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Ammonia emissions in Sweden

Inventories, projections and potential for reduction

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Summary

Ammonia has been identified as a major atmospheric pollutant which causes threats to human health, and detrimental environmental effects. Ammonia emissions mainly derive from agricultural sources and the agricultural sector therefore has the largest potential to reduce emissions of ammonia.

The aim of this study was to compare ammonia emission estimates and projections from the national Swedish inventory (SMED) and the GAINS model. A further objective was to identify the most promising policy options and best available techniques to reduce ammonia emissions from agricultural practices in Sweden, and thus reducing their harmful environmental effects.

The most recent ammonia estimate for Sweden from SMED (representing year 2015) was 60.3 ktonnes, and the majority of these emissions, 51.7 ktonnes (86 %), derived from agricultural sources. According to the results of the GAINS model scenario CLE, the ammonia estimate for Sweden (year 2015) was 49.0 ktonnes, and the majority of these emissions, 38.5 ktonnes (79 %), derived from agricultural sources. In general, the emission estimate from SMED is higher compared with GAINS (about 20 % higher for the year 2015). These differences are due to different emission factors, statistics and abatement measures being applied.

Also the forecasts are different. The latest SMED forecast for 2030 (calculated 2015) is at the same level as GAINS' MTFR-scenario (with maximum technically feasible reductions) for 2030.

The most cost effective ammonia abatement measures in Sweden are low nitrogen feed, low ammonia application of manure, and low emission manure storage. Measures to reduce housing emissions, e.g. designing the stable to reduce the surface and time manure is exposed to air, are also rather cost effective, particularly for new stables.

An important policy challenge with a great potential to reduce overall emissions of ammonia is measures to reduce meat and dairy consumption and measures to reduce food waste. In this context it is also important to consider the effect of emissions derived in other countries due to increased import.

Recommended policy action:

- Ammonia experts have concluded that (expressed as kg of nitrogen), abatement of ammonia emissions is rather cheap, compared with further abatement of nitrogen oxides (NO_x). In order to reduce overall nitrogen losses, policy efforts should be targeted at technical measures within the agricultural sector, which are more cost effective compared with nitrogen reductions within other sectors already subject to more stringent regulations.
- Main focus should be on implementing the most cost effective, practical and feasible measures (e.g. low protein feeding and low ammonia emission storage and spreading of manure). As long as the most practical and feasible measures (which do not lead to other negative environmental effects) are not fully applied, a further focus on the more demanding approaches might not be needed, such as acidification of slurry or low emission techniques in new and largely rebuilt pig and poultry houses, e.g. air purification.
- Policy makers should consider that small-scale farmers may have to receive financial or technical assistance in order to implement measures.
- The advisory Program "Greppa näringen" (Focus on Nutrients), in combination with support schemes and environmental investments within the Swedish Rural Development Program, has proven to be successful and should continue.

- An information campaign regarding changes in consumption behaviour should be launched, highlighting the benefits for the environment, health and global equality.
- A strict regulatory framework has proven to be effective in reducing ammonia emissions from the agricultural sector in Denmark. In Sweden there is a potential to expand the current rules and recommendations. However the effect (economic and on other pollutants and effects) need to be considered and further investigated first. Suggestions on new or extended rules and regulations:
  - Current regulations on coverage of slurry could be extended also to include digested manure.
  - Type of cover could be regulated to encourage more effective covers.
  - Regulations that manure spread on bare soil should be incorporated within 4 hours could be extended also to include digested manure.
  - The geographical area for regulations on manure application could be extended.
  - Rules and regulations regarding new livestock houses could be more stringent compared with existing livestock houses.
  - Setting rules demanding air purification in conjunction with permissions for new or expanded operations.

Further work should concentrate on:

- The SMED inventory is better adapted to Swedish agricultural conditions, but the GAINS model is more flexible for calculating and changing abatement measures, and to include the cost of different abatement measures. It is important to understand the differences between SMED and GAINS, both regarding inventories and forecasts, in order to reduce uncertainties in the Swedish ammonia calculation, e.g. why the livestock numbers in the SMED-inventory and the GAINS-inventory are different. Furthermore, the differences in forecasts, particularly the latest SMED-forecast (made in 2015) which is at the same level as GAINS MTFR-scenario for year 2030, need to be explored further.
- The complex interactions, synergies and trade-offs between different pollutants and environmental effects demands more research to find the right balance between potential conflicting interest, including e.g. emission savings, ethical values, costs and other environmental effects. Economy and profitability are important factors affecting type of production system and abatement measures chosen and design of support system for agriculture.
- From a policy perspective, in order to further motivate abatement of ammonia from agriculture, it is important to identify knowledge gaps as well as possible overlaps and gaps in existing policies on reactive nitrogen.

Sammanfattning

Ammoniak är ett luftförorenande ämne som påverkar både människors hälsa och ger skadlig miljöpåverkan. Ammoniakutsläpp kommer huvudsakligen från jordbruket och jordbrukssektorn har därför den största potentialen att minska utsläppen av ammoniak.

Syftet med den här studien var att jämföra uppskattningar och prognoser för ammoniakutsläpp från den nationella svenska inventeringen (SMED) och GAINS-modellen. Ett annat syfte var att identifiera de mest lovande politiska styrmedlen och bästa tillgängliga teknik för att minska ammoniakutsläpp från jordbruket i Sverige och därigenom minska de skadliga miljöeffekterna.

Den senaste ammoniakuppskattningen för Sverige från SMED (år 2015) var 60,3 kilo ton, och majoriteten av dessa utsläpp, 51.7 kilo ton (86 %), kom från jordbrukskällor. Enligt resultaten från GAINS-modellens CLE-scenario, var ammoniakuppskattningen för Sverige (år 2015) 49,0 kilo ton, och majoriteten av dessa utsläpp, 38,5 kilo ton (79 %), kom från jordbrukskällor. Generellt sett är emissionsuppskattningen från SMED högre jämfört med GAINS (ungefär 20 % högre för år 2015). Dessa skillnader beror på att det statistiska underlaget ser olika ut, samt att man har använt sig av olika emissionsfaktorer och antagit olika utsläppsminskningsstrategier.

Även prognoserna skiljer sig åt. Den senaste SMED-prognosen för 2030 (beräknad 2015) ligger på samma nivå som GAINS MTFR-scenario (med maximalt tekniskt genomförbara minskningar) år 2030.

De mest kostnadseffektiva åtgärderna för minskade ammoniakutsläpp från jordbruket i Sverige är att balansera proteinhalten i djurfodret, val av metod för gödselspridning och hur gödsel lagras. Åtgärder för att minska utsläppen från stallbyggnaden, t.ex. hur stallet är utformat för att minska ytan och tiden som gödsel utsätts för luft, är också ganska kostnadseffektivt, särskilt för nya stall.

En viktig politisk utmaning med stor potential att minska de totala utsläppen av ammoniak i Sverige är åtgärder för att minska kött- och mjölkkonsumtionen och åtgärder för att minska matsvinnet. I detta sammanhang är det också viktigt att överväga effekten av utsläpp som har sitt ursprung i andra länder på grund av ökad import.

Rekommenderade åtgärder:

- För att minska de totala kväveförlusterna bör insatser riktas mot tekniska åtgärder inom jordbrukssektorn, vilka är mer kostnadseffektiva jämfört med kväveminskningar inom andra sektorer som redan omfattas av strängare bestämmelser. Ammoniakexperter har kommit fram till att (uttryckt som kilogram kväve) är minskningen av ammoniakutsläpp förhållandevis billig jämfört med ytterligare minskning av kväveoxider (NO_X).
- Huvudfokus bör vara att genomföra de mest kostnadseffektiva, praktiska och genomförbara åtgärderna först (t.ex. balansera proteinhalten i djurfodret och lämpliga metoder för lagring och spridning av gödsel). Så länge som de mest praktiska och genomförbara åtgärderna (som inte äventyrar andra viktiga miljöaspekter) inte tillämpas fullt ut, behöver man inte lägga något större fokus på de mer krävande tillvägagångssätten, såsom exempelvis surgörning av flytgödsel eller rening av frånluft från djurstallar med biofilter.
- Politiska beslutsfattare bör överväga att småskaliga jordbrukare bör få finansiellt eller tekniskt bistånd för att genomföra åtgärder.
- Det rådgivande programmet ”Greppa näringen” i kombination med stöd och ersättningar från det svenska Landsbygdsprogrammet har visat sig vara framgångsrikt och bör fortsätta.
- En informationskampanj om förändringar i konsumtionsbeteendet (angående diet och matsvinn) bör lanseras, för att belysa fördelarna för miljö, hälsa och global jämlikhet.

- Ett strikt regelverk har visat sig vara effektivt för att minska ammoniakutläppen från jordbrukssektorn i Danmark. I Sverige finns det potential att utöka de nuvarande reglerna och rekommendationerna. Effekten av ytterligare regler måste emellertid först beaktas och undersökas, både ur ekonomisk synvinkel och hur andra föroreningar och miljöproblem påverkas. Här ges några förslag på nya eller utvidgade regler och föreskrifter:
    - Nuvarande regler om täckning av gödsel kan utökas till att också omfatta rötat gödsel.
    - Typ av metod för att täcka flytgödsel kan regleras för att uppmuntra mer effektiva typer av täckning.
    - Regeln om att gödsel som sprids på barmark bör införlivas inom 4 timmar kan utökas till att också omfatta rötat gödsel.
    - Det geografiska området för bestämmelser om metoder för gödselspridning skulle kunna utökas.
    - Regler och bestämmelser för nya djurstallar skulle kunna vara strängare jämfört med befintliga djurstallar.
    - Regler som kräver luftrening i samband med tillståndsprövning för nya eller utvidgade verksamheter skulle kunna införas.

