle slurry	Bedding	
Wet weight	1.00	1.00	1.00	tonnes
% DM	7.5%	11.5%	85%	%
DM	0.0750	0.115	0,85	tonnes
VS	0.0604	0.098	0,77	tonnes
% VS of DM	81.1%	85.5%	90%	%
N-tot	6.00	6.40	5,44	kg/ tonnes
NH4-N	4.20	3.84	0,00	kg/ tonnes
P-tot	1.21	0.92	0,94	kg/ tonnes
K-tot	2.83	4.62	16,24	kg/ tonnes
S-tot	0.30	0.36	1,76	kg/ tonnes
C-tot	33.50	47.80	383	kg/ tonnes
C-tot, % DM	45%	45%	45%	%

Emissions

Emissions are calculated for nitrogen and carbon compounds. As emissions occur in the animal housing (Table 20), in the outdoor storage (Table 21) and when spreading (Table 22) emissions from manure is calculated separately from there.

Table 20. Emissions factors from housing for reference scenario Denmark

Emission	Pig	Cattle
NH_3-N	17 % of N_{tot} (Hamelin et al., 2013)	16 % of N_{tot} (Hamelin et al., 2013)
N_2O-N	0.46% of TAN. Use the EF for outdoor storage and allocate 30% to housing (Hamelin et al., 2013)	0.46% of TAN. Use the EF for outdoor storage and allocate 30% to housing (Hamelin et al., 2013)
NO-N	0.01 % of TAN (EEA, 2009)	0.01 % of TAN (EEA, 2009)
N_2-N	0.30 % of TAN (EEA, 2009)	0.30 % of TAN (EEA, 2009)
CH_4-C	Use the tier 2 calculation according to IPCC and allocate 25% to housing (Hamelin et al., 2013)	Use the tier 2 calculation according to IPCC and allocate 25% to housing (Hamelin et al., 2013)
CO_2-C	1.83 kg CO_2/ kg CH_4 (Hamelin et al., 2013)	1.83 kg CO_2/ kg CH_4 (Hamelin et al., 2013)
Indirect N_2O-N	1 % of NH_3 and NO emitted from housing (IPCC, 2006)	1 % of NH_3 and NO emitted from housing (IPCC, 2006)

Table 21. Emission factors from storage for reference scenario Denmark.

Emission	Pig	Cattle
NH_3-N	2.5 % of N_{tot} (Hamelin et al., 2013)	3.4 % of N_{tot} (Hamelin et al., 2013)
N_2O-N	0.46 % of TAN[B]. Use the EF for outdoor storage and allocate 70% to storage (Hamelin et al., 2013)	0.46 % of TAN[B]. Use the EF for outdoor storage and allocate 70% to storage (Hamelin et al., 2013)
NO-N	0.01 % of TAN (EEA, 2009)	0.01 % of TAN (EEA, 2009)
N_2-N	0.30 % of TAN (EEA, 2009)	0.30 % of TAN (EEA, 2009)
CH_4-C	Use the tier 2 calculation according to IPCC and allocate 75% to storage (Hamelin et al., 2013)	Use the tier 2 calculation according to IPCC and allocate 75% to storage (Hamelin et al., 2013)
CO_2-C	1.83 kg CO_2/ kg CH_4	2.13 kg CO_2/ kg CH_4[C]
Indirect N_2O-N	1 % of NH_3 and NO emitted from housing (IPCC, 2006)	1 % of NH_3 and NO emitted from housing (IPCC, 2006)

Table 22. Emission from spreading for reference scenario Denmark.

Emission	Pig	Cattle
NH_3-N	12 % of TAN (Hamelin et al., 2013)	16% of TAN (Hamelin et al., 2013)
N_2O-N	2.5 % of TAN (IPCC, 2006)	2.5 % of TAN (IPCC, 2006)
NO-N	0.436 % of TAN[A]	0.436 % of TAN[A]
N_2-N	-	-
Stot	-	-
CH_4-C	-	-
CO_2-C	-	-

Emission	Pig	Cattle
Indirect N_2O-N	1 % of NH_3 and NO from housing (IPCC, 2006)	1 % of NH_3 and NO from housing (IPCC, 2006)

[A] Calculated average

Energy use

Energy used is diesel fuel to tractors and electricity used when pumping, mixing and filling tank wagon (Table 23). The factor Addition of sulphuric acid from Table 23 is used show increased energy use when adding acid. The factor 1.10 is multiplied with energy use, in the case for acidification in housing and storage the factor is multiplied to energy us for pumping slurry from pre-tank to storage (2.40*1.10 = 2.64) and for acidification when spreading the factors is multiplied with energy use spreading slurry (1.63*1.10 = 1.79).

Table 23. Energy use when handling slurry in Denmark (kWh/ tonne slurry from storage)

	Pig		Cattle	
	Electricity	Diesel	Electricity	Diesel
Housing				
Evacuation of slurry	0.13	1.56	0.93	1.74
Addition of H_2SO_4	3.00		1.0	
Pumping slurry from pre-tank to storage	2.40		2.40	
Storage				
Addition of Acid	3.0		1.0	
Spreading				
Stirring and mixing	0.020		0.020	
Emptying of storage	0.00013		0.00013	
Transport to and from field		4.53		4.53
Spreading slurry		1.63		1.63
Addition of H_2SO_4		1.10[A]		1.10[A]
Spreading of lime		0.16		0.16

[A] Factor which describe the increases energy demand when adding acid in housing, storage or when spreading.

Estonia

Slurry composition

Slurry composition changes when the slurry is moved forward in the handling chain. To the initial composition of manure from animal, bedding material and water is added. Water is added from spillage, cleaning, precipitation etc. During the handling emissions of nitrogen and carbon changes the concentration of nitrogen and carbon available in slurry. Manure compositions (Table 24) is used as initial input data. To the manure from animal bedding material used in housing and addition of water from housing and outdoor storage is added. From the initial manure composition from animal emissions during handling is subtracted and the amount and composition of the manure is calculated for each step in the slurry handling chain. Ending in the amount of slurry spread each year.

Table 24. Slurry composition for slurry from animal, Estonia

	Pig slurry	Cattle slurry	Bedding	
Wet weight	1.00	1.00	1.00	tonnes
% DM	9.6%	11.5%	85%	%
DM	0.096	0.115	0,85	tonnes
VS	0.0758	0.093	0,77	tonnes
% VS of DM	79.2%	81.6%	90%	%
N-tot	6.96	5.90	5,44	kg/ tonnes
NH4-N	4.37	3.54	0,00	kg/ tonnes
P-tot	2.48	1.30	0,94	kg/ tonnes
K-tot	2.74	4.40	16,24	kg/ tonnes
S-tot	0.34	0.30	1,76	kg/ tonnes
C-tot	41.75	59.60	383	kg/ tonnes
C-tot, % DM	42%	52%	45%	%

Emissions

Emissions are calculated for nitrogen and carbon compounds. As emissions occur in the animal housing (Table 25), in the outdoor storage (Table 26) and when spreading (Table 27) emissions from manure is calculated separately from there.

Table 25. Emissions factors from housing for reference scenario, Estonia

Emission	Pig	Cattle
NH_3-N	13 % of N_{tot} (Hamelin et al., 2013)	7.5 % of N_{tot} (Hamelin et al., 2013)
N_2O-N	0.46% of TAN Use the EF for outdoor storage and allocate 30% to housing (Hamelin et al., 2013)	0.46% of TAN. Use the EF for outdoor storage and allocate 30% to housing (Hamelin et al., 2013)
NO-N	0.01 % of TAN (EEA, 2009)	0.01 % of TAN (EEA, 2009)
N_2-N	0.30 % of TAN (EEA, 2009)	0.30 % of TAN (EEA, 2009)
CH_4-C	Use the tier 2 calculation according to IPCC and allocate 25% to housing (Hamelin et al., 2013)	Use the tier 2 calculation according to IPCC and allocate 25% to housing (Hamelin et al., 2013)
CO_2-C	1.83 kg CO_2/ kg CH_4 (Hamelin et al., 2013)	1.83 kg CO_2/ kg CH_4 (Hamelin et al., 2013)
Indirect N_2O-N	1 % of NH_3 and NO emitted from housing (IPCC, 2006)	1 % of NH_3 and NO emitted from housing (IPCC, 2006)

Table 26. Emission factors from storage for reference scenario, Estonia.

Emission	Pig	Cattle
NH_3-N	10.0 % of N_{tot} (Hamelin et al., 2013)	3.1 % of N_{tot} (Hamelin et al., 2013)
N_2O-N	0.46 % of TAN[B]. Use the EF for outdoor storage and allocate 70% to storage (Hamelin et al., 2013)	0.46 % of TAN[B]. Use the EF for outdoor storage and allocate 70% to storage (Hamelin et al., 2013)
NO-N	0.01 % of TAN (EEA, 2009)	0.01 % of TAN (EEA, 2009)
N_2-N	0.30 % of TAN (EEA, 2009)	0.30 % of TAN (EEA, 2009)
CH_4-C	Use the tier 2 calculation according to IPCC and allocate 75% to storage (Hamelin et al., 2013)	Use the tier 2 calculation according to IPCC and allocate 75% to storage (Hamelin et al., 2013)
CO_2-C	1.83 kg CO_2/ kg CH_4 (Hamelin et al., 2013)	2.13 kg CO_2/ kg CH_4 (Hamelin et al., 2013)
Indirect N_2O-N	1 % of NH_3 and NO emitted from housing (IPCC, 2006)	1 % of NH_3 and NO emitted from housing (IPCC, 2006)

Table 27. Emission from spreading for reference scenario

Emission	Pig	Cattle
NH_3-N	22 % of TAN	22% of TAN
N_2O-N	2.5 % of TAN (IPCC, 2006)	2.5 % of TAN (IPCC, 2006)
NO-N	0.436 % of TAN (EEA, 2009)	0.436 % of TAN (EEA, 2009)
N_2-N	-	-
Stot	-	-
CH_4-C	-	-

Emission	Pig	Cattle
CO_2-C	-	-
Indirect N_2O-N	1 % of NH_3 and NO from housing (IPCC, 2006)	1 % of NH_3 and NO from housing (IPCC, 2006)

Energy use

Energy used is diesel fuel to tractors and electricity used when pumping, mixing and filling tank wagon (Table 28). The factor Addition of sulphuric acid from Table 23 is used show increased energy use when adding acid. The factor 1.10 is multiplied with energy use, in the case for acidification in housing and storage the factor is multiplied to energy us for pumping slurry from pre-tank to storage (2.40*1.10 = 2.64) and for acidification when spreading the factors is multiplied with energy use spreading slurry (1.63*1.10 = 1.79).

Table 28. Energy use when handling slurry in Estonia (kWh/ tonne slurry from storage)

	Pig		Cattle	
	Electricity	Diesel	Electricity	Diesel
Housing				
Evacuation of slurry	0.13	1.63	0.93	1.74
Addition of H_2SO_4	3.00		1.00	
Pumping slurry from pre-tank to storage	2.40		2.40	
Storage				
Addition of Acid	3.00		1.00	
Spreading				
Stirring and mixing	0.020		0.020	
Emptying of storage	0.00013		0.00013	
Transport to and from field		4.53		4.53
Spreading slurry		1.63		1.63
Addition of H_2SO_4		1.10		1.10
Spreading of lime		0.16		0.16

Finland

Slurry composition

Slurry composition changes when the slurry is moved forward in the handling chain. To the initial composition of manure from animal, bedding material and water is added. Water is added from spillage, cleaning, precipitation etc. During the handling emissions of nitrogen and carbon changes the concentration of nitrogen and carbon available in slurry. Manure compositions (Table 29) is used as initial input data. To the manure from animal bedding material used in housing and addition of water from housing and outdoor storage is added. From the initial manure composition from animal emissions during handling is subtracted and the amount and composition of the manure is calculated for each step in the slurry handling chain. Ending in the amount of slurry spread each year.

Table 29. Slurry composition for slurry from animal, Finland

	Pig slurry	Cattle slurry	Bedding	
Wet weight	1.00	1.00	1.00	tonnes
% DM	7.0%	10.4%	85%	%
DM	0.070	0.104	0,85	tonnes
VS	0.056	0.085	0,77	tonnes
% VS of DM	80.4%	81.4%	90%	%
N-tot	5.36	6.25	5,44	kg/ tonnes
NH4-N	3.48	4.05	0,00	kg/ tonnes
P-tot	1.28	0.96	0,94	kg/ tonnes
K-tot	2.14	6.18	16,24	kg/ tonnes
S-tot	0.30	0.30	1,76	kg/ tonnes
C-tot	33.31	46.40	383	kg/ tonnes
C-tot, % DM	59%	55%	45%	%

Emissions

Emissions are calculated for nitrogen and carbon compounds. As emissions occur in the animal housing (Table 30), in the outdoor storage (Table 31) and when spreading (Table 32) emissions from manure is calculated separately from there.

Table 30. Emissions factors from housing for reference scenario, Finland.