Framtida arbete bör fokusera på:

- SMED-inventeringen är bättre anpassad till svenska jordbruksförhållanden, men GAINS-modellen är mer flexibel för beräkning och förändring av utsläppsminskningsstrategier och för att inkludera kostnader för olika åtgärder. Det är viktigt att förstå vad skillnaderna mellan SMED och GAINS beror på, både avseende uppskattningarna av dagens utsläppsnivåer och framtida prognoser, för att minska osäkerheten i den svenska beräkningen av ammoniak-utsläpp. Exempelvis så skiljer sig djurantalet i SMED- och GAINS-beräkningen. Dessutom måste skillnaderna i prognoserna, särskilt den senaste SMED-prognosen (som beräknades 2015), som ligger på samma nivå som GAINS MTFR-scenario för år 2030, undersökas ytterligare.
- De komplexa sambanden, synergierna och avvägningarna mellan olika föroreningar och miljöeffekter kräver mer forskning för att hitta rätt balans mellan potentiellt motstridiga intressen, som till exempel utsläppsminskningar, etiska värden, kostnader och annan miljöpåverkan. Ekonomi och lönsamhet är viktiga faktorer som påverkar typ av produktions-system, val av åtgärder och utformning av utsläppsminskningsstrategier för jordbruket.
- För att ytterligare motivera minskningen av ammoniak från jordbruket är det viktigt att identifiera kunskapsbrister och möjliga överlappningar och luckor i befintliga styrmedel som reglerar kväveutsläpp.

1 Background

Agriculture is an important source of reactive nitrogen through emissions of ammonia, nitrate and nitrous oxides, see Figure 1. Ammonia emissions have been identified as a major atmospheric pollutant which causes threats to human health, and detrimental environmental effects (Galloway et al. 2003; Krupa, 2003; Sutton et al. 2009a; 2009b¸2011; 2013). Ammonia contributes to the formation of secondary inorganic aerosols, a major constituent of particulate matter (PM) which may cause health problems. Other environmental effects of ammonia include the deposition of excess nutrients and acidifying substances on soils, which is a threat to biodiversity and may result in both soil acidification and nitrogen saturation. Excess loads of nutrients to surface waters may result in eutrophication of both fresh water and coastal ecosystems. Ammonia emissions also indirectly contribute to climate change through contributions to nitrous oxide, which is a greenhouse gas.

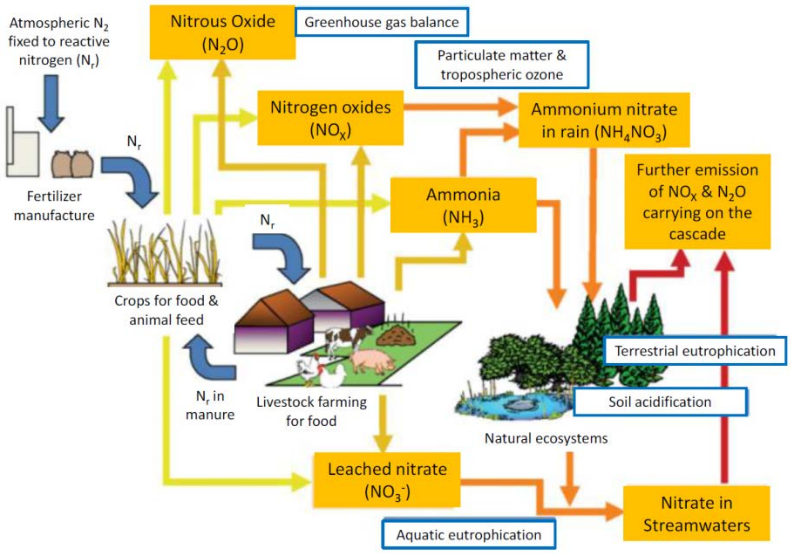


Figure 1. A simplified view of the nitrogen cycle and its cascading effects. Source: Sutton et al. (2011).

The most important international agreements regarding ammonia emissions include the Gothenburg Protocol and the EU National Emissions Ceilings (NEC) Directive. Through the Gothenburg Protocol, Sweden has committed to reduce ammonia emissions by 15 % by 2020, from the base year (2005) level of 57 ktonnes as reported from SMED to NEC and CLRTAP (European Parliament, 2016). On 30 June, 2016, a new NEC directive was agreed (AirClim, 2016). Through the NEC-directive, Sweden has agreed to reduce ammonia emissions by 17 % by 2030 compared with the base year 2005. The reduction commitments between 2020 and 2030 are identical in the NEC-directive and the Gothenburg Protocol.

The targets for reduction of ammonia emissions in the international environmental agreements have not been as ambitious as for SO_2 and NO_x. Therefore the relative contribution of ammonia to impacts of nitrogen and acidity is increasing. By 2020 it is estimated that ammonia will be the largest single contributor to acidification, eutrophication and secondary particulate matter formation in Europe (Reis et al., 2015). Furthermore projections indicate relatively small emission reductions in the coming years. It is clear that action and incentives are necessary to stimulate further reductions. Today there are many measures available both at sectoral as well as at farm level that could be taken, but these measures are not always viable, and the reasons for not applying these measures need to be identified and dealt with.

1.1 Aim of the project

The aim of this study was to compare ammonia emission estimates and projections from the national Swedish inventory and GAINS model scenarios. A further objective was to identify the most promising policy options and best available techniques to reduce ammonia emissions from agricultural practices in Sweden, and thus reducing their harmful environmental effects.

2 Ammonia emissions in Sweden

There are two ways to calculate ammonia emissions in Sweden (of relevance for this report):

- SMED – Swedish Environmental Emissions Data (www.smed.se) – is responsible for the annual national ammonia inventory for Sweden, see Section 2.1.
- GAINS – The GAINS-model is an international emission model calculating emissions every 5th year from 2005 to 2030 based on different scenarios, see Section 2.2.

2.1 The National Swedish inventory - SMED

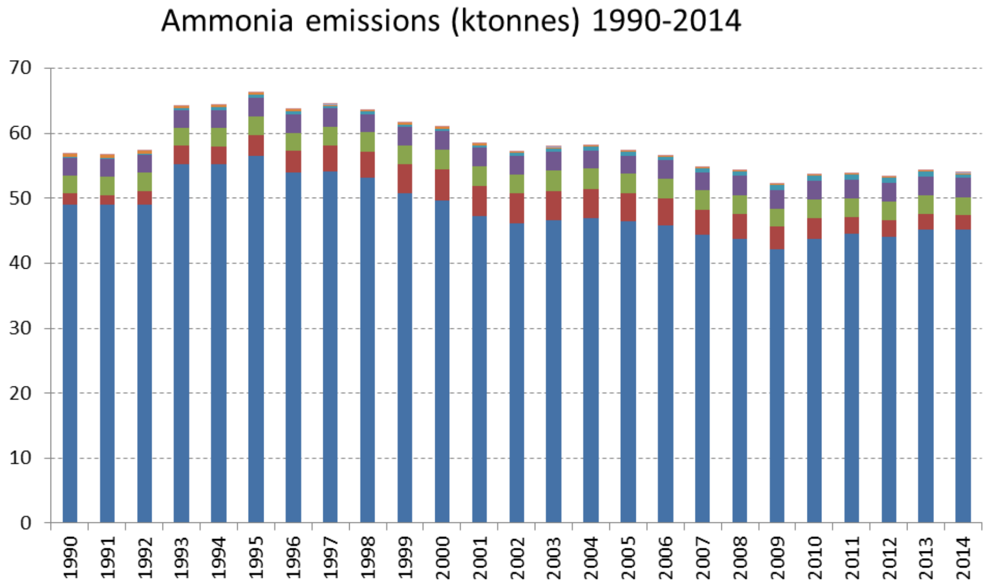
Ammonia emissions from agriculture in Sweden are calculated within the Swedish emission consortium SMED (Swedish Environmental Emissions Data, www.smed.se) by Statistics Sweden. Ammonia estimates in Sweden have been calculated from year 1990 and onwards, see Figure 2.

The latest ammonia estimate for Sweden (representing year 2015) was 60.3 ktonnes, and the majority of these emissions, 51.7 ktonnes (86 %), derived from agricultural sources (SEPA, 2017).

Ammonia emissions have been reduced by about 8 % since 1990. The reduction in emissions is mainly a result of declined livestock numbers, reduced use of inorganic fertilizers and a more effective production. Between 2014 and 2015 emissions increased by 1 %.