Emission	Pig	Cattle
NH_3-N	17 % of N_{tot} (Hamelin et al., 2013)	16 % of N_{tot} (Hamelin et al., 2013)
N_2O-N	0.46% of TAN. Use the EF for outdoor storage and allocate 30% to housing (Hamelin et al., 2013)	0.46% of TAN. Use the EF for outdoor storage and allocate 30% to housing (Hamelin et al., 2013)
NO-N	0.01 % of TAN (EEA, 2009)	0.01 % of TAN (EEA, 2009)
N_2-N	0.30 % of TAN (EEA, 2009)	0.30 % of TAN (EEA, 2009)
CH_4-C	Use the tier 2 calculation according to IPCC and allocate 25% to housing (Hamelin et al., 2013)	Use the tier 2 calculation according to IPCC and allocate 25% to housing (Hamelin et al., 2013)
CO_2-C	1.83 kg CO_2/ kg CH_4 (Hamelin et al., 2013)	1.83 kg CO_2/ kg CH_4 (Hamelin et al., 2013)
Indirect N_2O-N	1 % of NH_3 and NO emitted from housing (IPCC, 2006)	1 % of NH_3 and NO emitted from housing (IPCC, 2006)

Table 31. Emission factors from storage for reference scenario, Finland.

Emission	Pig	Cattle
NH_3-N	2.5 % of N_{tot} (Hamelin et al., 2013)	3.4 % of N_{tot} (Hamelin et al., 2013)
N_2O-N	0.46 % of TAN[B]. Use the EF for outdoor storage and allocate 70% to storage (Hamelin et al., 2013)	0.46 % of TAN[B]. Use the EF for outdoor storage and allocate 70% to storage (Hamelin et al., 2013)
NO-N	0.01 % of TAN (EEA, 2009)	0.01 % of TAN (EEA, 2009)
N_2-N	0.30 % of TAN (EEA, 2009)	0.30 % of TAN (EEA, 2009)
CH_4-C	Use the tier 2 calculation according to IPCC and allocate 75% to storage (Hamelin et al., 2013)	Use the tier 2 calculation according to IPCC and allocate 75% to storage (Hamelin et al., 2013)
CO_2-C	1.83 kg CO_2/ kg CH_4 (Hamelin et al., 2013)	1.83 kg CO_2/ kg CH_4 (Hamelin et al., 2013)
Indirect N_2O-N	1 % of NH_3 and NO emitted from housing (IPCC, 2006)	1 % of NH_3 and NO emitted from housing (IPCC, 2006)

Table 32. Emission from spreading for reference scenario, Finland.

Emission	Pig	Cattle
NH_3-N	13 % of TAN (Hamelin et al, 2013)	16% of TAN (Hamelin et al, 2013)
N_2O-N	2.5 % of TAN (IPCC, 2006)	2.5 % of TAN (IPCC, 2006)
NO-N	0.436 % of TAN (EEA, 2009)	0.436 % of TAN (EEA, 2009)
N_2-N	-	-
Stot	-	-
CH_4-C	-	-

Emission	Pig	Cattle
CO_2-C	-	-
Indirect N_2O-N	1 % of NH_3 and NO from housing (IPCC, 2006)	1 % of NH_3 and NO from housing

Energy use

Energy used is diesel fuel to tractors and electricity used when pumping, mixing and filling tank wagon (Table 33The factor Addition of sulphuric acid from Table 23 is used show increased energy use when adding acid. The factor 1.10 is multiplied with energy use, in the case for acidification in housing and storage the factor is multiplied to energy us for pumping slurry from pre-tank to storage (2.40*1.10 = 2.64) and for acidification when spreading the factors is multiplied with energy use spreading slurry (1.63*1.10 = 1.79).

Table 33. Energy use when handling slurry in Finland (kWh/ tonne slurry from storage).

	Pig		Cattle	
	Electricity	Diesel	Electricity	Diesel
Housing				
Evacuation of slurry	0.13	1.56	0.93	1.74
Addition of H_2SO_4	3.00		1.00	
Pumping slurry from pre-tank to storage	2.40		2.40	
Storage				
Addition of Acid	3.00		1.00	
Spreading				
Stirring and mixing	0.020		0.020	
Emptying of storage	0.00013		0.00013	
Transport to and from field		4.53		4.53
Spreading slurry		1.63		1.63
Addition of H_2SO_4		1.10		1.10
Spreading of lime		0.16		0.16

Sweden

Slurry compositions

Slurry composition changes when the slurry is moved forward in the handling chain. To the initial composition of manure from animal, bedding material and water is added. Water is added from spillage, cleaning, precipitation etc. During the handling emissions of nitrogen and carbon changes the concentration of nitrogen and carbon available in slurry. Manure compositions (Table 34) is used as initial input data. To the manure from animal bedding material used in housing and addition of water from housing and outdoor storage is added. From the initial manure composition from animal emissions during handling is subtracted and the amount and composition of the manure is calculated for each step in the slurry handling chain. Ending in the amount of slurry spread each year.

Table 34. Slurry composition for slurry from animal, Sweden.

	Pig slurry	Cattle slurry	Bedding	
Wet weight	1.00	1.00	1.00	tonnes
% DM	9.6%	12.1%	85%	%
DM	0.096	0.12	0,85	tonnes
VS	0.076	0.099	0,77	tonnes
% VS of DM	79.2%	81.6%	90%	%
N-tot	6.96	7.11	5,44	kg/ tonnes
NH4-N	4.37	4.28	0,00	kg/ tonnes
P-tot	2.48	0.91	0,94	kg/ tonnes
K-tot	2.74	5.45	16,24	kg/ tonnes
S-tot	0.41	0.57	1,76	kg/ tonnes
C-tot	40.02	62.41	383	kg/ tonnes
C-tot, % DM	42%	45%	45%	%

Emission

Emissions are calculated for nitrogen and carbon compounds. As emissions occur in the animal housing (Table 35), in the outdoor storage (Table 36) and when spreading (Table 37) emissions from manure is calculated separately from there.

Table 35. Emissions factors from housing for reference scenario, Sweden.

Emission	Pig	Cattle
NH_3-N	14 % of N_{tot} -(Hamelin et al, 2013)	4 % of N_{tot} Hamelin et al, 2013)
N_2O-N	0.46% of TAN[A]. Use the EF for outdoor storage and allocate 5% to housing (Hamelin et al., 2013, SEPA, 2017)	0.46% of TAN[A]. Use the EF for outdoor storage and allocate 5% to housing (Hamelin et al., 2013, SEPA, 2017)
NO-N	0.01 % of TAN (EEA, 2009)	0.01 % of TAN (EEA, 2009)
N_2-N	0.30 % of TAN (EEA, 2009)	0.30 % of TAN (EEA, 2009)
CH_4-C	Use the tier 2 calculation according to IPCC and allocate 5% to housing (Hamelin et al., 2013)	Use the tier 2 calculation according to IPCC and allocate 5% to housing (Hamelin et al., 2013)
CO_2-C	1.83 kg CO_2/ kg CH_4 (Hamelin et al, 2013)	1.83 kg CO_2/ kg CH_4 (Hamelin et al, 2013)
Indirect N_2O-N	1 % of NH_3 and NO emitted from housing (IPCC, 2006)	1 % of NH_3 and NO emitted from housing (IPCC, 2006)

Emissions of ammonia from storage is calculated as an average value considering type of cover or open storage and if the storage is filled and emptied from the above or beneath the surface.

Table 36. Emission factors from storage for reference scenario, Sweden.

Emission	Pig	Cattle
NH_3-N	3.1 % of N_{tot}[A]	3.1 % of N_{tot}[A]
N_2O-N	0.46 % of TAN[B]. Use the EF for outdoor storage and allocate 5% to housing (Hamelin et al., 2013)	0.46 % of TAN[B]. Use the EF for outdoor storage and allocate 5% to housing (Hamelin et al., 2013)
NO-N	0.01 % of TAN (EEA, 2009)	0.01 % of TAN (EEA, 2009)
N_2-N	0.30 % of TAN (EEA, 2009)	0.30 % of TAN (EEA, 2009)
CH_4-C	Use the tier 2 calculation according to IPCC and allocate 95% to housing (Hamelin et al., 2013) MCF Sweden 3.5% as average (Rodhe et al, 2008, SEPA, 2016	Use the tier 2 calculation according to IPCC and allocate 95% to housing (Hamelin et al., 2013) MCF Sweden 3.5% as average (Rodhe et al, 2008, SEPA, 2016
CO_2-C	1.83 kg CO_2/ kg CH_4[C]	2.13 kg CO_2/ kg CH_4[C]
Indirect N_2O-N	1 % of NH_3 and NO emitted from housing (IPCC, 2006)	1 % of NH_3 and NO emitted from housing (IPCC, 2006)

Emissions of ammonia when spreading slurry is calculated as a national average considering; 1) Technique used spreading slurry 2) Time of year when spreading slurry and spread to or on what (growing cereal crop, ley or open soil) 3) time after spreading slurry is incorporated into soil (Karlsson & Rodhe, 2002 and Statistic Sweden, 2017).

Table 37. Emission from spreading for reference scenario, Sweden.

Emission	Pig	Cattle
NH_3-N	21 % of TAN	21% of TAN
N_2O-N	2.5 % of TAN (IPCC, 2006)	2.5 % of TAN (IPCC, 2006)
NO-N	0.436 % of TAN (EEA, 2009)	0.436 % of TAN (EEA, 2009)
N_2-N	-	-
Stot	-	-
CH_4-C	-	-
CO_2-C	-	-
Indirect N_2O-N	1 % of NH_3 and NO from housing	1 % of NH_3 and NO from housing

Energy use

Energy used is diesel fuel to tractors and electricity used when pumping, mixing and filling tank wagon (Table 38). The factor Addition of sulphuric acid from Table 23 is used show increased energy use when adding acid. The factor 1.10 is multiplied with energy use, in the case for acidification in housing and storage the factor is multiplied to energy us for pumping slurry from pre-tank to storage (2.40*1.10 = 2.64) and for acidification when spreading the factors is multiplied with energy use spreading slurry (1.63*1.10 = 1.79).

Table 38. Energy use when handling slurry in Finland (kWh/ tonne slurry from storage)

	Pig		Cattle	
	Electricity	Diesel	Electricity	Diesel
Housing				
Evacuation of slurry	0.13	1.56	0.93	1.74
Addition of H_2SO_4	3.00		1.00	
Pumping slurry from pre-tank to storage	2.40		2.40	
Storage				
Addition of Acid	3.00		1.00	
Spreading				
Stirring and mixing	0.020		0.020	
Emptying of storage	0.00013		0.00013	
Transport to and from field		4.53		4.53
Spreading slurry		1.63		1.63
Addition of H_2SO_4		1.10		1.10
Spreading of lime		0.16		0.16

Appendix 2 Results for countries

Appendix 2 show the results for each country modelled. This includes the slurry composition, emission from animal housing, outdoor storage and spreading, the nitrogen balance and efficiency for both total nitrogen and ammonium and environmental impact, global warming, potential eutrophication and potential acidification. Environmental impacts are shown for pig slurry, cattle slurry and for slurry combining pig and cattle manure as total slurry. These results are shown for Denmark, Estonia, Finland and Sweden

The slurry composition for the scenarios is for 1 tonne slurry wet weight. Slurry composition is shown when slurry leaving the animal housing, emptied from storage and after initial losses when spreading. The compositions of pig, cattle and pig & cattle slurry are shown for scenarios, reference, housing storage and spreading.

Emissions are shown for all scenarios, reference, acidification in housing, acidification at storage and acidification when spreading for pig, cattle and pig & cattle slurry. Emissions are shown from animal housing, from the outdoor storage and initial losses when spreading slurry. All emissions are presented as kg emission per tonne slurry spread. Slurry spread is the slurry from housing.

Nitrogen balance is presented for total nitrogen and for ammonium. Four stages are included; 1) Incoming, that is nitrogen entering the system with manure from pig and cattle and nitrogen in bedding material, straw 2) Nitrogen leaving the animal housing (from housing) 3) Nitrogen in slurry from storage and 4) Nitrogen available for plants after spreading. Nitrogen efficiency is the amount of nitrogen available for plants compared to incoming amount of nitrogen. Nitrogen efficiency is presented for total nitrogen and ammonium nitrogen respectively.

Slurry composition, base scenario Denmark

Table 39. Slurry composition for pig, cattle and total slurry for Denmark, reference scenario

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.4%	7.1%	7.1%	%
DM	74	71	71	kg/tonne
VS	60	57	57	kg/tonne
% VS of DM	81%	81%	81%	%
N-tot	5.25	5.04	4.61	kg/tonne
NH4-N	3.46	3.28	2.85	kg/tonne
P-tot	1.21	1.18	1.19	kg/tonne
K-tot	2.82	2.77	2.77	kg/tonne
S-tot	0.37	0.36	0.36	kg/tonne
C-tot	33.21	31.95	31.95	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.0%	11.0%	10.7%	%
DM	110	107	107	kg/tonne
VS	94	92	92	kg/tonne
% VS of DM	85.7%	85.5%	85.5%	%
N-tot	5.30	5.11	4.63	kg/tonne
NH4-N	2.93	2.77	2.29	kg/tonne
P-tot	0.85	0.83	0.83	kg/tonne
K-tot	4.32	4.26	4.26	kg/tonne
S-tot	0.34	0.33	0.33	kg/tonne
C-tot	45.96	44.76	44.76	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.2%	9.0%	9.0%	%
DM	92	90	90	kg/tonne
VS	78	75	75	kg/tonne
% VS of DM	84%	84%	84%	%
N-tot	5.28	5.07	4.62	kg/tonne
NH4-N	3.19	3.02	2.57	kg/tonne
P-tot	1.03	1.01	1.01	kg/tonne
K-tot	3.57	3.52	3.52	kg/tonne
S-tot	0.35	0.35	0.35	kg/tonne
C-tot	39.59	38.35	38.35	kg/tonne

Table 40. Slurry composition for pig, cattle and total slurry for Denmark, Acidification in housing scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.4%	7.2%	7.2%	%
DM	74	72	72	kg/tonne
VS	60	59	59	kg/tonne
% VS of DM	81%	81%	81%	%
N-tot	5.74	5.59	5.40	kg/tonne
NH4-N	3.95	3.84	3.65	kg/tonne
P-tot	1.20	1.18	1.18	kg/tonne
K-tot	2.81	2.76	2.76	kg/tonne
S-tot	1.40	1.37	1.37	kg/tonne
C-tot	33.26	32.52	32.52	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.0%	11.0%	10.8%	%
DM	110	108	108	kg/tonne
VS	94	92	93	kg/tonne
% VS of DM	86%	86%	86%	%
N-tot	5.67	5.55	5.34	kg/tonne
NH4-N	3.31	3.23	3.02	kg/tonne
P-tot	0.84	0.83	0.83	kg/tonne
K-tot	4.31	4.24	4.24	kg/tonne
S-tot	1.37	1.35	1.35	kg/tonne
C-tot	45.9	45.1	45.1	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.2%	9.1%	9.1%	%
DM	92	91	91	kg/tonne
VS	78	76	76	kg/tonne
% VS of DM	93%	84%	84%	%
N-tot	5.71	5.57	5.37	kg/tonne
NH4-N	3.63	3.53	3.33	kg/tonne
P-tot	1.02	1.00	1.00	kg/tonne
K-tot	3.56	3.50	3.50	kg/tonne
S-tot	1.38	1.36	1.36	kg/tonne
C-tot	39.60	38.83	38.83	kg/tonne

Table 41. Slurry composition for pig, cattle and total slurry for Denmark, Acidification at storage scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.4%	7.1%	7.1%	%
DM	74	71	71	kg/tonne
VS	60	57	57	kg/tonne
% VS of DM	81%	81%	81%	%
N-tot	5.25	5.04	4.88	kg/tonne
NH4-N	3.46	3.28	3.12	kg/tonne
P-tot	1.21	1.18	1.18	kg/tonne
K-tot	2.82	2.77	2.76	kg/tonne
S-tot	0.37	0.36	1.12	kg/tonne
C-tot	33.21	31.95	31.87	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.0%	11.0%	10.7%	%
DM	110	107	107	kg/tonne
VS	94	92	92	kg/tonne
% VS of DM	86%	86%	86%	%
N-tot	5.30	5.11	4.95	kg/tonne
NH4-N	2.93	2.77	2.61	kg/tonne
P-tot	0.85	0.83	0.83	kg/tonne
K-tot	4.32	4.26	4.26	kg/tonne
S-tot	0.34	0.33	1.09	kg/tonne
C-tot	46.0	44.8	44.8	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.2%	9.0%	9.0%	%
DM	92	90	90	kg/tonne
VS	78	76	76	kg/tonne
% VS of DM	84%	84%	84%	%
N-tot	5.28	5.14	4.97	kg/tonne
NH4-N	3.20	3.09	2.92	kg/tonne
P-tot	1.03	1.01	1.01	kg/tonne
K-tot	3.57	3.51	3.51	kg/tonne
S-tot	0.35	1.27	1.27	kg/tonne
C-tot	39.59	38.64	38.64	kg/tonne

Table 42. Slurry composition for pig, cattle and total slurry for Denmark, Acidification when spreading scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.4%	7.2%	7.2%	%
DM	74	72	72	kg/tonne
VS	60	58	58	kg/tonne
% VS of DM	81%	81%	81%	%
N-tot	5.26	5.11	4.95	kg/tonne
NH4-N	3.47	3.35	3.19	kg/tonne
P-tot	1.21	1.18	1.18	kg/tonne
K-tot	2.82	2.77	2.77	kg/tonne
S-tot	0.37	1.29	1.29	kg/tonne
C-tot	33.21	32.42	32.42	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.0%	11.0%	10.7%	%
DM	110	107	107	kg/tonne
VS	94	92	92	kg/tonne
% VS of DM	86%	86%	86%	%
N-tot	5.30	5.17	4.99	kg/tonne
NH4-N	2.93	2.83	2.65	kg/tonne
P-tot	0.85	0.83	0.83	kg/tonne
K-tot	4.32	4.26	4.26	kg/tonne
S-tot	0.34	1.26	1.26	kg/tonne
C-tot	46.0	44.9	44.9	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.2%	9.0%	9.0%	%
DM	92	90	90	kg/tonne
VS	78	76	76	kg/tonne
% VS of DM	84%	84%	84%	%
N-tot	5.28	5.14	4.97	kg/tonne
NH4-N	3.20	3.09	2.92	kg/tonne
P-tot	1.03	1.01	1.01	kg/tonne
K-tot	3.57	3.51	3.51	kg/tonne
S-tot	0.35	1.27	1.27	kg/tonne
C-tot	39.59	38.64	38.64	kg/tonne

Emissions from slurry handling in Denmark, base scenario

Table 43. Emissions from pig manure management, base scenario Denmark (kg/ tonne slurry spread)

	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.85	0.26	0.85	0.85
N_2O	0.013	0.013	0.013	0.013
NO	0.00088	0.00035	0.00088	0.00088
N_2	0.012	0.0037	0.0031	0.012
CH_4	0.17	0.018	0.17	0.17
CO_2bio	0.32	0.035	0.32	0.32
Indirect N_2O	0.011	0.0033	0.011	0.011
Storage				
NH_3	0.10	0.015	0.026	0.10
N_2O	0.030	0.030	0.030	0.030
NO	0.00073	0.00011	0.00018	0.00073
N_2	0.010	0.0015	0.0026	0.010
CH_4	0.50	0.055	0.10	0.50
CO_2bio	0.97	0.11	0.19	0.97
Indirect N_2O	0.0013	0.00020	0.00034	0.0013
Spreading				
NH_3	0.48	0.19	0.17	0.14
N_2O	0.040	0.044	0.040	0.040
NO	0.031	0.012	0.011	0.0092
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0064	0.0026	0.0022	0.0019
Total emissions				
NH_3	1.43	0.46	1.04	1.10
N_2O	0.082	0.087	0.083	0.082
NO	0.032	0.013	0.012	0.011
N_2	0.023	0.0052	0.0056	0.023
CH_4	0.67	0.073	0.27	0.67
CO_2bio	1.29	0.14	0.52	1.29
Indirect N_2O	0.019	0.0061	0.014	0.014

Table 44. Emissions from cattle manure management, base scenario Denmark (kg/ tonne slurry spread).

	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.67	0.20	0.67	0.67
N_2O	0.012	0.012	0.012	0.012
NO	0.00074	0.00030	0.00074	0.00074
N_2	0.010	0.0031	0.0104	0.010
CH_4	0.14	0.018	0.14	0.14
CO_2bio	0.27	0.035	0.27	0.27
Indirect N_2O	0.009	0.0026	0.009	0.009
Storage				
NH_3	0.11	0.02	0.03	0.11
N_2O	0.029	0.029	0.029	0.029
NO	0.00062	0.00009	0.00015	0.00062
N_2	0.009	0.0013	0.0086	0.009
CH_4	0.42	0.055	0.32	0.42
CO_2bio	0.81	0.11	0.63	0.81
Indirect N_2O	0.0014	0.00023	0.00034	0.0014
Spreading				
NH_3	0.54	0.21	0.19	0.16
N_2O	0.040	0.044	0.041	0.040
NO	0.026	0.010	0.009	0.0078
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0071	0.0028	0.0025	0.0021
Total emissions				
NH_3	1.32	0.43	0.89	0.94
N_2O	0.082	0.085	0.082	0.082
NO	0.027	0.011	0.010	0.009
N_2	0.019	0.0044	0.0190	0.019
CH_4	0.56	0.073	0.46	0.56
CO_2bio	1.08	0.14	0.90	1.08
Indirect N_2O	0.017	0.0057	0.012	0.012

Table 45. Emissions from pig and cattle manure management, base scenario Denmark (kg/ tonne slurry spread).

	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.76	0.23	0.76	0.76
N_2O	0.013	0.013	0.013	0.013
NO	0.00081	0.00032	0.00081	0.00081
N_2	0.011	0.0034	0.0068	0.011
CH_4	0.15	0.018	0.15	0.15
CO_2bio	0.30	0.04	0.30	0.30
Indirect N_2O	0.010	0.0029	0.010	0.010
Storage				
NH_3	0.10	0.02	0.03	0.10
N_2O	0.029	0.029	0.029	0.029
NO	0.00067	0.00010	0.00017	0.00067
N_2	0.009	0.0014	0.0057	0.009
CH_4	0.46	0.055	0.22	0.46
CO_2bio	0.89	0.11	0.42	0.89
Indirect N_2O	0.0014	0.00021	0.00034	0.0014
Spreading				
NH_3	0.51	0.20	0.18	0.15
N_2O	0.040	0.044	0.040	0.040
NO	0.028	0.011	0.010	0.0084
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0068	0.0027	0.0024	0.0020
Total emissions				
NH_3	1.37	0.45	0.96	1.02
N_2O	0.082	0.086	0.082	0.082
NO	0.030	0.012	0.011	0.010
N_2	0.021	0.0048	0.0125	0.021
CH_4	0.61	0.073	0.37	0.61
CO_2bio	1.18	0.14	0.71	1.18
Indirect N_2O	0.018	0.0059	0.013	0.013

Nitrogen balance for base scenario, Denmark

Table 46. Nitrogen balance for base scenario Denmark for total nitrogen, N-tot (kg/ tonne slurry) for pig, cattle and total slurry

	Incoming	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	6.00	5.25	5.04	4.61	78%
AC in housing	6.00	5.74	5.59	5.40	92%
AC at storage	6.00	5.26	5.11	4.95	84%
AC when spreading	6.00	5.25	5.04	4.88	83%
Cattle slurry					
Reference	6.40	5.30	5.11	4.63	80%
AC in housing	6.40	5.67	5.55	5.34	93%
AC at storage	6.40	5.30	5.17	4.99	87%
AC when spreading	6.40	5.30	5.11	4.95	86%
Pig and cattle slurry					
Reference	6.20	5.28	5.07	4.62	79%
AC in housing	6.20	5.70	5.57	5.37	93%
AC at storage	6.20	5.28	5.14	4.97	86%
AC when spreading	6.20	5.28	5.07	4.92	85%

Table 47. Nitrogen balance for base scenario Denmark for total nitrogen, N-tot (kg/ tonne slurry) for pig, cattle and total slurry.

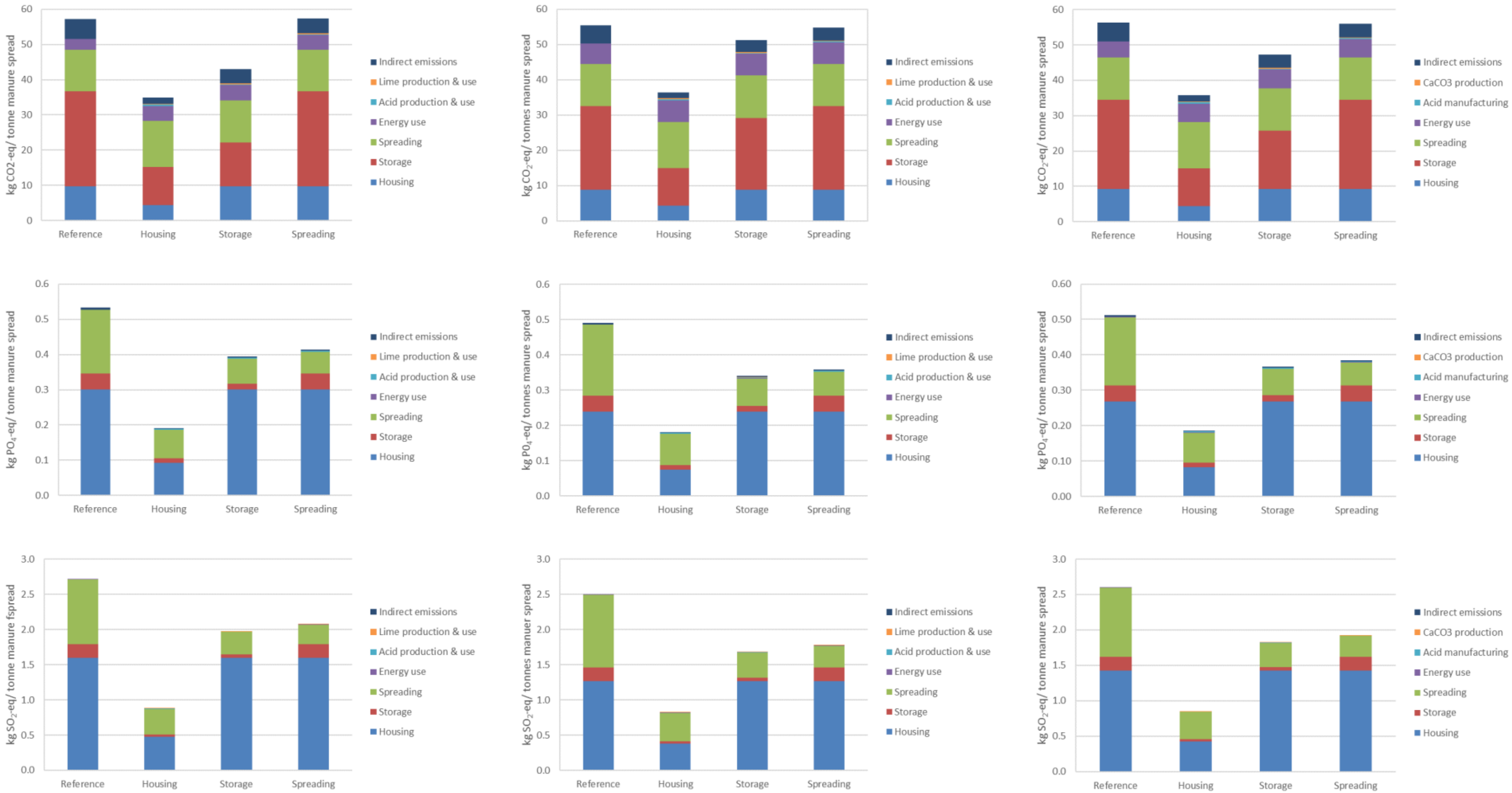
	Incoming	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	6.00	5.25	5.04	4.61	78%
AC in housing	6.00	5.74	5.59	5.40	92%
AC at storage	6.00	5.26	5.11	4.95	84%
AC when spreading	6.00	5.25	5.04	4.88	83%
Cattle slurry					
Reference	6.40	5.30	5.11	4.63	80%
AC in housing	6.40	5.67	5.55	5.34	93%
AC at storage	6.40	5.30	5.17	4.99	87%
AC when spreading	6.40	5.30	5.11	4.95	86%
Pig and cattle slurry					
Reference	6.20	5.28	5.07	4.62	79%
AC in housing	6.20	5.70	5.57	5.37	93%
AC at storage	6.20	5.28	5.14	4.97	86%
AC when spreading	6.20	5.28	5.07	4.92	85%