During 2016 the ammonia calculation model was improved (SEPA, 2017), which resulted in higher levels of ammonia emissions (Figure 2b) compared with previous estimates (Figure 2a). The previous ammonia calculation (Figure 2a) had a time series break between 1994 and 1995, but the recalculation enables SMED to provide a consistent time series from 1990 and onwards.

a)



b)

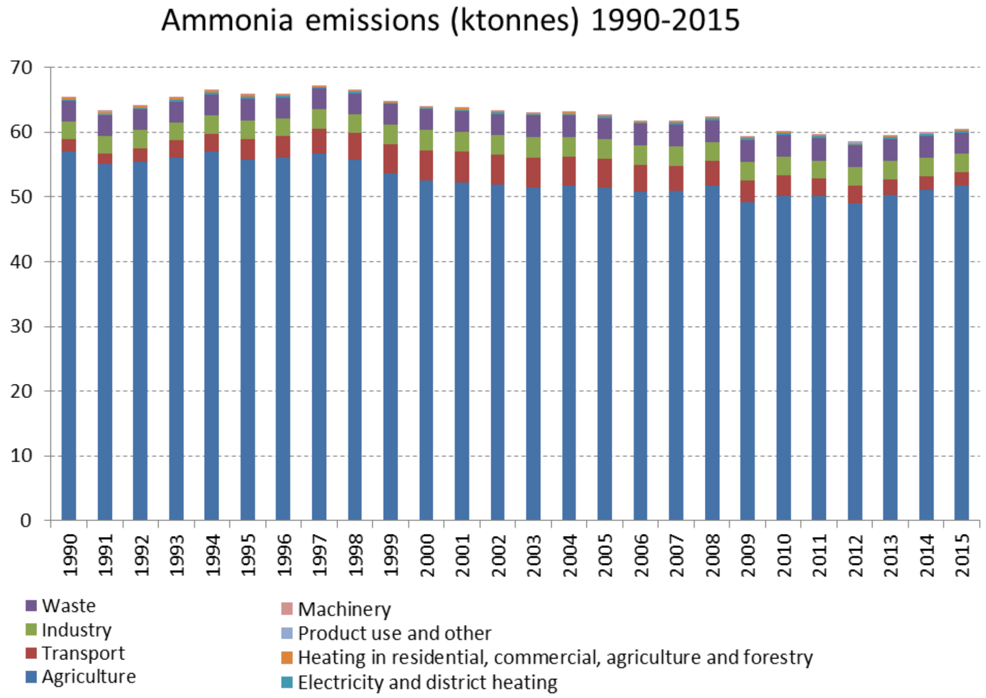


Figure 2. Ammonia emissions in Sweden (ktonnes), a) 1990-2014 (SMED inventory 2016), b) 1990-2015 (SMED inventory 2017). Data from SMED reported to NEC and CLRTAP 2017. Source: SEPA (2016; 2017), Swedish Environmental Protection Agency, http://www.utslappshandel.se/Sa-mar-miljon/Statistik-A-O/Ammoniak

The calculation improvements in the most recent ammonia inventory (Figure 2b) include more detailed activity data from the fertilizer and animal manure survey and updated data on the distribution of different manure management systems. Furthermore, the calculation includes more livestock categories. For instance, previously the inventory included only two cattle categories (dairy cattle and non-dairy cattle), which has now been extended also to include different non-dairy categories, i.e. suckler cows, heifers, bulls and steers and calves. Furthermore, the nitrogen excretion rates have been reviewed, to ensure consistency in excretion rates with the Swedish nutrient balances reported to Eurostat.

2.2 GAINS Europe (Scandinavia)

The GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model, developed by the International Institute of Applied Systems Analysis (IIASA), is applied to conduct integrated assessment model analysis in support of the Gothenburg Protocol (Klimont and Winiwarter, 2015). The GAINS model calculates ammonia emissions every 5th year from year 2005 to 2030 based on different scenarios. This report mainly focuses on two scenarios (Amann, 2015):

- CLE - Current legislation (WPE_2014_CLE) - This scenario incorporates full implementation of national legislations as of 2013, including known implementation failures.

- MTFR - Maximum technically feasible reductions (WPE_2014_MTFR) – This scenario incorporates all currently available control technologies. It is subject to site-specific application limits. It disregards implementation barriers, costs, institutional issues, etc.

Figure 3 shows the GAINS-online emission calculation based on the CLE-scenario. For year 2030 also the result of the MTFR-scenario is shown. The ammonia estimate for Sweden (year 2015) was 49.0 ktonnes, and the majority of these emissions, 38.5 ktonnes (79 %), derived from agricultural sources. According to GAINS CLE-scenario, ammonia emissions in Sweden have been reduced by about 9 % since 2005. However, in 2030 the emissions are expected to remain at about the same level as today. However, if the MTFR-scenario is implemented, ammonia emissions in Sweden will be about 36 ktonnes in 2030, which represents a reduction by 26 % compared with today. This reduction reflects the implementation of measures to the point which is technically feasible.

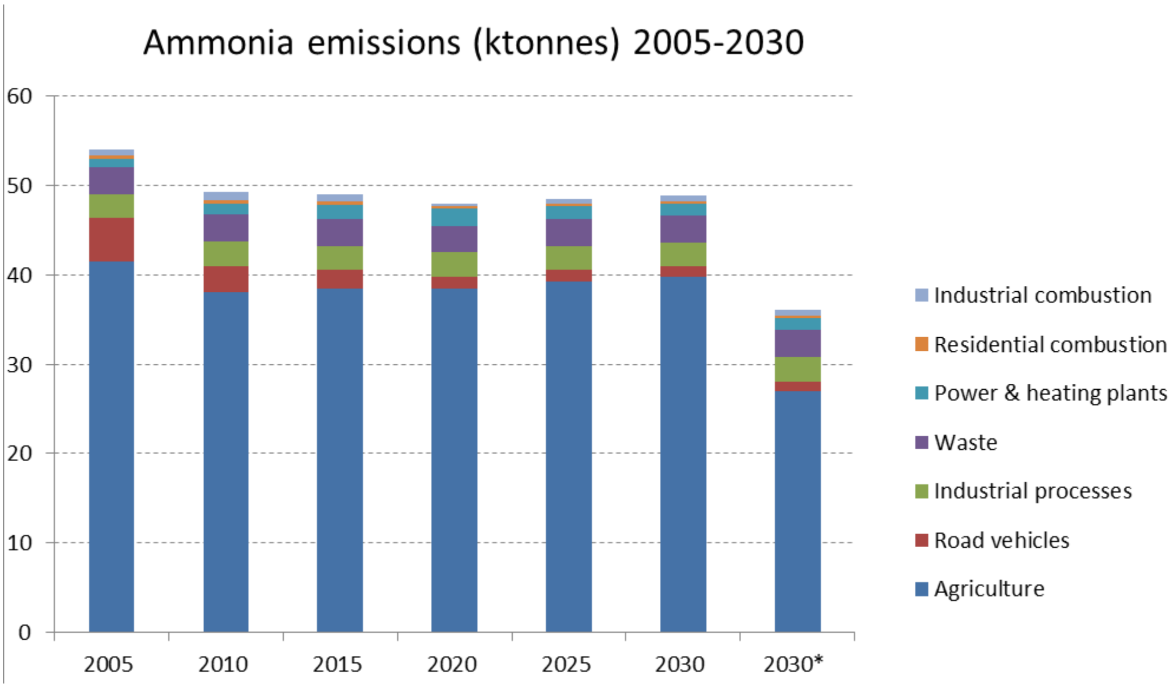


Figure 3. Ammonia emissions in Sweden (ktonnes), 2005-2030 as calculated by the GAINS-online model (CLE-scenario). For 2030, also ammonia emissions from the *MFTR-scenario is shown. Source: GAINS-online model (http://gains.iiasa.ac.at/gains/EUN/index.login?logout=1).

2.3 Comparing ammonia emissions in SMED and GAINS

A comparison between the national Swedish ammonia inventory by SMED (SEPA, 2017) and the GAINS-online calculation (CLE-scenario) is shown in Table 1 for year 2005, 2010 and 2015. Ammonia emissions from GAINS CLE-scenario were lower for all three years (14 %, 18 % and 19 % lower, respectively) compared with the national Swedish inventory (SMED). Agricultural ammonia emissions were 19 %, 24 % and 26 % lower in GAINS CLE. The non-agricultural emissions on the other hand were higher (13 %, 13 % and 22 % respectively). The differences regarding agricultural emissions are likely due to differences both regarding livestock numbers, emission potentials and abatement measures applied, see section 2.3.1. and 2.3.2.

Table 1. Comparison of ammonia emissions (thousand tonnes) from the GAINS CLE-scenario and the SMED inventory for year 2005 and 2010.

	2005			2010			2015		
	SMED	GAINS	Diff	SMED	GAINS	Diff	SMED	GAINS	Diff
Agri	51.5	41.5	-19 %	50.2	38.0	-24 %	51.7	38.5	-26 %
Non-agri	11.1	12.5	+13 %	9.9	11.2	+13 %	8.6	10.5	+22 %
Total	62.6	54.0	-14 %	60.1	49.2	-18 %	60.3	49.0	-19 %

2.3.1 Livestock numbers are different

Livestock numbers (year 2005, 2010 and 2015) applied in the GAINS model scenario CLE and in SMED (SEPA, 2017) are shown in Table 2. Number of cattle is similar in the two inventories. Some of the other livestock categories and years are rather different, particularly laying hens 2015 (34 % less in GAINS), other poultry 2010 (27 % more in GAINS), sheep and goats 2010 (22 % less in GAINS) and fur animals 2010 and 2015 (59 % and 36 % more in GAINS).

Table 2. Number of livestock [1000 livestock] as predicted by the Swedish national ammonia emission inventory, SMED (SEPA, 2017) and by the GAINS model scenario CLE for year 2005, 2010 and 2015.

	2005			2010			2015		
	SMED	GAINS	Diff	SMED	GAINS	Diff	SMED	GAINS	Diff
Dairy cows	393	391	-1%	348	348	0%	348	339	-3%
Other cattle	1212	1143	-6%	1189	1126	-5%	1137	1082	-5%
Pigs	1811	1797	-1%	1520	1607	6%	1356	1526	13%
Laying hens	5100	5065	-1%	6061	6037	0%	7571	4996	-34%
Other poultry	10275	11435	11%	10936	13904	27%	12966	13747	6%
Sheep (and goats)	477	514	8%	571	448	-22%	601	512	-15%
Horses	323	300	-7%	363	300	-17%	363	300	-17%
Fur animals	290	286	-1%	180	286	59%	210	286	36%

Number of livestock included in an agricultural ammonia emission estimate has a big impact on the emission calculation result, and it is therefore important to understand why the numbers are so different. For instance, if the number of laying hens is underestimated in the GAINS model, also ammonia emissions from poultry in Sweden are underestimated. These differences need to be further investigated in order to reduce uncertainties in the Swedish ammonia calculation.