Table 48. Nitrogen balance for base scenario Denmark for ammonium nitrogen. NH_4-N (kg/tonne slurry) for pig. cattle and total slurry

	From animal	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	4.20	3.46	3.28	2.85	69%
AC in housing	4.20	3.95	3.84	3.65	89%
AC at storage	4.20	3.47	3.35	3.19	78%
AC when spreading	4.20	3.46	3.28	3.12	76%
Cattle slurry					
Reference	3.84	2.93	2.77	2.29	66%
AC in housing	3.84	3.31	3.23	3.02	88%
AC at storage	3.84	2.93	2.83	2.65	77%
AC when spreading	3.84	2.93	2.77	2.61	75%
Pig and cattle slurry					
Reference	4.02	3.18	3.02	2.56	68%
AC in housing	4.02	3.62	3.52	3.32	89%
AC at storage	4.02	3.19	3.09	2.91	77%
AC when spreading	4.02	3.18	3.02	2.86	76%

Environmental impact base scenario Denmark

First column is pig slurry, second column is cattle slurry and third column are pig and cattle slurry



Estonia

Slurry composition, base scenario Estonia

Table 49. Slurry composition for pig, cattle and total slurry for Estonia, reference scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.2%	8.2%	8.2%	%
DM	92	82	82	kg/tonne
VS	73	64	64	kg/tonne
% VS of DM	79%	79%	79%	%
N-tot	6.18	5.24	4.84	kg/tonne
NH4-N	3.67	2.96	2.56	kg/tonne
P-tot	2.40	2.18	2.18	kg/tonne
K-tot	2.66	2.41	2.41	kg/tonne
S-tot	0.33	0.30	0.30	kg/tonne
C-tot	40.27	35.73	35.73	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.0%	11.0%	9.9%	%
DM	110	99	99	kg/tonne
VS	91	81	81	kg/tonne
% VS of DM	82.0%	81.8%	81.8%	%
N-tot	5.20	4.62	4.17	kg/tonne
NH4-N	2.99	2.62	2.16	kg/tonne
P-tot	1.20	1.09	1.09	kg/tonne
K-tot	4.14	3.77	3.77	kg/tonne
S-tot	0.33	0.30	0.30	kg/tonne
C-tot	56.95	51.30	51.30	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	10.5%	9.4%	9.4%	%
DM	105	94	94	kg/tonne
VS	85	76	76	kg/tonne
% VS of DM	81%	81%	81%	%
N-tot	5.69	4.93	4.51	kg/tonne
NH4-N	3.33	2.79	2.36	kg/tonne
P-tot	1.80	1.63	1.64	kg/tonne
K-tot	3.40	3.09	3.09	kg/tonne
S-tot	0.33	0.30	0.30	kg/tonne

	From housing	From storage	To plant	
C-tot	48.61	43.51	43.51	kg/tonne

Table 50. Slurry composition for pig, cattle and total slurry for Estonia, Acidification in housing scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9,2%	8,3%	8,3%	%
DM	92	83	83	kg/tonne
VS	73	66	66	kg/tonne
% VS of DM	79%	79%	79%	%
N-tot	6,55	5,85	5,67	kg/tonne
NH4-N	4,04	3,59	3,41	kg/tonne
P-tot	2,39	2,16	2,16	kg/tonne
K-tot	2,65	2,40	2,40	kg/tonne
S-tot	1,36	1,23	1,23	kg/tonne
C-tot	40,33	36,37	36,37	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11,0%	11,0%	10,0%	%
DM	110	100	100	kg/tonne
VS	91	82	82	kg/tonne
% VS of DM	82%	82%	82%	%
N-tot	5,35	4,81	4,63	kg/tonne
NH4-N	3,16	2,82	2,63	kg/tonne
P-tot	1,20	1,09	1,09	kg/tonne
K-tot	4,13	3,75	3,75	kg/tonne
S-tot	1,36	1,24	1,24	kg/tonne
C-tot	56,9	51,7	51,7	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	10,5%	9,5%	9,5%	%
DM	105	95	95	kg/tonne
VS	85	77	77	kg/tonne
% VS of DM	81%	81%	81%	%
N-tot	5,95	5,33	5,15	kg/tonne
NH4-N	3,60	3,20	3,02	kg/tonne
P-tot	1,80	1,63	1,63	kg/tonne
K-tot	3,39	3,07	3,07	kg/tonne
S-tot	1,36	1,24	1,23	kg/tonne
C-tot	48,61	44,01	44,01	kg/tonne

Table 51. Slurry composition for pig, cattle and total slurry for Estonia, Acidification at storage scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.2%	8.3%	8.3%	%
DM	92	83	83	kg/tonne
VS	73	66	66	kg/tonne
% VS of DM	79%	79%	79%	%
N-tot	6.19	5.49	5.33	kg/tonne
NH4-N	3.67	3.22	3.05	kg/tonne
P-tot	2.40	2.17	2.17	kg/tonne
K-tot	2.66	2.41	2.41	kg/tonne
S-tot	0.33	1.15	1.15	kg/tonne
C-tot	40.27	36.24	36.24	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.0%	11.0%	10.0%	%
DM	110	100	100	kg/tonne
VS	91	82	82	kg/tonne
% VS of DM	82%	82%	82%	%
N-tot	5.20	4.68	4.50	kg/tonne
NH4-N	2.99	2.68	2.50	kg/tonne
P-tot	1.20	1.09	1.09	kg/tonne
K-tot	4.14	3.76	3.77	kg/tonne
S-tot	0.33	1.16	1.16	kg/tonne
C-tot	57.0	51.6	51.6	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	10.5%	9.5%	9.5%	%
DM	105	95	95	kg/tonne
VS	85	77	77	kg/tonne
% VS of DM	81%	81%	81%	%
N-tot	5.70	5.08	4.92	kg/tonne
NH4-N	3.33	2.95	2.78	kg/tonne
P-tot	1.80	1.63	1.63	kg/tonne
K-tot	3.40	3.09	3.09	kg/tonne
S-tot	0.33	1.15	1.15	kg/tonne
C-tot	48.61	43.92	43.92	kg/tonne

Table 52. Slurry composition for pig, cattle and total slurry for Estonia, Acidification when spreading scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.2%	8.2%	8.2%	%
DM	92	82	82	kg/tonne
VS	73	64	64	kg/tonne
% VS of DM	79%	79%	79%	%
N-tot	6.18	5.24	5.09	kg/tonne
NH4-N	3.67	2.96	2.81	kg/tonne
P-tot	2.40	2.18	2.17	kg/tonne
K-tot	2.66	2.41	2.40	kg/tonne
S-tot	0.33	0.30	1.05	kg/tonne
C-tot	40.27	35.73	35.64	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.0%	11.0%	9.9%	%
DM	110	99	99	kg/tonne
VS	91	81	81	kg/tonne
% VS of DM	82%	82%	82%	%
N-tot	5.20	4.62	4.47	kg/tonne
NH4-N	2.99	2.62	2.46	kg/tonne
P-tot	1.20	1.09	1.09	kg/tonne
K-tot	4.14	3.77	3.77	kg/tonne
S-tot	0.33	0.30	1.06	kg/tonne
C-tot	57.0	51.3	51.3	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	10.5%	9.4%	9.4%	%
DM	105	94	94	kg/tonne
VS	85	76	76	kg/tonne
% VS of DM	81%	81%	81%	%
N-tot	5.69	4.93	4.78	kg/tonne
NH4-N	3.33	2.79	2.64	kg/tonne
P-tot	1.80	1.63	1.63	kg/tonne
K-tot	3.40	3.09	3.09	kg/tonne
S-tot	0.33	0.30	1.05	kg/tonne
C-tot	48.61	43.51	43.47	kg/tonne

Nitrogen balance for base scenario, Estonia

Table 53. Nitrogen balance for base scenario Estonia for total nitrogen, N-tot (kg/tonne) for pig, cattle and total slurry.

	From animal	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	6.96	6.18	5.24	4.84	79%
AC in housing	6.96	6.55	5.85	5.67	93%
AC at storage	6.96	6.19	5.49	5.33	87%
AC when spreading	6.96	6.18	5.24	5.09	83%
Cattle slurry					
Reference	5.90	5.20	4.62	4.17	84%
AC in housing	5.90	5.35	4.81	4.63	94%
AC at storage	5.90	5.20	4.68	4.50	91%
AC when spreading	5.90	5.20	4.62	4.47	91%
Pig and cattle slurry					
Reference	6.24	5.50	4.81	4.38	83%
AC in housing	6.24	5.72	5.13	4.95	94%
AC at storage	6.24	5.48	4.91	4.74	90%
AC when spreading	6.24	5.50	4.81	4.66	88%

Table 54. Nitrogen balance for base scenario Estonia for ammonium nitrogen. NH_4-N (kg/tonne) for pig. cattle and total slurry.

	From animal	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	4.37	3.67	2.96	2.56	67%
AC in housing	4.37	4.04	3.59	3.41	89%
AC at storage	4.37	3.67	3.22	3.05	80%
AC when spreading	4.37	3.67	2.96	2.81	73%
Cattle slurry					
Reference	3.54	2.99	2.62	2.16	73%
AC in housing	3.54	3.16	2.82	2.63	89%
AC at storage	3.54	2.99	2.68	2.50	85%
AC when spreading	3.54	2.99	2.62	2.46	83%
Pig and cattle slurry					
Reference	3.80	3.20	2.72	2.29	71%
AC in housing	3.80	3.43	3.05	2.87	89%
AC at storage	3.80	3.19	2.83	2.66	83%
AC when spreading	3.80	3.20	2.72	2.57	80%

Emissions from slurry handling in Estonia, base scenario

Table 55. Emissions from pig manure management, base scenario Estonia (kg/ tonne slurry).

	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.61	0.18	0.61	0.61
N_2O	0.013	0.013	0.013	0.013
NO	0.00082	0.00033	0.00082	0.00082
N_2	0.012	0.0035	0.0029	0.012
CH_4	0.19	0.021	0.19	0.19
CO_2bio	0.36	0.040	0.36	0.36
Indirect N_2O	0.008	0.0024	0.008	0.008
Storage				
NH_3	0.40	0.06	0.10	0.40
N_2O	0.031	0.031	0.031	0.031
NO	0.00071	0.00010	0.00018	0.00071
N_2	0.010	0.0014	0.0025	0.010
CH_4	0.56	0.062	0.11	0.56
CO_2bio	1.09	0.12	0.22	1.09
Indirect N_2O	0.0052	0.00075	0.00131	0.0052
Spreading				
NH_3	0.43	0.18	0.16	0.13
N_2O	0.041	0.046	0.043	0.041
NO	0.028	0.011	0.010	0.0083
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0058	0.0024	0.0021	0.0017
Total emissions				
NH_3	1.44	0.42	0.87	1.14
N_2O	0.085	0.090	0.087	0.085
NO	0.029	0.012	0.011	0.010
N_2	0.021	0.0049	0.0054	0.021
CH_4	0.75	0.083	0.30	0.75
CO_2bio	1.45	0.16	0.58	1.45
Indirect N_2O	0.019	0.0055	0.011	0.015

Table 56. Emissions from cattle manure management, base scenario Estonia (kg/ tonne slurry).

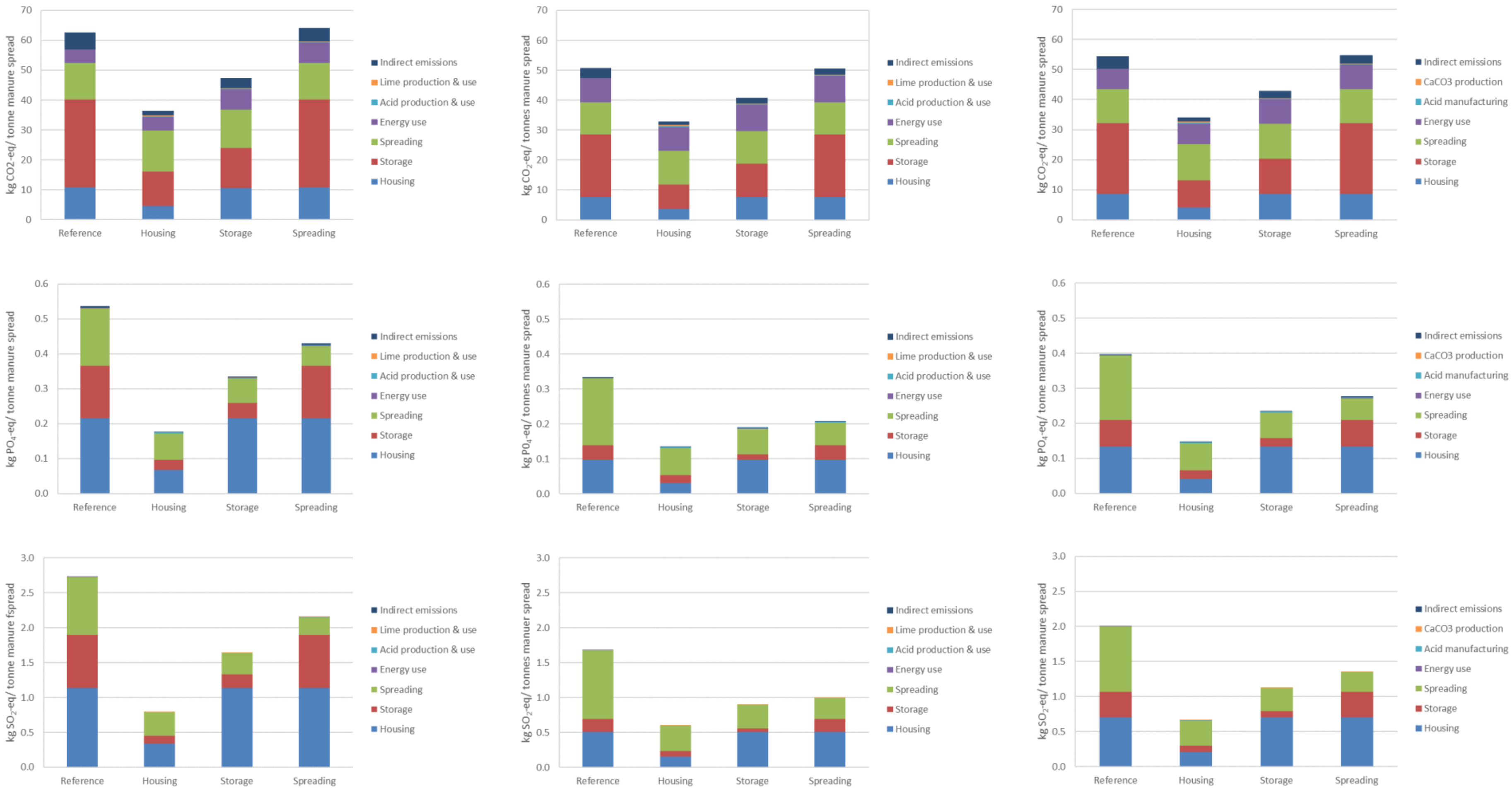
	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.27	0.08	0.27	0.27
N_2O	0.011	0.011	0.011	0.011
NO	0.00063	0.00025	0.00063	0.00063
N_2	0.009	0.0027	0.0089	0.009
CH_4	0.12	0.016	0.12	0.12
CO_2bio	0.24	0.031	0.24	0.24
Indirect N_2O	0.003	0.0010	0.003	0.003
Storage				
NH_3	0.10	0.05	0.02	0.10
N_2O	0.025	0.025	0.025	0.025
NO	0.00058	0.00008	0.00015	0.00058
N_2	0.008	0.0011	0.0082	0.008
CH_4	0.37	0.018	0.10	0.37
CO_2bio	0.72	0.03	0.20	0.72
Indirect N_2O	0.0013	0.00059	0.00032	0.0013
Spreading				
NH_3	0.51	0.19	0.18	0.15
N_2O	0.036	0.038	0.037	0.036
NO	0.024	0.009	0.008	0.0073
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0068	0.0025	0.0024	0.0020
Total emissions				
NH_3	0.88	0.31	0.47	0.52
N_2O	0.072	0.074	0.072	0.072
NO	0.026	0.009	0.009	0.009
N_2	0.017	0.0038	0.0170	0.017
CH_4	0.50	0.034	0.23	0.50
CO_2bio	0.96	0.07	0.44	0.96
Indirect N_2O	0.012	0.0041	0.006	0.007

Table 57. Emissions from pig and cattle manure management, base scenario Estonia (kg/ tonne slurry).

	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.37	0.11	0.37	0.37
N_2O	0.011	0.011	0.011	0.011
NO	0.00069	0.00028	0.00069	0.00069
N_2	0.010	0.0029	0.0070	0.010
CH_4	0.14	0.018	0.14	0.14
CO_2bio	0.28	0.03	0.28	0.28
Indirect N_2O	0.005	0.0015	0.005	0.005
Storage				
NH_3	0.19	0.05	0.05	0.19
N_2O	0.027	0.027	0.027	0.027
NO	0.00062	0.00009	0.00016	0.00062
N_2	0.009	0.0012	0.0064	0.009
CH_4	0.43	0.031	0.11	0.43
CO_2bio	0.83	0.06	0.21	0.83
Indirect N_2O	0.0025	0.00064	0.00063	0.0025
Spreading				
NH_3	0.49	0.19	0.17	0.15
N_2O	0.038	0.041	0.039	0.038
NO	0.025	0.010	0.009	0.0076
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0065	0.0025	0.0023	0.0019
Total emissions				
NH_3	1.05	0.35	0.59	0.71
N_2O	0.076	0.079	0.077	0.076
NO	0.027	0.010	0.010	0.009
N_2	0.018	0.0041	0.0134	0.018
CH_4	0.58	0.049	0.25	0.58
CO_2bio	1.11	0.09	0.48	1.11
Indirect N_2O	0.014	0.0046	0.008	0.009

Environmental impact base scenario Estonia

First column is pig slurry, second column is cattle slurry and third column are pig and cattle slurry



Slurry composition, base scenario Finland

Table 58. Slurry composition for pig, cattle and total slurry for Finland, reference scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.0%	6.0%	6.0%	%
DM	70	60	60	kg/tonne
VS	56	48	48	kg/tonne
% VS of DM	80%	80%	80%	%
N-tot	5.03	4.12	3.74	kg/tonne
NH4-N	3.15	2.47	2.09	kg/tonne
P-tot	1.28	1.13	1.13	kg/tonne
K-tot	2.14	1.88	1.88	kg/tonne
S-tot	0.33	0.29	0.29	kg/tonne
C-tot	33.14	28.57	28.57	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.7%	9.7%	9.0%	%
DM	97	90	90	kg/tonne
VS	79	73	73	kg/tonne
% VS of DM	81.7%	81.5%	81.5%	%
N-tot	5.36	4.88	4.36	kg/tonne
NH4-N	3.36	3.01	2.50	kg/tonne
P-tot	0.87	0.81	0.81	kg/tonne
K-tot	5.62	5.24	5.24	kg/tonne
S-tot	0.34	0.31	0.31	kg/tonne
C-tot	43.22	39.89	39.89	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	8.7%	7.8%	7.8%	%
DM	87	78	78	kg/tonne
VS	71	63	63	kg/tonne
% VS of DM	81%	81%	81%	%
N-tot	5.20	4.50	4.05	kg/tonne
NH4-N	3.26	2.74	2.29	kg/tonne
P-tot	1.07	0.97	0.97	kg/tonne
K-tot	3.88	3.56	3.56	kg/tonne
S-tot	0.33	0.30	0.30	kg/tonne
C-tot	38.18	34.23	34.23	kg/tonne

Table 59. Slurry composition for pig, cattle and total slurry for Denmark, Acidification in housing scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.0%	6.1%	6.1%	%
DM	70	61	61	kg/tonne
VS	56	49	49	kg/tonne
% VS of DM	80%	80%	80%	%
N-tot	5.24	4.54	4.38	kg/tonne
NH4-N	3.36	2.90	2.73	kg/tonne
P-tot	1.28	1.12	1.12	kg/tonne
K-tot	2.13	1.87	1.87	kg/tonne
S-tot	1.36	1.19	1.19	kg/tonne
C-tot	33.18	29.06	29.06	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.7%	9.7%	9.0%	%
DM	97	90	90	kg/tonne
VS	79	74	74	kg/tonne
% VS of DM	82%	82%	82%	%
N-tot	5.52	5.10	4.89	kg/tonne
NH4-N	3.53	3.24	3.04	kg/tonne
P-tot	0.86	0.80	0.80	kg/tonne
K-tot	5.60	5.22	5.22	kg/tonne
S-tot	1.37	1.27	1.27	kg/tonne
C-tot	43.2	40.2	40.2	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.2%	6.6%	6.6%	%
DM	72	66	66	kg/tonne
VS	59	54	54	kg/tonne
% VS of DM	82%	82%	82%	%
N-tot	3.88	3.56	3.42	kg/tonne
NH4-N	2.48	2.27	2.13	kg/tonne
P-tot	0.70	0.65	0.65	kg/tonne
K-tot	3.27	3.04	3.04	kg/tonne
S-tot	1.27	1.18	1.17	kg/tonne
C-tot	29.07	26.93	26.93	kg/tonne

Table 60. Slurry composition for pig, cattle and total slurry for Finland, Acidification at storage scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.0%	6.1%	6.1%	%
DM	70	61	61	kg/tonne
VS	56	49	49	kg/tonne
% VS of DM	80%	80%	80%	%
N-tot	5.04	4.34	4.18	kg/tonne
NH4-N	3.16	2.68	2.53	kg/tonne
P-tot	1.28	1.12	1.12	kg/tonne
K-tot	2.14	1.88	1.88	kg/tonne
S-tot	0.33	1.11	1.11	kg/tonne
C-tot	33.14	28.96	28.96	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.7%	9.7%	9.0%	%
DM	97	90	90	kg/tonne
VS	79	73	73	kg/tonne
% VS of DM	82%	82%	82%	%
N-tot	5.36	4.95	4.75	kg/tonne
NH4-N	3.36	3.08	2.89	kg/tonne
P-tot	0.87	0.81	0.81	kg/tonne
K-tot	5.62	5.24	5.24	kg/tonne
S-tot	0.34	1.19	1.19	kg/tonne
C-tot	43.2	40.0	40.0	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.2%	6.6%	6.6%	%
DM	72	66	66	kg/tonne
VS	59	54	54	kg/tonne
% VS of DM	82%	81%	81%	%
N-tot	3.76	3.44	3.31	kg/tonne
NH4-N	2.35	2.14	2.01	kg/tonne
P-tot	0.71	0.65	0.65	kg/tonne
K-tot	3.28	3.05	3.05	kg/tonne
S-tot	0.24	1.09	1.09	kg/tonne
C-tot	29.07	26.79	26.79	kg/tonne

Table 61. Slurry composition for pig, cattle and total slurry for Denmark, Acidification when spreading scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.0%	6.0%	6.0%	%
DM	70	60	60	kg/tonne
VS	56	48	48	kg/tonne
% VS of DM	80%	80%	80%	%
N-tot	5.03	4.12	3.98	kg/tonne
NH4-N	3.15	2.47	2.33	kg/tonne
P-tot	1.28	1.13	1.12	kg/tonne
K-tot	2.14	1.88	1.88	kg/tonne
S-tot	0.33	0.29	1.04	kg/tonne
C-tot	33.14	28.57	28.50	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	9.7%	9.7%	9.0%	%
DM	97	90	90	kg/tonne
VS	79	73	73	kg/tonne
% VS of DM	82%	81%	81%	%
N-tot	5.36	4.88	4.71	kg/tonne
NH4-N	3.36	3.01	2.84	kg/tonne
P-tot	0.87	0.81	0.81	kg/tonne
K-tot	5.62	5.24	5.24	kg/tonne
S-tot	0.34	0.31	1.07	kg/tonne
C-tot	43.2	39.9	39.9	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.2%	6.6%	6.6%	%
DM	72	66	66	kg/tonne
VS	59	53	53	kg/tonne
% VS of DM	82%	81%	81%	%
N-tot	3.76	3.36	3.24	kg/tonne
NH4-N	2.35	2.05	1.94	kg/tonne
P-tot	0.71	0.65	0.65	kg/tonne
K-tot	3.28	3.05	3.05	kg/tonne
S-tot	0.24	0.22	0.98	kg/tonne
C-tot	29.07	26.65	26.63	kg/tonne

Nitrogen balance for base scenario, Finland

Table 62. Nitrogen balance for base scenario Finland for total nitrogen, N-tot (kg/ tonne) for pig, cattle and total slurry.