2.3.2 Emission factors and abatement measures are different

The method to calculate emissions is different in the two approaches (see Appendix 1 and 2); therefore it is difficult to compare the emission factors applied in SMED with the emission factors applied in the GAINS model scenarios.

SMED calculates emissions based on type of livestock, emission stage, emission factor and type of manure management (SEPA, 2017). Abatement measures are therefore indirectly taken into consideration based on statistics, surveys and emission factors applied.

The GAINS approach calculates emissions based on livestock category, abatement technique, emission stage, livestock population, emission factor, reduction potential of abatement technique and implementation rate of the abatement technique (Klimont and Winiwarter, 2011). The emission factors therefore depend on type and implementation rate of abatement. Furthermore, ammonia factors of each manure management stage (housing-->storage-->spreading) are influenced by the nitrogen losses at previous stages.

The emission calculations in the GAINS model scenarios are more flexible for calculating and changing abatement measures, because the model includes parameters on implementation rate and reduction potential for the different abatement techniques. On the other hand, the SMED inventory is better adapted to Swedish agricultural conditions.

2.4 Future emissions of ammonia in Sweden

Ammonia emissions in Sweden have decreased by about 8 % since 1990, and about 10 % since the peak (67.1 ktonnes) in 1997 (SEPA, 2017). Agricultural ammonia emissions have decreased by about 9 % during the same time period, from 57,1 ktonnes in 1990 to 51.7 ktonnes year 2015. Agricultural ammonia emissions are expected to continue to decrease due to a reduced number of livestock, a transition to liquid manure systems and better manure handling technology. However, ammonia forecasts are very uncertain and dependent on future agricultural policies. EU agricultural policies and prices have a big influence. Future ammonia emissions depend on the development of import and how the Swedish production of dairy and meat develops. National policy measures may be necessary to counteract an increase of imported products in the future.

The latest SMED forecast (2015) predicts a greater ammonia emission reduction (35 ktonnes) compared with the previous forecast from 2013 (48 ktonnes) for total ammonia emissions 2030. Agricultural emissions are expected to be 30 ktonnes (forecast 2015) and 42 ktonnes (forecast 2013), see Figure 4. The reason for the big differences in the SMED forecast from 2013 and 2015 are due to different future scenarios on activity data for the agricultural sector that have been applied (see Appendix 2).

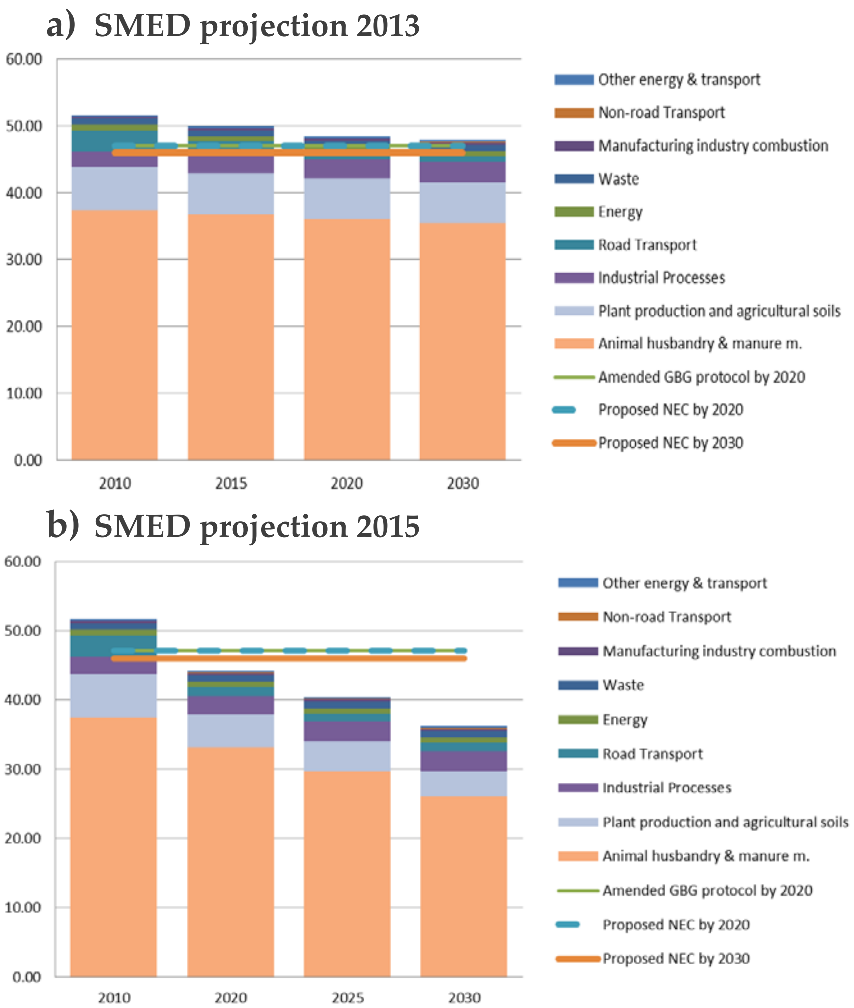


Figure 4. SMED emission projections for Sweden. a) year 2013, b) year 2015. Note that the years on the y-axel are not identical in the two figures. Source: http://cdr.eionet.europa.eu/se/eu/colp93lqa/

For cattle, emissions have decreased by about 30 % between 1995 and 2013, see Figure 5. The emissions are predicted to decrease further, by more than half (56 %) until 2030. Ammonia emissions from pigs have decreased by about 42 % between 1995 and 2013. However, according to the SMED prediction (2015), the emissions are expected to increase through to 2030. For other livestock, emissions are relatively constant until 2009, increase by 35 % until 2013, and are then expected to decrease slightly until 2020 and stay at this level until 2030. Ammonia emissions from mineral fertilizers have been at a relatively constant level between 1995 and 2013, but are expected to decrease by almost 40 % until 2030.

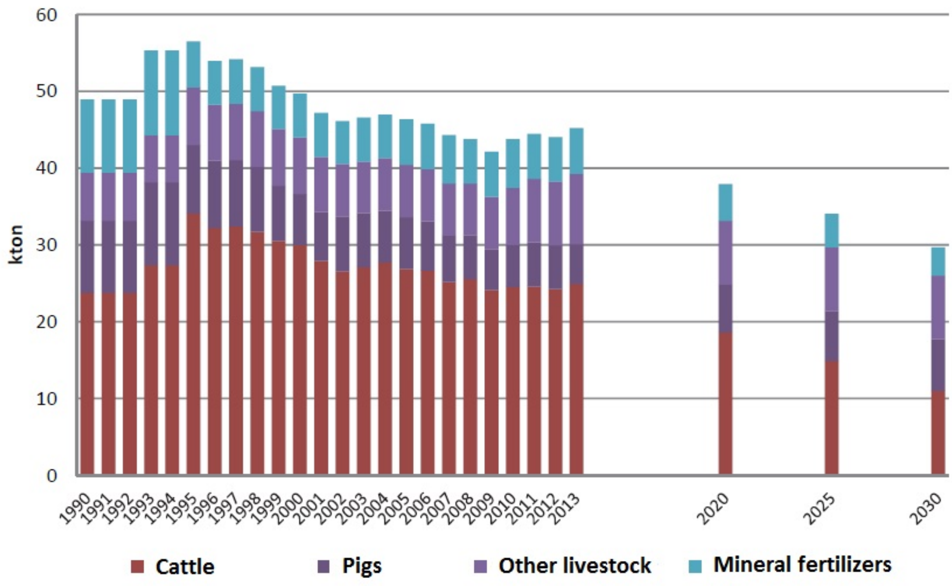


Figure 5. Ammonia emissions from agriculture 1990-2013, and a prognosis for 2020, 2025 and 2030, based on the SMED projection from 2015. Source: SEPA (2015b). Note: Ammonia emissions during 1990-2014 have been recalculated in the latest SMED inventory for ammonia (SEPA, 2017), hence the emissions in this diagram are different from the emissions presented in Figure 2b.

The GAINS model predicts future ammonia emissions in Sweden based on different scenarios. Table 3 presents the emission calculation for the CLE-scenario, and for year 2030, also the result of the MTFR-scenario is presented. In the CLE-scenario, ammonia emissions are predicted to remain at the same level as today (2015), about 49 kt/yr, in 2030. In the MTFR-scenario, on the other hand, ammonia emissions decrease by 26 % compared with year 2015 to 36.1 kt/yr in 2030.

Regarding agricultural ammonia emissions, the GAINS CLE-scenario predicts an increase by 3 %, from 38.5 kt/yr 2015 to 39.8 kt/yr year 2030. In the MTFR-scenario, agricultural emissions decrease by 30 % compared with year 2015 to 27 kt/yr in 2030. This can be compared with the national forecast (SMED) predicting 30 and 42 ktonnes per year by 2030, depending on SMED projection applied, see Table 4.

Table 3. Ammonia emissions in Sweden 2005-2030, as calculated by the GAINS model for the CLE-scenario (Current legislation). For 2030 also the results of the MTFR-scenario (Maximum technically feasible emission reduction) is presented.

NH3 [kt/yr] , Sweden	2005	2010	2015	2020	2025	2030	2030 *
Power & heating plants	0.9	1.3	1.6	1.9	1.5	1.3	1.3
Fuel conversion	0	0	0	0	0	0	0
Residential combustion	0.4	0.4	0.4	0.3	0.3	0.3	0.3
Industrial combustion	0.7	0.8	0.8	0.3	0.5	0.7	0.7
Industrial processes	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Road vehicles	4.8	3	2	1.4	1.2	1.1	1.1
Non-road machinery	0	0	0	0	0	0	0
Agriculture	41.5	38	38.5	38.4	39.3	39.8	27
Waste	3	3	3	3	3	3	3
Sum	**54**	**49.2**	**49**	**48.1**	**48.7**	**48.9**	**36.1**

The GAINS scenario based on current legislation is more pessimistic and does not predict any ammonia reduction until year 2030. However, assuming maximum technically feasible emission reduction in GAINS, would reduce ammonia emissions by 26 % compared with today's (2015) emissions. This reduction is still smaller compared with the latest SMED forecast. This indicates that either the latest SMED forecast is too optimistic regarding ammonia reduction in Sweden, or the GAINS model scenario fails to incorporate the expected decrease in livestock numbers and/or important emission reduction strategies which are technically feasible in Sweden. This issue needs to be explored further.

Table 4 summarises predicted ammonia emissions in Sweden year 2030. The 2015 SMED-forecast is at the same emission level as the GAINS scenario with maximum technically feasible emission reduction. The previous SMED-forecast from 2013 on the other hand, is at the same level as the CLE-scenario in GAINS. Only looking at agricultural emissions, GAINS MTFR-scenario predicts the lowest ammonia emission year 2030, followed by the SMED forecast 2015. The highest agricultural ammonia emission is predicted by the SMED-forecast 2013. Non-agricultural ammonia emissions are generally much higher in GAINS compared with SMED.

According to the new NEC-directive, ammonia emissions in Sweden should be reduced by 17 % between 2005 and 2030 (AirClim, 2016). A 17 % reduction in the SMED inventory (based on SEPA, 2015b) results in an ammonia level of 45 kt/yr by 2030 (compared with 52 ktonnes as predicted by SEPA (2017), see chapter 4.2). This goal (45 kt/yr) will be met by the SMED forecast from 2015, but not by the more pessimistic forecast from 2013, see Table 4 and Figure 4. The GAINS CLE-scenario, however, predicts that current legislation is not enough to reach the target, as a 17 % reduction from 2005 corresponds to 48 kt/yr. Hence, according to the GAINS prediction, more measures are needed to reduce ammonia emissions and to achieve the set air pollution targets. The difference between the two GAINS scenarios in Table 4 clearly shows that the biggest reduction potential regarding implementation of technical measures to reduce ammonia emissions lie in the agricultural sector.

Table 4. Ammonia emissions in Sweden year 2030 according to different forecasts and scenarios.

	Agricultural emissions	Non-agricultural emissions	Total emissions
SMED-forecast 2013	42	6	48
SMED-forecast 2015	30	7	36
GAINS, CLE-scenario	40	9	49
GAINS, MTFR-scenario	27	9	36

An Overview of differences and similarities between the SMED-approach and the GAINS-approach to estimate ammonia emissions and forecasts is provided in Table 5.

Table 5. Overview of differences and similarities between the SMED-approach and the GAINS-approach to estimate ammonia emissions and forecasts.

	Data	Methodology	Forecasts	Emissions	Strengths
SMED – The national Swedish inventory (Swedish Environmental Emissions Data, www.smed.se) Calculated by Statistics Sweden.	Livestock data, manure and fertilizer data and emission factors are based on national statistics, surveys and expert judgements. Livestock numbers are generally lower in SMED compared with GAINS.	Emissions are calculated based on type of livestock, emission stage, emission factor and type of manure management. Abatement measures are indirectly taken into consideration based on statistics, surveys and emission factors applied.	Based on future scenarios of livestock numbers and activity data (predicted by the Swedish Board of Agriculture).	Calculated annually from 1990 and onwards. The emissions are generally lower compared with the ammonia estimates within GAINS.	The SMED inventory is better adapted to Swedish agricultural conditions.
GAINS Greenhouse Gas and Air Pollution Interactions and Synergies Calculated by IIASA (the International Institute of Applied Systems Analysis)	Livestock data and manure and fertilizer data are based on international statistics (e.g. FAO and EUROSTAT) and national submissions to CLRP. Statistical sources have been validated by national experts. Emission factors depend on type and implementation rate of abatement.	Calculates emissions based on different scenarios. Emissions are based on livestock category, abatement technique, emission stage, livestock population, emission factor, reduction potential of abatement technique and implementation rate of the abatement technique. Ammonia factors of each manure management stage are influenced by the nitrogen losses at previous stages.	Based on national projections and work of international organizations (FOA, EFMA, IFA and OECD). The CAPRI model is applied (Common Agricultural Policy Regionalised Impact Modelling System, www.capri-model.org)	Calculated every 5th year from 2005 to 2030. The emissions are scenario specific. When comparing the CLE-scenario with SMED, the emissions are generally higher compared with the ammonia estimates within SMED.	The emission calculations are more flexible for calculating and changing abatement measures, and to include the cost of different abatement measures. Trade-offs and co-benefits with other pollutants are considered.

3 Measures and costs to reduce ammonia emissions

In the previous chapter we concluded that the agricultural sector has the largest potential to reduce emissions of ammonia. The complexity of ammonia is that measures need to consider potential downstream emissions as nitrogen conserved at each manure management stage is available for ammonia volatilisation in the next stage (animal feed and housing, manure storage and application of manure and mineral fertilisers to the fields).

Table 6 provides an overview of measures to reduce ammonia emissions in Sweden. The most cost effective abatement measures in Sweden are low nitrogen feed, low ammonia application of manure, and low emission manure storage (covering slurry and adding peat to manure). Measures to reduce housing emissions, e.g. designing the stable to reduce the surface and time manure is exposed to air, are also rather cost effective, particularly for new stables. Although measures such as air purification and reducing pH of liquid manure, are more expensive.

In Finland, Grönroos (2014) concluded that the choice of spreading method was considered to be most cost effective. Of the combined measures examined, the combination of enhanced feeding, covering storages and low ammonia spreading techniques were considered to be most efficient.

These conclusions correspond well with the conclusions of the UNECE Task Force on Reactive Nitrogen, who has provided a ranked list of priority measures for ammonia emission reduction, *"Top 5 Measures"*, with highest priority given first (Howard et al. (2015):

1. Low emission application of manures and fertilizers to land
2. Animal feeding strategies to reduce nitrogen excretion
3. Low emission techniques for all new stores
4. Strategies to improve nitrogen use efficiencies and reduce nitrogen surpluses
5. Low emission techniques in new and largely rebuilt pig and poultry housing

The UNECE Task Force on Reactive Nitrogen has recently summarized a guidance document regarding options for ammonia mitigation (UNECE, 2014; Bittman et al., 2014). However, this document is based on international research on farming systems that may not be applicable to Swedish conditions. Animal housing and manure removal systems in Sweden differ in certain respects from agricultural systems applied in other countries as a result of tradition, climate and animal welfare. Therefore some of the abatement measures recommended internationally may not be suitable for Swedish agricultural systems.

Table 6. Overview of measures to reduce ammonia emissions in Sweden (primarily based on cost estimates from Sweden and Denmark).

Measure	Reduction potential	Cost per kg N reduced	Comment
Low nitrogen feed	About 20 %	-0.5 – 0.5 € (van Vuuren et al., 2015).	Cost effective. Reduce ammonia emissions at many stages of manure management, from excretion in housing, through storage of manure to application on land. Also positive effects on animal health and indoor climate. This measure could be increased by providing information and counselling about low nitrogen feed.
Low emission housing	20-90 %	1-17 €* (Montalvo et al. 2015)	Measures to reduce the surface and time manure is exposed to air, e.g. design of the stable and manure handling system. Most cost effective for new stables. This measure could be increased through rules and regulations regarding new livestock houses.
Air purification	About 60 % (at 20% of the ventilation capacity)	3-17 € (NIRAS Kons, 2009)	Today air scrubbers and other technologies to clean exhaust air from livestock buildings hardly occur in Sweden. This measure could be increased by setting rules and demanding air purification in conjunction with permissions for new or expanded operations.
Covered storage	50-95 % depending on type of cover	0.5-2 € (SBA, 2010)	Today a majority of slurry and urine containers in Sweden are covered. The reduction emission potential lies in applying more effective covers than natural crusts. There are regulations regarding cover of slurry and urine containers in southern Sweden. This measure would increase if also covers for digested manure were required, and if type of cover was regulated (more effective than natural crusts).
Low ammonia application of manure (and urea)	45-90 % depending on type of manure and time after spreading (< 4 h)	About 0.5 € (SBA, 2010)	Cost effective. Southern Sweden has regulations that slurry and manure spread on bare soil should be incorporated within 4 hours. Also urea should be incorporated within 4 hours. The Swedish Board of Agriculture suggests that these regulations should be extended also to include urine and digested manure. Furthermore the geographical area could also be extended.
Using peat during storage of solid manure	About 50 %	About 0.5 € (SBA, 2010)	Cost effective. An effective method which does not require any large investments. Advantages include more easily spread manure and a better housing environment and animal health. A disadvantage is the trade off with climate change effects and other environmental effects of increased peat extraction. The use of peat as litter is very limited in Sweden today, but this measure could be increased by providing information and counselling, to facilitate contacts with peat producers or by offering subsidies for farmers using at least 50 % peat as litter.
Anaerobic digestion of manure	Small	-	Expensive, but an investment support for manure digestion plants exists. Digestion provides better control of the nutrient content of the manure, which in turn increases precision during spreading. Therefore emissions of ammonia, methane and nitrous oxide are smaller compared with spreading of undigested manure. Furthermore, digested manure smells much less than fresh manure when it is spread. The production of biogas also results in savings of carbon dioxides.
Acidification of liquid manure	About 80 % during storage and 70 % during spreading	3-14 € (NIRAS Kons, 2009)	Difficult to implement in Sweden because this measure requires liquid manure systems which are not common in Sweden. Although methane emissions are being reduced, this measure discourages the development of biogas production, which is even more effective regarding the reduction of greenhouse gases. Information activities and subsidies could be possible instruments to encourage the use of acidifying substances in Sweden.