	Incoming	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	5.36	5.03	4.12	3.74	80%
AC in housing	5.36	5.24	4.54	4.38	93%
AC at storage	5.36	5.04	4.34	4.18	85%
AC when spreading	5.36	5.03	4.12	3.98	85%
Cattle slurry					
Reference	6.25	5.36	4.88	4.36	83%
AC in housing	6.25	5.52	5.10	4.89	94%
AC at storage	6.25	5.36	4.95	4.75	91%
AC when spreading	6.25	5.36	4.88	4.71	90%
Pig and cattle slurry					
Reference	5.89	5.24	4.58	4.12	83%
AC in housing	5.89	5.44	4.91	4.72	94%
AC at storage	5.89	5.24	4.71	4.53	91%
AC when spreading	5.89	5.24	4.58	4.43	89%

Table 63. Nitrogen balance for base scenario Finland for ammonium nitrogen, NH_4-N (kg/ tonne) for pig, cattle and total slurry

	From animal	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	3.48	3.15	2.47	2.09	68%
AC in housing	3.48	3.36	2.90	2.73	90%
AC at storage	3.48	3.16	2.68	2.53	83%
AC when spreading	3.48	3.15	2.47	2.33	76%
Cattle slurry					
Reference	4.05	3.36	3.01	2.50	74%
AC in housing	4.05	3.53	3.24	3.04	90%
AC at storage	4.05	3.36	3.08	2.89	85%
AC when spreading	4.05	3.36	3.01	2.84	84%
Pig and cattle slurry					
Reference	3.82	3.28	2.80	2.34	73%
AC in housing	3.82	3.48	3.12	2.93	90%
AC at storage	3.82	3.28	2.93	2.75	85%
AC when spreading	3.82	3.28	2.80	2.65	82%

Emissions from slurry handling in Finland, base scenario

Table 64. Emissions from pig manure management, base scenario Finland (kg/ tonne slurry spread).

	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.15	0.04	0.15	0.15
N_2O	0.005	0.005	0.005	0.005
NO	0.00029	0.00012	0.00029	0.00029
N_2	0.004	0.0012	0.0010	0.004
CH_4	0.07	0.007	0.07	0.07
CO_2bio	0.13	0.014	0.13	0.13
Indirect N_2O	0.002	0.0006	0.002	0.002
Storage				
NH_3	0.15	0.02	0.04	0.15
N_2O	0.011	0.011	0.011	0.011
NO	0.00026	0.00004	0.00007	0.00026
N_2	0.004	0.0005	0.0009	0.004
CH_4	0.20	0.022	0.04	0.20
CO_2bio	0.38	0.04	0.08	0.38
Indirect N_2O	0.0019	0.00027	0.00048	0.0019
Spreading				
NH_3	0.19	0.07	0.07	0.06
N_2O	0.014	0.016	0.015	0.014
NO	0.010	0.004	0.004	0.0031
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0025	0.0010	0.0009	0.0007
Total emissions				
NH_3	0.48	0.14	0.25	0.35
N_2O	0.030	0.031	0.030	0.030
NO	0.011	0.004	0.004	0.004
N_2	0.008	0.0017	0.0019	0.008
CH_4	0.26	0.029	0.11	0.26
CO_2bio	0.51	0.06	0.20	0.51
Indirect N_2O	0.006	0.0018	0.003	0.005

Table 65. Emissions from cattle manure management, base scenario Finland (kg/ tonne slurry spread).

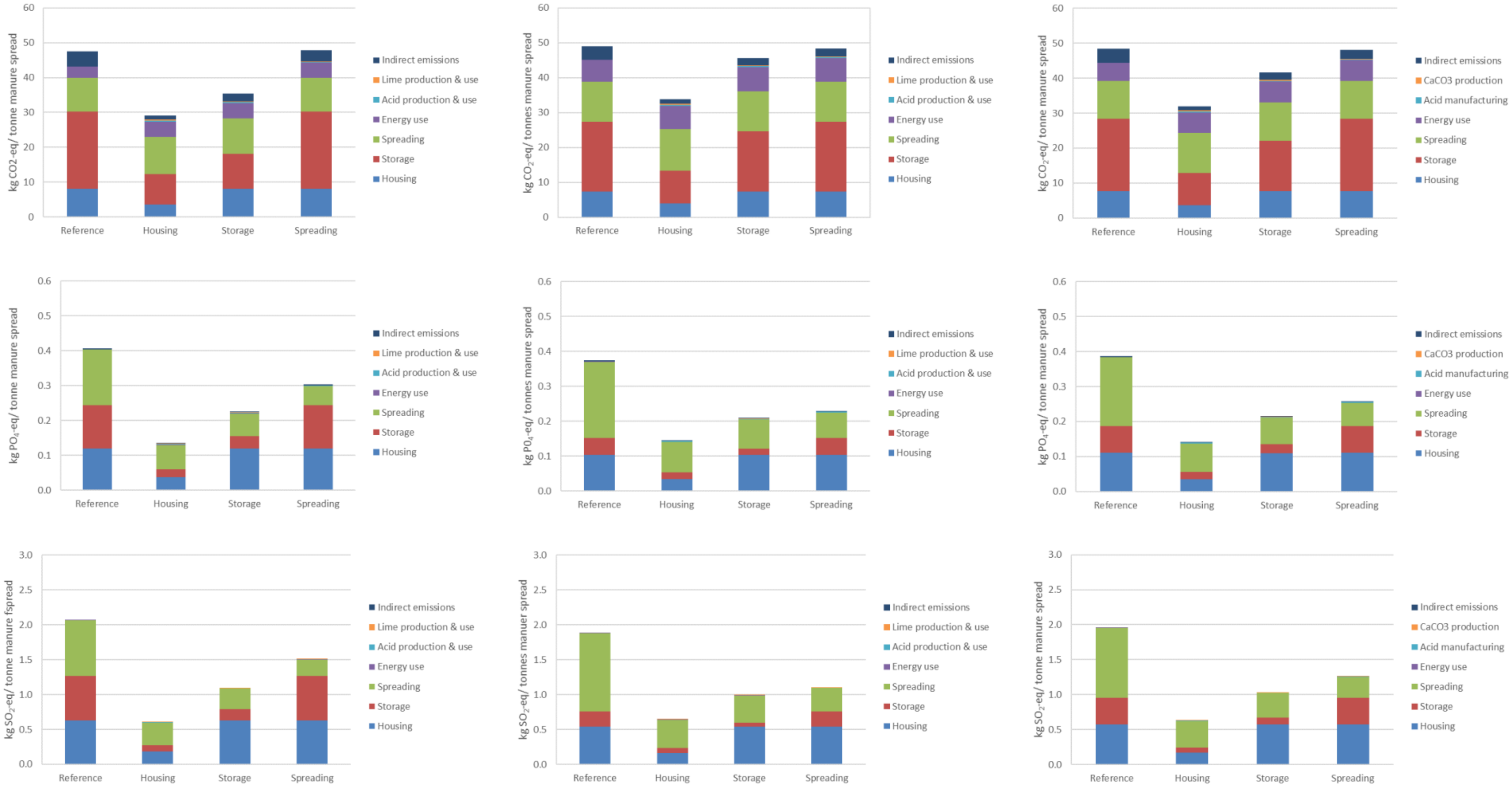
	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.29	0.09	0.29	0.29
N_2O	0.011	0.011	0.011	0.011
NO	0.00073	0.00029	0.00073	0.00073
N_2	0.010	0.0030	0.0102	0.010
CH_4	0.11	0.015	0.11	0.11
CO_2bio	0.22	0.028	0.22	0.22
Indirect N_2O	0.004	0.0011	0.004	0.004
Storage				
NH_3	0.11	0.04	0.03	0.11
N_2O	0.026	0.026	0.026	0.026
NO	0.00067	0.00009	0.00017	0.00067
N_2	0.009	0.0013	0.0094	0.009
CH_4	0.34	0.044	0.26	0.34
CO_2bio	0.65	0.08	0.50	0.65
Indirect N_2O	0.0015	0.00047	0.00037	0.0015
Spreading				
NH_3	0.59	0.22	0.20	0.18
N_2O	0.038	0.040	0.039	0.038
NO	0.028	0.010	0.010	0.0084
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0078	0.0029	0.0027	0.0023
Total emissions				
NH_3	0.99	0.34	0.52	0.58
N_2O	0.076	0.078	0.077	0.076
NO	0.030	0.011	0.011	0.010
N_2	0.020	0.0043	0.0196	0.020
CH_4	0.45	0.058	0.37	0.45
CO_2bio	0.86	0.11	0.72	0.86
Indirect N_2O	0.013	0.0045	0.007	0.008

Table 66. Emissions from pig and cattle manure management, base scenario Finland (kg/ tonne slurry spread).

	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.23	0.07	0.23	0.23
N_2O	0.009	0.009	0.009	0.009
NO	0.00056	0.00022	0.00056	0.00056
N_2	0.008	0.0023	0.0066	0.008
CH_4	0.09	0.012	0.09	0.09
CO_2bio	0.18	0.02	0.18	0.18
Indirect N_2O	0.003	0.0009	0.003	0.003
Storage				
NH_3	0.13	0.03	0.03	0.13
N_2O	0.020	0.020	0.020	0.020
NO	0.00051	0.00007	0.00013	0.00051
N_2	0.007	0.0010	0.0061	0.007
CH_4	0.28	0.035	0.17	0.28
CO_2bio	0.55	0.07	0.33	0.55
Indirect N_2O	0.0017	0.00039	0.00041	0.0017
Spreading				
NH_3	0.43	0.16	0.15	0.13
N_2O	0.029	0.031	0.030	0.029
NO	0.021	0.008	0.007	0.0063
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0057	0.0021	0.0020	0.0017
Total emissions				
NH_3	0.79	0.26	0.42	0.49
N_2O	0.058	0.060	0.059	0.058
NO	0.022	0.008	0.008	0.007
N_2	0.015	0.0033	0.0127	0.015
CH_4	0.38	0.047	0.27	0.38
CO_2bio	0.73	0.09	0.52	0.73
Indirect N_2O	0.010	0.0034	0.005	0.006

Environmental impact base scenario Finland

Figure 14. First column is pig slurry, second column is cattle slurry and third column are pig and cattle slurry



Slurry composition, base scenario, Sweden

Table 67. Slurry composition for pig, cattle and total slurry for Sweden, reference scenario

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.4%	7.1%	7.1%	%
DM	74	71	71	kg/tonne
VS	59	56	56	kg/tonne
% VS of DM	80%	79%	79%	%
N-tot	4.75	4.57	3.96	kg/tonne
NH4-N	2.79	2.64	2.03	kg/tonne
P-tot	1.86	1.83	1.83	kg/tonne
K-tot	2.10	2.06	2.07	kg/tonne
S-tot	0.31	0.30	0.30	kg/tonne
C-tot	30.93	29.67	29.67	kg/tonne
C-tot. % DM	42%	42%	42%	%
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.3%	11.3%	8.1%	%
DM	113	81	81	kg/tonne
VS	94	67	67	kg/tonne
% VS of DM	83.3%	83.0%	83.0%	%
N-tot	5.30	3.76	3.27	kg/tonne
NH4-N	3.05	2.13	1.63	kg/tonne
P-tot	0.70	0.51	0.51	kg/tonne
K-tot	4.49	3.26	3.26	kg/tonne
S-tot	0.47	0.34	0.34	kg/tonne
C-tot	56.55	40.56	40.56	kg/tonne
C-tot. % DM	62%	50%	50%	%
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	10.7%	8.0%	8.0%	%
DM	107	80	80	kg/tonne
VS	88	66	66	kg/tonne
% VS of DM	83%	83%	83%	%
N-tot	5.02	4.17	3.61	kg/tonne
NH4-N	2.92	2.38	1.83	kg/tonne
P-tot	1.28	1.17	1.17	kg/tonne
K-tot	3.29	2.66	2.66	kg/tonne
S-tot	0.39	0.32	0.32	kg/tonne
C-tot	43.74	35.11	35.11	kg/tonne

	From housing	From storage	To plant	
C-tot. % DM	41%	44%	46%	%

Table 68. Slurry composition for pig, cattle and total slurry for Sweden, Acidification in housing scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.4%	7.2%	7.2%	%
DM	74	72	72	kg/tonne
VS	59	57	57	kg/tonne
% VS of DM	80%	79%	79%	%
N-tot	5.06	4.94	4.69	kg/tonne
NH4-N	3.11	3.03	2.77	kg/tonne
P-tot	1.85	1.82	1.82	kg/tonne
K-tot	2.09	2.05	2.05	kg/tonne
S-tot	1.34	1.32	1.32	kg/tonne
C-tot	30.85	30.24	30.24	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.2%	11.2%	8.1%	%
DM	112	81	81	kg/tonne
VS	94	68	68	kg/tonne
% VS of DM	83%	83%	83%	%
N-tot	5.38	3.88	3.69	kg/tonne
NH4-N	3.14	2.25	2.06	kg/tonne
P-tot	0.70	0.51	0.51	kg/tonne
K-tot	4.48	3.25	3.25	kg/tonne
S-tot	1.50	1.09	1.09	kg/tonne
C-tot	56.4	40.9	40.9	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	10.6%	8.0%	8.0%	%
DM	106	80	80	kg/tonne
VS	88	67	67	kg/tonne
% VS of DM	83%	83%	83%	%
N-tot	5.22	4.41	4.19	kg/tonne
NH4-N	3.12	2.64	2.42	kg/tonne
P-tot	1.27	1.16	1.16	kg/tonne
K-tot	3.28	2.65	2.65	kg/tonne
S-tot	1.42	1.20	1.20	kg/tonne
C-tot	43.62	35.56	35.56	kg/tonne

Table 69. Slurry composition for pig, cattle and total slurry for Sweden, Acidification at storage scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.4%	7.2%	7.2%	%
DM	74	72	72	kg/tonne
VS	59	57	57	kg/tonne
% VS of DM	80%	79%	79%	%
N-tot	4.75	4.63	4.40	kg/tonne
NH4-N	2.79	2.71	2.48	kg/tonne
P-tot	1.86	1.82	1.82	kg/tonne
K-tot	2.10	2.06	2.06	kg/tonne
S-tot	0.31	1.23	1.23	kg/tonne
C-tot	30.93	30.25	30.25	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.3%	11.3%	8.1%	%
DM	113	81	81	kg/tonne
VS	94	67	67	kg/tonne
% VS of DM	83%	83%	83%	%
N-tot	5.30	3.81	3.63	kg/tonne
NH4-N	3.05	2.18	1.99	kg/tonne
P-tot	0.70	0.51	0.51	kg/tonne
K-tot	4.49	3.26	3.26	kg/tonne
S-tot	0.47	1.03	1.03	kg/tonne
C-tot	56.6	40.7	40.7	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	10.7%	8.0%	8.0%	%
DM	107	80	80	kg/tonne
VS	88	66	66	kg/tonne
% VS of DM	83%	83%	83%	%
N-tot	5.02	4.22	4.01	kg/tonne
NH4-N	2.92	2.44	2.24	kg/tonne
P-tot	1.28	1.17	1.17	kg/tonne
K-tot	3.29	2.66	2.66	kg/tonne
S-tot	0.39	1.13	1.13	kg/tonne
C-tot	43.74	35.46	35.46	kg/tonne

Table 70. Slurry composition for pig, cattle and total slurry for Sweden, Acidification when spreading scenario.

	From housing	From storage	To plant	
Pig manure				
Wet weight	1 000	1 000	1 000	kg
% DM	7.4%	7.1%	7.1%	%
DM	74	71	71	kg/tonne
VS	59	56	56	kg/tonne
% VS of DM	80%	79%	79%	%
N-tot	4.75	4.57	4.36	kg/tonne
NH4-N	2.79	2.64	2.43	kg/tonne
P-tot	1.86	1.83	1.82	kg/tonne
K-tot	2.10	2.06	2.06	kg/tonne
S-tot	0.31	0.30	1.06	kg/tonne
C-tot	30.93	29.67	29.59	kg/tonne
Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	11.3%	11.3%	8.1%	%
DM	113	81	81	kg/tonne
VS	94	67	67	kg/tonne
% VS of DM	83%	83%	83%	%
N-tot	5.30	3.76	3.60	kg/tonne
NH4-N	3.05	2.13	1.97	kg/tonne
P-tot	0.70	0.51	0.51	kg/tonne
K-tot	4.49	3.26	3.26	kg/tonne
S-tot	0.47	0.34	1.10	kg/tonne
C-tot	56.6	40.6	40.6	kg/tonne
Pig & Cattle manure				
Wet weight	1 000	1 000	1 000	kg
% DM	10.7%	8.0%	8.0%	%
DM	107	80	80	kg/tonne
VS	88	66	66	kg/tonne
% VS of DM	83%	83%	83%	%
N-tot	5.02	4.17	3.98	kg/tonne
NH4-N	2.92	2.38	2.20	kg/tonne
P-tot	1.28	1.17	1.17	kg/tonne
K-tot	3.29	2.66	2.66	kg/tonne
S-tot	0.39	0.32	1.08	kg/tonne
C-tot	43.74	35.11	35.08	kg/tonne

Nitrogen balance for base scenario, Sweden

Table 71. Nitrogen balance for base scenario Sweden for total nitrogen, N-tot (kg/ tonne) for pig, cattle and total slurry

	From animal	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	6.96	4.75	4.57	3.96	77%
AC in housing	6.96	5.06	4.94	4.69	92%
AC at storage	6.96	4.75	4.63	4.40	86%
AC when spreading	6.96	4.75	4.57	4.36	85%
Cattle slurry					
Reference	7.11	5.30	3.76	3.27	85%
AC in housing	7.11	5.38	3.88	3.69	96%
AC at storage	7.11	5.30	3.81	3.63	94%
AC when spreading	7.11	5.30	3.76	3.60	94%
Pig and cattle slurry					
Reference	7.09	5.22	3.86	3.35	84%
AC in housing	7.09	5.35	4.02	3.83	96%
AC at storage	7.09	5.22	3.91	3.72	93%
AC when spreading	7.09	5.22	3.86	3.69	92%

Table 72. Nitrogen balance for base scenario Sweden for ammonium nitrogen, NH_4-N (kg/ tonne) for pig, cattle and total slurry

	From animal	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	4.37	2.79	2.64	2.03	63%
AC in housing	4.37	3.11	3.03	2.77	87%
AC at storage	4.37	2.79	2.71	2.48	77%
AC when spreading	4.37	2.79	2.64	2.43	76%
Cattle slurry					
Reference	4.28	3.05	2.13	1.63	70%
AC in housing	4.28	3.14	2.25	2.06	89%
AC at storage	4.28	3.05	2.18	1.99	86%
AC when spreading	4.28	3.05	2.13	1.97	85%
Pig and cattle slurry					
Reference	4.30	3.01	2.19	1.68	69%
AC in housing	4.30	3.14	2.35	2.16	89%
AC at storage	4.30	3.01	2.24	2.05	85%
AC when spreading	4.30	3.01	2.19	2.02	83%

Emissions from slurry handling in Sweden, base scenario

Table 73. Emissions from pig manure management, base scenario Sweden (kg/ tonne slurry spread).

	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.55	0.16	0.55	0.55
N_2O	0.011	0.011	0.011	0.011
NO	0.00069	0.00028	0.00069	0.00069
N_2	0.010	0.0029	0.0097	0.010
CH_4	0.03	0.004	0.03	0.03
CO_2bio	0.06	0.007	0.06	0.06
Indirect N_2O	0.007	0.0021	0.007	0.007
Storage				
NH_3	0.10	0.01	0.03	0.10
N_2O	0.026	0.026	0.026	0.026
NO	0.00059	0.00009	0.00015	0.00059
N_2	0.008	0.0012	0.0021	0.008
CH_4	0.62	0.068	0.12	0.62
CO_2bio	1.20	0.13	0.24	1.20
Indirect N_2O	0.0013	0.00019	0.00033	0.0013
Spreading				
NH_3	0.71	0.28	0.25	0.21
N_2O	0.036	0.039	0.036	0.036
NO	0.025	0.010	0.009	0.0074
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0093	0.0036	0.0032	0.0028
Total emissions				
NH_3	1.36	0.46	0.82	0.86
N_2O	0.073	0.076	0.073	0.073
NO	0.026	0.010	0.009	0.009
N_2	0.018	0.0041	0.0117	0.018
CH_4	0.65	0.072	0.16	0.65
CO_2bio	1.26	0.14	0.30	1.26
Indirect N_2O	0.018	0.0060	0.011	0.011

Table 74. Emissions from cattle manure management, base scenario Sweden (kg/ tonne slurry spread).

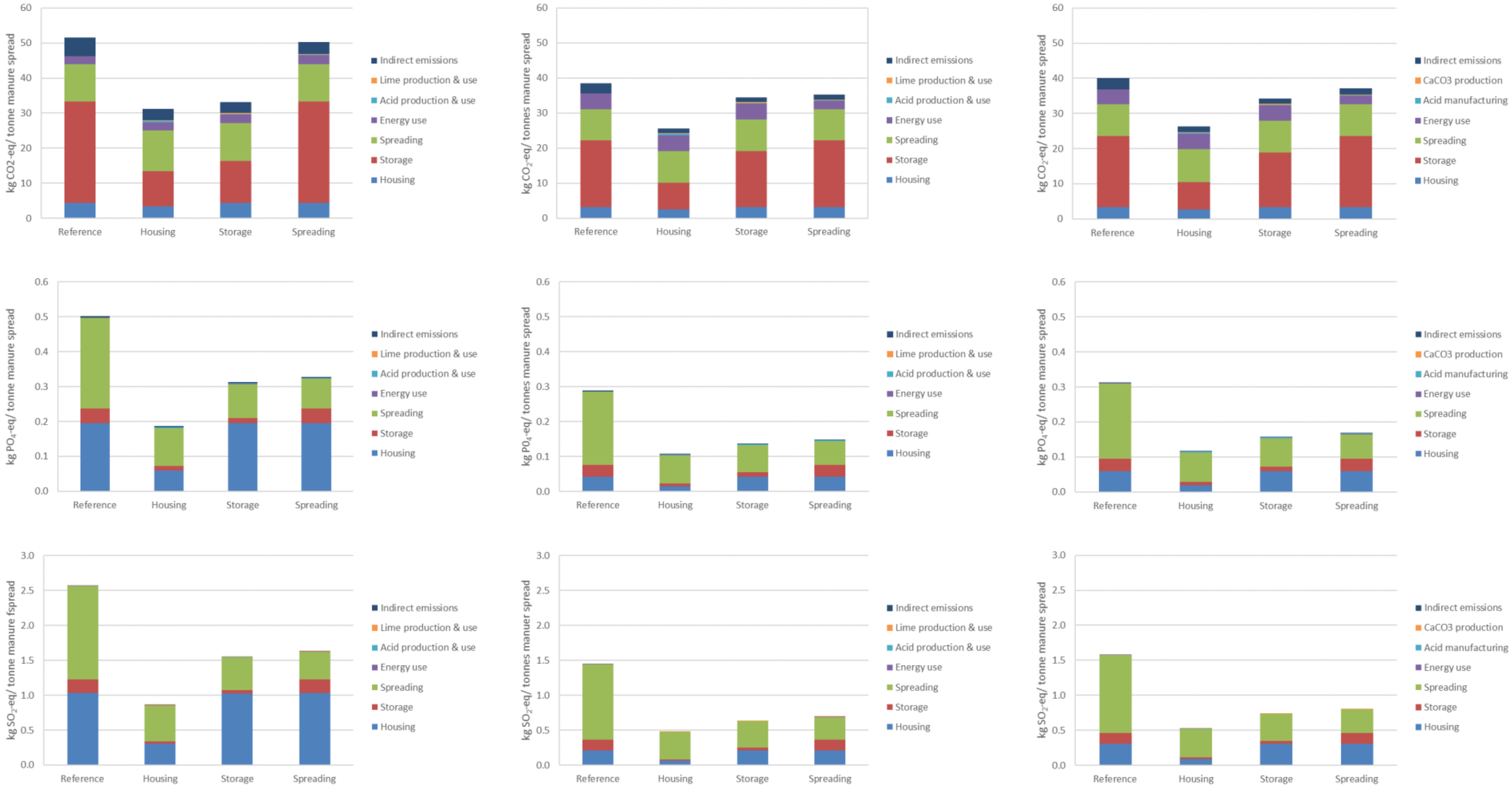
	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.11	0.03	0.11	0.11
N_2O	0.008	0.008	0.008	0.008
NO	0.00050	0.00020	0.00050	0.00050
N_2	0.007	0.0021	0.0070	0.007
CH_4	0.02	0.003	0.02	0.02
CO_2bio	0.04	0.005	0.04	0.04
Indirect N_2O	0.001	0.0004	0.001	0.001
Storage				
NH_3	0.08	0.01	0.02	0.08
N_2O	0.019	0.019	0.019	0.019
NO	0.00047	0.00006	0.00012	0.00047
N_2	0.007	0.0009	0.0066	0.007
CH_4	0.39	0.051	0.30	0.39
CO_2bio	0.75	0.10	0.58	0.75
Indirect N_2O	0.0010	0.00014	0.00026	0.0010
Spreading				
NH_3	0.57	0.21	0.20	0.17
N_2O	0.030	0.031	0.030	0.030
NO	0.020	0.007	0.007	0.0060
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0075	0.0027	0.0026	0.0022
Total emissions				
NH_3	0.76	0.25	0.33	0.36
N_2O	0.057	0.058	0.058	0.057
NO	0.021	0.007	0.008	0.007
N_2	0.014	0.0030	0.0136	0.014
CH_4	0.41	0.053	0.32	0.41
CO_2bio	0.79	0.10	0.62	0.79
Indirect N_2O	0.010	0.0033	0.004	0.005

Table 75. Emissions from pig and cattle manure management, base scenario Sweden (kg/ tonne slurry spread).

	Reference	Acidification in housing	Acidification at storage	Acidification when spreading
Housing				
NH_3	0.16	0.05	0.16	0.16
N_2O	0.009	0.009	0.009	0.009
NO	0.00052	0.00021	0.00052	0.00052
N_2	0.007	0.0022	0.0073	0.007
CH_4	0.02	0.003	0.02	0.02
CO_2bio	0.04	0.01	0.04	0.04
Indirect N_2O	0.002	0.0006	0.002	0.002
Storage				
NH_3	0.08	0.01	0.02	0.08
N_2O	0.020	0.020	0.020	0.020
NO	0.00049	0.00007	0.00012	0.00049
N_2	0.007	0.0009	0.0061	0.007
CH_4	0.42	0.053	0.28	0.42
CO_2bio	0.81	0.10	0.54	0.81
Indirect N_2O	0.0011	0.00015	0.00027	0.0011
Spreading				
NH_3	0.58	0.21	0.20	0.18
N_2O	0.030	0.032	0.031	0.030
NO	0.020	0.007	0.007	0.0061
N_2	0	0	0	0
CH_4	0	0	0	0
CO_2bio	0	0	0	0
Indirect N_2O	0.0077	0.0028	0.0027	0.0023
Total emissions				
NH_3	0.83	0.27	0.39	0.42
N_2O	0.059	0.061	0.060	0.059
NO	0.021	0.008	0.008	0.007
N_2	0.014	0.0031	0.0134	0.014
CH_4	0.44	0.056	0.30	0.44
CO_2bio	0.85	0.11	0.58	0.85
Indirect N_2O	0.011	0.0036	0.005	0.006

Environmental impact base scenario Sweden

Figure 15. First column is pig slurry, second column is cattle slurry and third column are pig and cattle slurry



Emissions from slurry handling in Sweden, BAT scenario

Table 76. Emissions from pig manure management, BAT scenario Sweden (kg/ tonne slurry spread).