*Includes expensive measures such as air purification.

3.1 Emission control options in the GAINS model

In the GAINS model, five control measures can be applied at different stages of production for the different livestock categories, low nitrogen feed, low emission housing, air purifiction, covered storage and low ammonia application of manure and urea, see Table 7.

Table 7. Emission control options for ammonia in agriculture in the GAINS model. Source: adapted from Wagner et al. 2011.

	Feed	Housing		Storage	Application	
Livestock category	Low nitrogen feed	Low emission housing	Air purification	Covered storage*	Low ammonia application of manure*	Low ammonia application of urea
Dairy cows	X	X		X	X	
Other cattle		X		X	X	
Pigs	X	X	X	X	X	
Laying hens	X	X	X	X	X	
Other poultry**	X	X	X	X.	X	
Sheep					X	
Mineral fertilizer						X

*Differentiate between a low and high efficiency option.

**Includes also poulty manure incineration.

GAINS has restrictions in the application of measures, e.g. that only farms above a threshold size can apply certain measures. Applicability to some extent also reflects current national policies. GAINS' applicability rates of manures in Sweden, divided into the different control measures are shown in Table 8.

Table 8. Application rates of manures in Sweden (%) applied in the GAINS-online model, CLE-scenario year 2015.

Livestock category	Low nitrogen feed	Low emission housing	Air purifi-cation	Covered storage* (low)	Covered storage* (high)	Low ammonia application* (low)	Low ammonia application* (high)
Dairy cows – liquid systems	100	70	0	100	92	93	50
Dairy cows – solid systems	99.3	0	0	0	0	89.4	74.5
Other cattle - liquid systems	0	0	0	100	90	93	50
Other cattle - solid systems	0	0	0	0	0	84.7	70.6
Pigs – liquid systems	100	10	90	100	99	95	50
Pigs – solid systems	97.8	0	88	0	0	92.9	73.3
Laying hens	49.6	89.2	94.2	0	89.2	79.3	89.2
Other poultry	50	95.0	95	0	95	80	95
Sheep	0	0	0	0	0	56.8	30.5

*Differentiate between a low and high efficiency option

3.1.1 Low nitrogen feed

Low nitrogen feed represents a dietary change with lower protein (nitrogen) feed, which results in reduced nitrogen excretion. The feeding must be adjusted so that the production of meat and dairy is not affected. Low nitrogen feeding strategies can reduce ammonia emissions at many stages of manure management, from excretion in housing, through storage of manure to application on land.

In Sweden, crude protein levels in pig feed have been low since 1990, due to positive effects on animal health, indoor climate and ammonia emissions. Therefore the potential to reduce ammonia emissions is limited. Feed for a standard growing-finishing pig in Sweden traditionally contains 14.5 % crude protein (Botermans et al., 2010). Lowering the crude protein level further to 12.5 % would result in a reduction in ammonia emissions by about 20 %.

The GAINS-CLE scenario (2015) assumes that low protein feed is applied only for poultry and pigs. However in 2030 it is also believed to be applied for dairy cows. In the MTFR-scenario for 2030 it is expected to be applied for practically all dairy cows and pigs, and for about half of the poultry in Sweden, see Table 9.

Table 9. Low nitrogen feed (%) in Sweden 2015 and 2030, as predicted by the two GAINS scenarios CLE and MTFR.

Livestock category	Manure system	2015 CLE	2030 CLE	2030 MTFR
Dairy cows	liquid systems	0	0	100
	solid systems	0	10	99
Other cattle	liquid systems	0	0	0
	solid systems	0	0	0
Pigs	liquid systems	17	17	100
	solid systems	0	0	98
Poultry	laying hens	41	41	50
	other poultry	60	60	60

In addition to low nitrogen feed, a number of other livestock feeding strategies are possible to implement to lower ammonia emissions (Bittman et al., 2014), e.g. phase feeding (young, high productive livestock demands more protein compared with older livestock), increasing the non-starch polysaccharide content of the feed, adding pH lowering substances (e.g. benzoic acid). Also increasing the grazing period provides a means of reducing ammonia emissions, as ammonia emissions from housed livestock are higher than grazing livestock.

Calculating the cost of different feeding strategies is complicated as it depends on market price of feed ingredient as well as the original feed composition. Economic cost of improved feeding strategies have been roughly estimated at -0.5 to 0.5 € per kg NH_3-N saved (van Vuuren et al., 2015). The cost increases with ambition level of ammonia abatement.

3.1.2 Low emission housing

Low emission housing includes a number of options to reduce the surface area and exposure time of manure in the animal house.

A generalisation of estimated reduction levels and costs of ammonia abatement techniques during housing is presented in Table 10. A more detailed description of ammonia abatement costs for housing emissions is provided in Montalvo et al. (2015). Jeppsson and Gustafsson (2009) provide a review of techniques to reduce ammonia emissions from animal houses and list measures with the greatest potential to reduce ammonia emissions from new or largely rebuilt housing for cattle, pigs, and poultry in Sweden. Measures include e.g. design of the stable to decrease the manure surface area, rapid removal of urine and decreasing the air velocity and temperature above the manure. Low emission housing also includes measures such as reducing the pH and temperature of the manure, drying poultry litter and removing ammonia from exhaust air (using scrubbers) – see Section 3.1.3.

The effectiveness and costs of implementing the measures depend on a range of factors, such as size and age of the housing system, and obviously higher costs often reflects a higher level of ammonia abatement. The cheapest abatement method in poultry houses involves keeping the manure dry by ventilation and avoiding spillage of water. Techniques with a high abatement potential, e.g. air scrubbing technology (see Section 3.1.3), are associated with a higher cost compared with methods that involve modest design changes, such as partially slatted floors for pigs. Improving existing buildings with low emission technologies is costly. Therefore it is better to focus abatement strategies on new (or largely rebuilt) buildings.

Table 10. Estimated reduction levels and costs of ammonia emission abatement techniques for livestock housing. (Source: Bittman et al., 2014).

Category	Emission reduction (%)	Cost (€/kg NH3-N reduced)
Large, existing pig and poultry farms (>2000 fattening pigs, or >750 sows, or >40000 poultry)	20	0-3
Cattle housing (new or largely rebuilt)	0-70	1-20*
Pig housing (new or largely rebuilt)	20-90	1-20*
Broiler housing (new or largely rebuilt)	20-90	1-15*
Layer housing (new or largely rebuilt)	20-90	1-9
Other livestock (new or largely rebuilt)	0-90	1-20*

*Costs also reflects air scrubbers (Section 2.1.3).

In the GAINS CLE-scenario (2015), low emission housing is assumed to be applied only for poultry and pigs, and in 2030 it is expected to remain at about the same level as today. However, the MTFR-scenario predicts that also all dairy cows on liquid systems will have low emission housing in 2030 compared with none today, Table 11.

Table 11. Low emission housing (%) in Sweden 2015 and 2030, as predicted by the two GAINS scenarios CLE and MTFR.

Livestock category	Manure system	2015 CLE	2030 CLE	2030 MTFR
Dairy cows	liquid systems	0	0	100
	solid systems	0	0	0
Other cattle	liquid systems	0	0	0
	solid systems	0	0	0
Pigs	liquid systems	17	17	17
	solid systems	0	0	0
Poultry	laying hens	20	20	20
	other poultry	50	50	60

3.1.3 Air purification

Air purification represents options to treat the air ventilated from animal housing, e.g. acid scrubbers to treat the exhaust air. Air scrubbing technology is costly, but has a high abatement potential. The cost per slaughter pig and per kg N reduced in Denmark is summarised in Table 12. The cost per kg N reduced has been estimated at about 3 - 43 €. Operating costs for scrubbers are lower in pig houses compared with poultry houses, due to higher dust emissions from poultry.

Table 12. Costs for air scrubbers in pig houses for slaughter pigs in pig houses for 75-950 Danish livestock units (LU), i.e. about 2600-33300 slaughter pigs. (NIRAS Konsulenterne, 2009). (1 Danish LU = 35 slaughter pigs).

Type of air scrubber	Share of the airflow that is purified (%)	Cost, €	
		Per kg N reduced	Per slaughter pig
ScanAirclean	100	7.5-9.0	2.6-3.1
	20	2.7-7.8	0.5-1.6
Turbovent	100	36.3-43.2	12.5-14.9
	20	14.5-17.2	3.1-3.6

In Sweden the majority of new built livestock houses for cattle (about 90-95 %) are ventilated by natural ventilation. Air scrubbers require mechanical ventilation, and therefore the potential of ammonia reductions from cattle housing in Sweden is small. Pig and poultry housing on the other hand, are almost exclusively using mechanical ventilation. If the exhaust air from all pig and poultry houses in Sweden was treated and cleaned at a level of 90 %, ammonia emission would be reduced by about 2950 tonnes (SBA, 2010). Applying partial cleaning of the air (about 20 % of the ventilation capacity), the ammonia emissions could be reduced by 60 %, i.e. 1770 tonnes if applied to all pig and poultry houses in Sweden.

The GAINS model scenarios predict that air purification can be technically feasible to implement in intensive pig and poultry houses (up to almost 90 %), see Table 13. According to the GAINS CLE-scenario, air purification is not considered to be used as a measure to reduce ammonia emissions in livestock houses, not even year 2030. Today air scrubbers and other technologies to clean exhaust air from livestock buildings hardly occur in Sweden. Setting rules and demanding air purification in conjunction with permissions for new or expanded operations, could be one way to move towards more air purification in agricultural buildings in Sweden. The GAINS scenarios in Table 11 seem realistic, i.e. if no control system is applied, air purification will not be applied even year 2030, although it is technically feasible in a majority of the pig and poultry houses.

Table 13. Air purification (%) in Sweden 2015 and 2030, as predicted by the two GAINS scenarios CLE and MTFR.

Livestock category		2015 CLE	2030 CLE	2030 MTFR
Dairy cows	liquid systems	0	0	0
	Solid systems	0	0	0
Other cattle	liquid systems	0	0	0
	Solid systems	0	0	0
Pigs	liquid systems	0	0	83
	Solid systems	0	0	88
Poultry	Laying hens	0	0	80
	Other poultry**	0	0	40

3.1.4 Covered storage

Covered storage is a means to reduce the exposure of stored manure to air and hence reduce ammonia volatilisation. Actions to reduce ammonia volatilisation from stored manure are easier to implement for slurry storages, than for solid manure. There are few practical applicable measures to reduce ammonia emissions from solid manure systems. The main options are covering, applying litter (e.g. peat, see Section 3.2.1) and (for poultry manure) keeping it dry prior to land application.

The GAINS model scenarios distinguishes between low efficiency systems, e.g. floating foils or polysterene and high efficiency systems, e.g. using concrete, corrugated iron or polyester caps (Klimont and Winiwarter, 2015).

The Swedish Board of Agriculture summarises the most common techniques to cover slurry and manure in Sweden and their ammonia reduction potential and cost, see Table 14. The costs vary depending on type of cover and manure. The Swedish Board of Agriculture have estimated a total cost of 400-650 million SEK (42-68 million €) to cover slurry storages in Sweden (SBA, 2012). Bittman et al. (2014) have estimated costs at about 0.3-2.5 € per kg NH_3-N saved, which is slightly lower compared with the cost estimates by the Swedish Board of Agriculture. Ammonia abatement techniques appear to be more cost effective for manure storage compared with livestock housing.

Table 14. The most common techniques to cover slurry and urine in Sweden and their ammonia reduction potential and cost (SBA, 2010). The lower cost estimate represents pigs and the higher cattle.

Cover	Reduction potential (%)	Cost per kg reduced N	Comment
Concrete lid	95		Only applicable for small tanks
Wood/sheet metal roof (not tightly closed)	50	37-50	
Plastic sheet roof (tightly closed)	90	18-25	
Floating plastic sheet	90		Only for urine
Peat	90	18-25	Only for slurry
Hexa-cover (plastic)	90	22-30	
Hydrograins (leca)	70	11-14	Primarily for very liquid slurry and urine
Straw	60		Only for slurry
Crust	50-60	7-9	

The majority of slurry stores in Sweden are covered. Year 2013 about 98 % of all slurry were covered, and 91 % of urine kept in a container also had some sort of cover (SCB, 2014), see Table 15. The main reduction emission potential is therefore not to increase the number of covers, but rather to apply more effective covers than natural crusts. Tightly closed covers, like roofs or lids, are most effective and reduce ammonia losses by 90-95 %. Having more efficient covers is particularly important for urine and digested manure, as the ammonia emission is larger than from slurry. The cover cost is lower for urine compared with slurry because the ammonia emissions from urine are so much higher without cover.

Covering urine containers in southern Sweden would reduce emissions by about 700 tonnes at a cost of about 5-17 SEK (0.5-1.7 €) per kg N reduced (SBA, 2010). If all urine containers were applied with a cover that reduces 90 % of the ammonia emission, SBA (2010) estimates that ammonia emissions can be reduced by about 870 tonnes.

Table 15. Cover method for slurry and urine in Sweden, percent of total livestock units (LU), year 2013 (SCB, 2014).

	Crust	Roof	Other method*
Slurry	95	4	0
Urine	67	27	7

*Leca, straw, concrete lid or plastic lid.

Today there are regulations regarding cover of slurry and urine containers in southern Sweden. But for digested manure, there are no rules regarding cover. Hence demanding covers also on digested manure, and also regulate type of cover (more effective than natural crust) could reduce ammonia emissions further. Extending the regulations to cover a greater geographical area of Sweden would reduce the emissions even more.

The GAINS CLE-scenario assumes that covered storage will remain at the same level as today. According to GAINS MTFR-scenario it is technically feasible to increase covered storage in the future and to apply it also for pig slurry, see Table 16. It is also predicted that more high efficiency covered storages will be used in the future, compared with e.g. natural crusts.

Table 16. Covered storage, includes both high and low efficiency, (%) in Sweden 2015 and 2030, as predicted by the two GAINS scenarios CLE and MTFR.

Livestock category		2015 CLE	2030 CLE	2030 MTFR
Dairy cows	liquid systems	38	38	38
	Solid systems	0	0	0
Other cattle	liquid systems	38	38	100
	Solid systems	0	0	0
Pigs	liquid systems	0	0	83
	Solid systems	0	0	0
Poultry	Laying hens	21	21	80
	Other poultry	40	40	40

3.1.5 Low ammonia application of manure

Low ammonia application of manure represents a means to distribute manure to agricultural fields in a way to minimize surface exposure, i.e. by placing it underneath the soil or plant cover layer instead of spreading it over the surface (broad spreading). Broad spreading is the cheapest method of manure spreading but is associated with high ammonia emissions. Applying other manure spreading techniques, such as band application, shallow injection or direct incorporation, have the potential to reduce ammonia emission during spreading by up to 95 %.

As for storage, application techniques to reduce ammonia volatilisation during spreading are more effective for slurry than for solid manure. The most feasible technique for solid manure is rapid incorporation into the soil and immediate irrigation.

Table 17 provides a summary of estimated reduction levels and costs of low ammonia emission application methods for slurry and manure. The cost of low ammonia application of manure varies depending on type and amount of manure, soil conditions and type of crop. The choice of application method needs to be adapted to local conditions, depending on e.g. soil stoniness and growing phase of the crop. Immediate incorporation is associated with the smallest cost, but is not always feasible to apply. Farm size and equipment sharing is important, and has the greatest effect on cost estimates from land application of slurry and solid manure. Low emission manure spreading becomes more cost effective from manure which originates from low emission manure storage, as this leaves more NH_4 in the manure. Farmers should therefore ensure that slurries have previously been kept using low emission storage.

Table 17. Estimated reduction levels and costs of ammona emission abatement techniques for manure application (SBA, 2010).

Manure spreading technique	Ammonia reduction (%)	Cost per kg N reduced **(SEK)
Band application with trailing hose	0-65	9-13 (26)
Band application with trailing shoe*	25-95	*
Shallow injection (2 V-shaped discs)	55-95	10-11 (31)
Direct incorporation following surface application	50-95	
Incorporation after 4 hours	25-75	

*Are not yet sold in Sweden.
** Value in paranthesis represents cost when the machine is not so extensively used.

Broad spreading of manure, i.e. spreading it on the surface, is the cheapest method of manure spreading. It is also associated with high ammonia emissions. In Sweden, the most common way to spread urine is still broad spreading (57 %), see Table 18. During a 10 year period band spreading, either with a hose or a shoe, has increased from 35 to 63 percent until 2013 for slurry and from 22 to 36 percent for urine (SCB, 2014). The Swedish Board of Agriculture (SBA, 2010) estimates that band spreading will continue to increase steadily in the future, even without regulations and controls.

Table 18. Different manure application techniques (%) applied in Sweden year 2013 (SCB, 2014).

	Broad spreading	Band spreading (hose/shoe)	Shallow injection	Other method
Slurry	33	63	2	1
Urine	57	36	1	6

Shallow injection is not very common in Sweden (1-2 %). It is a rather expensive method which is not applicable to all soil conditions. Although spreading equipment for shallow injection is more expensive compared with band spreading, the cost per kg N saved is almost the same, see Table 17. The Swedish Board of Agriculture (SBA, 2010) estimates that shallow injection is not likely to increase without regulations and controls. Today manure spreading regulations exist for slurry spreading in southern Sweden where spreading methods with reduced ammonia emissions should be used. The Swedish Board of Agriculture suggests that these regulations should also apply for urine. In that case ammonia emissions would be reduced by about 50 tonnes at a cost of 3-14 SEK (0.3-1.4 €) per kg reduced N. These regulations should also apply to digested manure. However, shallow injection can increase emissions of nitrous oxide (Rodhe and Pell, 2005). Direct incorporation following surface application has not shown these negative effects.

In theory it is possible to incorporate all manure on bare soil after application. Table 19 shows the time between spreading of manure and incorporation in Sweden, and the emission reduction potential compared with broad spreading is shown in Table 20. The potential to reduce ammonia emissions through rapid incorporation is mainly by incorporating the manure which today is broad spread on bare soil and by quicker incorporation of the manure which is already incorporated. However practical problems associated with the use of farm machinery and having to alternate between different farming machinery makes it difficult.

Table 19. Time between spreading of animal manure and incorporation in Sweden in 2012/13, percent of treated area (SCB, 2014).

	Within 4 hours	Within 5-24 hours	24 hours or not at all	
			Bare soil	Growing crop
Slurry	35	9	10	42
Manure	16	3	4	77
Urine	4	1	4	90

Table 20. Rough estimate of the ammonia emission reduction potential compared with broad spreading, based on Karlsson and Rodhe (2002).