	Reference	Acidification in housing	Acidification at storage	Acidification when spread-ing	BAT
Housing					
NH_3	0.55	0.16	0.55	0.55	0.55
N_2O	0.011	0.011	0.011	0.011	0.011
NO	0.00069	0.00028	0.00069	0.00069	0.00069
N_2	0.010	0.0029	0.010	0.010	0.010
CH_4	0.033	0.0036	0.033	0.033	0.033
CO_2bio	0.063	0.0069	0.063	0.063	0.063
Indirect N_2O	0.0071	0.0021	0.0071	0.0071	0.0071
Storage					
NH_3	0.10	0.015	0.026	0.10	0.033
N_2O	0.026	0.026	0.026	0.026	0.026
NO	0.00059	0.000086	0.00015	0.00059	0.00059
N_2	0.0082	0.0012	0.0021	0.0082	0.0082
CH_4	0.62	0.068	0.12	0.62	0.62
CO_2bio	1.20	0.13	0.24	1.20	1.20
Indirect N_2O	0.0013	0.00019	0.00033	0.0013	0.00044
Spreading					
NH_3	0.71	0.28	0.25	0.21	0.11
N_2O	0.036	0.039	0.036	0.036	0.036
NO	0.025	0.010	0.0086	0.0074	0.025
N_2	0	0	0	0	0
CH_4	0	0	0	0	0
CO_2bio	0	0	0	0	0
Indirect N_2O	0.0093	0.0036	0.0032	0.0028	0.0016
Total emissions					
NH_3	1.36	0.46	0.82	0.86	0.69
N_2O	0.073	0.076	0.073	0.073	0.073
NO	0.026	0.010	0.0094	0.0087	0.026
N_2	0.018	0.0041	0.012	0.018	0.018
CH_4	0.65	0.072	0.16	0.65	0.65
CO_2bio	1.26	0.14	0.30	1.26	1.26
Indirect N_2O	0.018	0.0060	0.011	0.011	0.0091

Table 77. Emissions from cattle manure management, BAT scenario Sweden (kg/ tonne slurry spread).

	Reference	Acidification in housing	Acidification at storage	Acidification when spread-ing	BAT
Housing					
NH_3	0.11	0.034	0.11	0.11	0.11
N_2O	0.0083	0.0083	0.0083	0.0083	0.0083
NO	0.00050	0.00020	0.00050	0.00050	0.00050
N_2	0.0070	0.0021	0.0070	0.0070	0.0070
CH_4	0.021	0.0062	0.021	0.021	0.021
CO_2bio	0.040	0.012	0.040	0.040	0.040
Indirect N_2O	0.0015	0.00044	0.0015	0.0015	0.0015
Storage					
NH_3	0.082	0.011	0.020	0.081	0.027
N_2O	0.019	0.019	0.019	0.019	0.019
NO	0.00047	0.000064	0.00012	0.00047	0.00047
N_2	0.0066	0.0009	0.0066	0.0066	0.0066
CH_4	0.39	0.117	0.15	0.39	0.39
CO_2bio	0.75	0.23	0.28	0.75	0.75
Indirect N_2O	0.0011	0.00014	0.00026	0.0010	0.00035
Spreading	Spreading				
NH_3	0.57	0.21	0.20	0.17	0.088
N_2O	0.030	0.031	0.030	0.030	0.030
NO	0.020	0.007	0.0069	0.0060	0.020
N_2	0	0	0	0	0
CH_4	0	0	0	0	0
CO_2bio	0	0	0	0	0
Indirect N_2O	0.0075	0.0027	0.0026	0.0022	0.0013
Total emissions					
NH_3	1.13	0.37	0.55	0.60	0.41
N_2O	0.077	0.079	0.077	0.077	0.077
NO	0.028	0.010	0.0101	0.0093	0.028
N_2	0.018	0.0041	0.017	0.018	0.018
CH_4	0.59	0.143	0.21	0.59	0.59
CO_2bio	1.13	0.28	0.40	1.13	1.13
Indirect N_2O	0.015	0.0049	0.0072	0.0078	0.0055

Table 78. Emissions from pig and cattle manure management, BAT scenario Sweden (kg/ tonne slurry spread).

	Reference	Acidification in housing	Acidification at storage	Acidification when spread-ing	BAT
Housing					
NH_3	0.16	0.049	0.16	0.16	0.16
N_2O	0.0087	0.0087	0.0087	0.0087	0.0087
NO	0.00052	0.00021	0.00052	0.00052	0.00052
N_2	0.0073	0.0022	0.0073	0.0073	0.0073
CH_4	0.022	0.0059	0.022	0.022	0.022
CO_2bio	0.042	0.0113	0.042	0.042	0.042
Indirect N_2O	0.0021	0.0006	0.0021	0.0021	0.0021
Storage					
NH_3	0.085	0.011	0.021	0.083	0.028
N_2O	0.020	0.020	0.020	0.020	0.020
NO	0.00049	0.000066	0.00012	0.00049	0.00049
N_2	0.0068	0.00093	0.0061	0.0068	0.0068
CH_4	0.42	0.11	0.14	0.42	0.42
CO_2bio	0.81	0.21	0.28	0.81	0.81
Indirect N_2O	0.0011	0.00015	0.00027	0.0011	0.00036
Spreading					
NH_3	0.58	0.21	0.20	0.18	0.09
N_2O	0.030	0.032	0.031	0.030	0.031
NO	0.020	0.0075	0.0071	0.0061	0.021
N_2	0	0	0	0	0
CH_4	0	0	0	0	0
CO_2bio	0	0	0	0	0
Indirect N_2O	0.0077	0.0028	0.0027	0.0023	0.0013
Total emissions					
NH_3	1.15	0.38	0.58	0.63	0.45
N_2O	0.076	0.079	0.077	0.076	0.077
NO	0.028	0.010	0.0100	0.0092	0.028
N_2	0.018	0.0041	0.016	0.018	0.018
CH_4	0.59	0.134	0.20	0.59	0.59
CO_2bio	1.15	0.26	0.39	1.15	1.15
Indirect N_2O	0.015	0.0050	0.0076	0.0082	0.0060

Nitrogen balance for base scenario, Sweden

Table 79. Nitrogen balance for base scenario BAT Sweden for total nitrogen, N-tot (kg/ tonne) for pig, cattle and total slurry

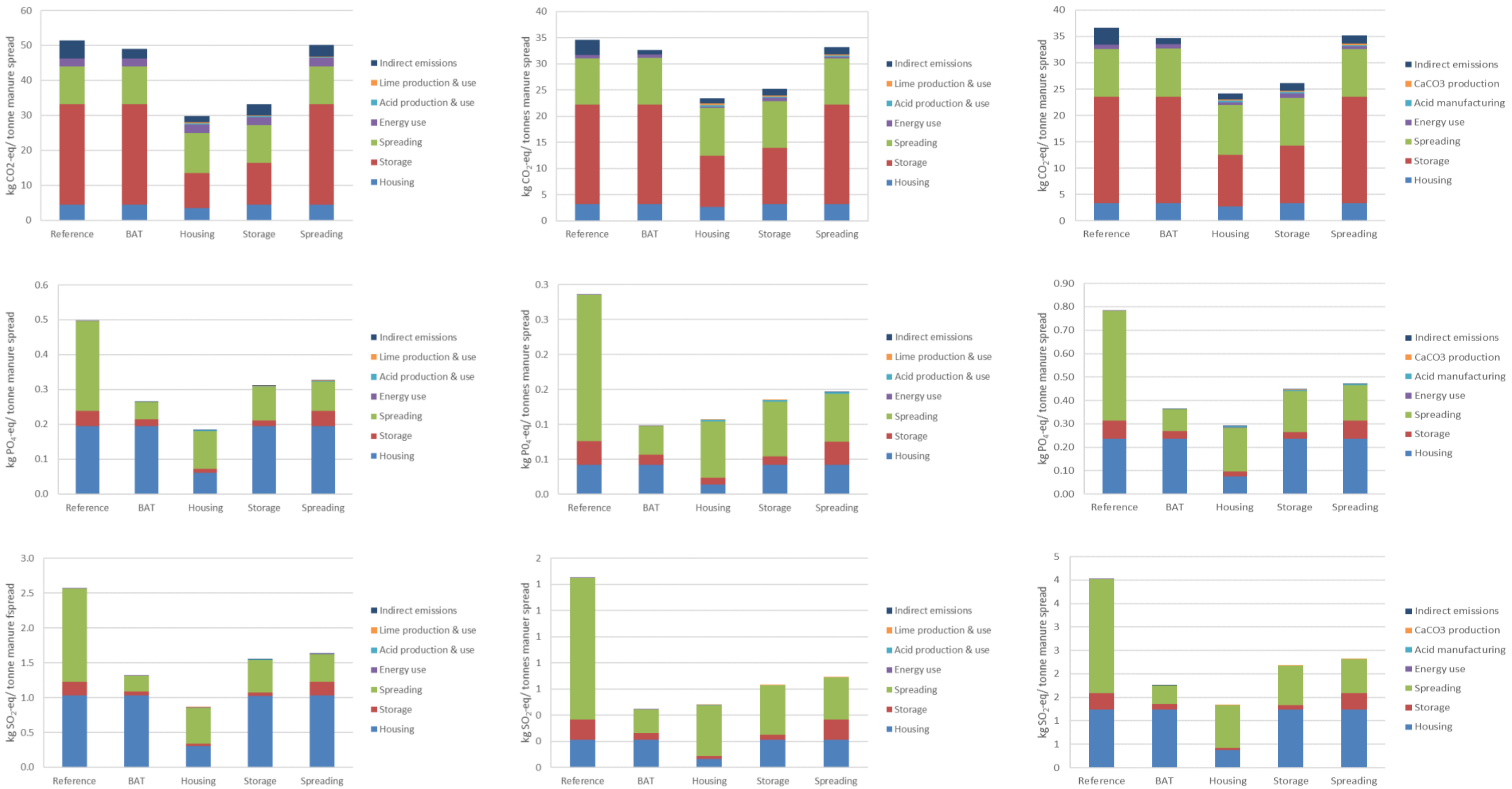
	From animal	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	6.96	4.75	4.57	3.96	77%
AC in housing	6.96	5.06	4.94	4.69	92%
AC at storage	6.96	4.75	4.63	4.40	86%
AC when spreading	6.96	4.75	4.57	4.36	85%
BAT	6.96	4.75	4.62	4.50	88%
Cattle slurry					
Reference	7.11	5.30	3.76	3.27	85%
AC in housing	7.11	5.38	3.88	3.69	96%
AC at storage	7.11	5.30	3.81	3.63	94%
AC when spreading	7.11	5.30	3.76	3.60	94%
BAT	7.11	5.30	3.81	3.71	96%
Pig and cattle slurry					
Reference	7.09	5.22	3.86	3.35	84%
AC in housing	7.09	5.35	4.02	3.83	96%
AC at storage	7.09	5.22	3.91	3.72	93%
AC when spreading	7.09	5.22	3.86	3.69	92%
BAT	7.09	5.22	3.90	3.80	95%

Table 80. Nitrogen balance for base scenario BAT Sweden for ammonium nitrogen, NH_4-N (kg/ tonne) for pig, cattle and total slurry

	From animal	From housing	from storage	To plant	Nitrogen efficiency
Pig slurry					
Reference	4.37	2.79	2.64	2.03	63%
AC in housing	4.37	3.11	3.03	2.77	87%
AC at storage	4.37	2.79	2.71	2.48	77%
AC when spreading	4.37	2.79	2.64	2.43	76%
BAT	4.37	2.79	2.70	2.57	80%
Cattle slurry					
Reference	4.28	3.05	2.13	1.63	70%
AC in housing	4.28	3.14	2.25	2.06	89%
AC at storage	4.28	3.05	2.18	1.99	86%
AC when spreading	4.28	3.05	2.13	1.97	85%
BAT	4.28	3.05	2.17	2.07	89%
Pig and cattle slurry					
Reference	4.30	3.01	2.19	1.68	69%
AC in housing	4.30	3.14	2.35	2.16	89%
AC at storage	4.30	3.01	2.24	2.05	85%
AC when spreading	4.30	3.01	2.19	2.02	83%
BAT	7.09	5.22	3.90	3.80	88%

Environmental impact BAT scenario Sweden

Figure 16. First column is pig slurry, second column is cattle slurry and third column are pig and cattle slurry



Baltic Slurry Acidification

www.balticslurry.eu

Summary of the project

Baltic Slurry Acidification is an agro-environmental project funded by the Interreg Baltic Sea Region program in the priority area Natural Resources focusing on Clear Waters. The aim of the project is to reduce nitrogen loss from animal production by testing, demonstrating and promoting the use of slurry acidification techniques in countries around the Baltic Sea.

Summary of the report

This report presents a systems analysis of how implementing slurry acidification techniques on farms in the Baltic Sea Region will affect the environment. In this analysis, four manure handling scenarios are evaluated: 1) a reference scenario with no acidification, 2) In-house acidification, 3) long-term in-storage acidification and 4) In-field acidification. The relative environmental impact of these scenarios on Climate Change, Eutrophication and Acidification are evaluated. Country level assessments of widespread SAT implementation on ammonia emissions were also made.

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