	Immediate incorporation	Within 4 hours	Within 5-24 hours
Slurry	90	75	65
Manure	70	50	30
Urine	65	45	25

Southern Sweden has regulations that manure spread on bare soil should be incorporated within 4 hours. The Swedish Board of Agriculture (SBA, 2010) suggests that these regulations should also apply for digested manure. Furthermore the geographical area should be extended. These additional regulations could reduce ammonia emissions by about 800 tonnes at a cost of 4 SEK (0.4 €) per kg reduced N. The cost has been estimated at about 3-5 SEK (0.3-0.5 €) per reduced N saved for slurry, and slightly more expensive, about 6-8 SEK (0.6-0.8 €), for urine (SBA, 2010).

The GAINS-model distinguishes between low efficiency systems and high efficiency systems for manure application. Low efficiency (liquid systems) include slit injection, trailing shoe, slurry dilution and band spreading, and (for solid manure) ploughing into the soil the day after application (Klimont and Winiwarter, 2015). High efficiency systems include deep and shallow injection of liquid manure and immediate incorporation by ploughing (within 4 h after application for liquid manure, and within 12 hours after application for solid manure.

According to the CLE-scenario of GAINS, low ammonia application of manure is already in operation (20 – 55 % depending on livestock category), but the MTFR-scenario predicts that low ammonia application of manure can be technically feasible to implement in Sweden by 85 - 95 % of livestock manure, see Table 21. Furthermore it is also predicted that high efficiency application of manure will increase in the future. High efficiency systems tend to be more cost-effective than low efficiency systems. However, there are strong technical limitations to the implementation of high efficiency systems, due to geomorphology and soil conditions.

Table 21. Low ammonia application of manure, includes both high and low efficiency, (%) in Sweden 2015 and 2030, as predicted by the two GAINS scenarios CLE and MTFR.

Livestock category		2015 CLE	2030 CLE	2030 MTFR
Dairy cows	liquid systems	30	30	93
	Solid systems	45	45	89
Other cattle	liquid systems	30	30	93
	Solid systems	45	45	85
Pigs	liquid systems	52	52	95
	Solid systems	55	55	93
Poultry	Laying hens	20	41	89
	Other poultry	20	30	95

In order to further stimulate low emission application on manures and fertilizers to land, the Swedish Board of Agriculture suggests that:

- The current regulations stating that '*manure spread on bare soil should be incorporated within 4 hours*', should be extended not only to comprise southern Sweden.
- The current regulations (mentioned above) should also apply for digested manure.

3.1.6 Low emission application of urea

Low emission application of urea refers to either appropriate timing and dose of application or to the substitution of urea by other chemical forms of fertilizers which are less easily releasing ammonia, e.g. ammonium nitrate. As for manure and slurry application, ammonia emissions are reduced if the source strength, emission surface and time that the emission can take place is reduced.

Swedish law and regulations demand that urea should be incorporated within 4 hours of spreading. Table 22 provides a summary of estimated reduction levels and costs of application methods for fertilizers to land. Costs depend on farm size, soil conditions and climate (dry conditions are associated with lower emissions).

Table 22. Estimated reduction levels and costs of ammona emission abatement techniques for application of urea-based fertilisers and ammonium carbonate, ammonium sulphate and ammonium phosphate fertilizers. Emission reference is broadcast surface spreading of urea-based fertilizer. (Source: Bittman et al., 2014).

Fertilizer type	Application techniques	Emission reduction (%)	Cost (€ per kg NH_3-N saved)
Urea and urea ammonium nitrate	Injection	>80	-0.5 - 1
	Urease inhibitors	>30	-0.5 – 2
	Injection of incorporation following surface application	>50	-0.5 – 2
	Surface spreading with irrigation	>40	-0.5 – 1
Ammonium sulphate and phosphate	Injection when applied to carbonate containing soils with high pH	>80	0 – 4
	Incorporation following surface application when applied to carbonate containing soils with high pH	>50	0 - 4
	Surface spreading with irrigation	>40	0 – 4
Ammonium carbonate	Prohibition of use as a mineral fertilizer (if replaced with injected urea or ammonium nitrate)	>90	-1 - 2

3.2 Swedish measures to control air pollution not included in GAINS

3.2.1 Using peat during storage of solid manure

The GAINS model scenarios do not suggest any measures regarding storage of solid manure from pigs and cattle, not even in the MTFR-scenario. Using peat is a means to reduce ammonia emissions from solid manures. Peat binds the nitrogen in the manure better than other litter such as straw (Larsson et al., 2000). Rogerstrand et al. (2005) showed that adding peat litter was as effective for reducing ammonia emissions from solid manure as covering the manure. Studies have also shown that peat litter is very effective regarding reducing ammonia emissions from horse manure (Steineck et al., 2000; Karlsson and Torstensson, 2003).

The use of peat as litter is very limited in Sweden today, and no statistical sources are available. Germundsson (2006) has estimated the use to be about 200 000 and 300 000 m^3 per year. The Swedish Board of Agriculture (SBA, 2010) estimates that doubling the use of peat (applied in year 2010) during manure storage in Sweden, national ammonia emission can be reduced by about 800 tons. The cost of using peat instead of straw is estimated at about 2.9 million SEK (0.3 million €). The value of the nitrogen saving due to reduced ammonia losses, is estimated at about 0.7 million SEK (73 000 €), hence the cost is about 4 SEK/kg (0.4 €/kg) reduced nitrogen.

If peat was used as litter at all farms with solid manure systems, ammonia emissions from housing and storage would probably be reduced by about 50 % (SBA, 2010). On a national level this corresponds to about 5930 tonnes. In addition, also the ammonia losses during manure application would be reduced. The potential would be even greater if also farms with liquid manure systems would use peat as litter. Assuming that the ammonia losses are reduced by half, another 2320 tonnes of ammonia could be reduced (SBA, 2010). All in all, peat has the potential to reduce ammonia emissions from housing and storage by about 8250 tonnes. However, using peat during storage of solid manure may be disadvantageous when it comes to climate change effects and other environmental effects of increased peat extraction (Hansen et al., 2016). These negative effects also need to be considered.

This is an effective method which does not require any large investments. The Swedish Board of Agriculture (SBA, 2010) estimates the cost at about 4 SEK (0.4 €) per nitrogen reduced (having included the savings due to a higher N retention in the manure). The Swedish Board of Agriculture suggests that the use of peat could be increased by providing information and counselling about peat and its effects, and to facilitate contacts between peat producers and farmers by creating an Internet-based marketplace for peat (SBA, 2010). Another possibility is to provide a peat contribution for farmers with solid manure systems using at least 50 % peat as litter.

3.2.2 Digestion of manure

Biogas plants with anaerobic digestion of manure have a positive effect, not only regarding climate change benefits like lower methane emissions and that the biogas replaces fossil energy, but also regarding nitrogen flows to the environment, as the nutrient load to the environment when spreading digested manure can be lower compared with undigested manure. Methane emissions during storage are reduced by 20-80 % (Höglund-Isaksson and Mechler, 2005; Höglund-Isaksson et al., 2013). However, during digestion of manure, ammonium and pH increases, which increases the risk of ammonia emissions during storage and spreading (Möller et al., 2008). Therefore it is important to cover the stores of digested manure. On the other hand, digested manure penetrates the soil more rapidly after application because it is more fluid, and therefore the risk of ammonia emissions is not so impending.

Through anaerobic digestion, farmers can better control the nitrogen content of the manure, hence providing a better precision during spreading, resulting in reduced emissions of ammonia, methane, and nitrous oxide, compared with fresh manure. Another advantage is that digested manure smells much less than fresh manure when it is spread. Field studied have shown that ammonia emissions from spreading of digested and fresh manure are at the same level (Bergström Nilsson, 2008).

In Sweden, the development of biogas is currently being implemented and an investment support for manure digestion plants exists. 40 manure digestion farm plants existed in Sweden in 2015 (SEA, 2016).

3.3 Other measures outside GAINS

3.3.1 Acidification of liquid manure

Acidification, i.e. reducing the pH of the manure by adding acidic substances reduces emissions of ammonia. In Denmark this measure is applied and the ammonia losses have been estimated to be reduced by more than 80 % during storage and by about 67 % during spreading (Nørregaard Hansen et al., 2008). Another advantage is that methane emissions are also reduced.

This measure is more difficult to implement in Sweden compared with Denmark, because liquid manure systems are not common in Sweden and therefore it is difficult to add acidifying substances in the stable. Furthermore, this measure is disadvantageous for production of biogas, which is even more effective regarding climate change benefits. A large-scale investment in acidification of slurry in Sweden would discourage the development of biogas production which is currently being implemented. However, acidification of the biogas residues could possibly be interesting as a measure to reduce ammonia emissions.

The Swedish Board of Agriculture have estimated that the potential for ammonia reduction, if applied for all liquid manure and urine in Sweden (which is not a realistic scenario), would be 9700 tonnes (SBA, 2010). It might be more realistic to assume an applicability of 1 % of all liquid manure (which is about the same level as in Denmark). In that case ammonia emissions could be reduced by about 100 tonnes.

The costs of adding acidifying substances to slurry depend on number of livestock – a smaller herd is associated with a larger cost. Table 23 summarises costs of implementation for various sizes of dairy farms in Denmark. The cost per kg N reduced has been estimated at about 32-129 SEK (NIRAS Konsulenterne, 2009). Information activities and investment support could be possible instruments to encourage the use of acidifying substances.

Table 23. Cost for acidification of slurry with sulfuric acid at dairy farms in Denmark (NIRAS Konsulenterne, 2009).

Size	Cost (€)	
(Danish LU)	Per kg nitrogen reduced	Per annual dairy cow
75	13	191
250	5.5	79
500	4	58
950	3	48

4 Opportunities and barriers

4.1 Co-benefits and trade-offs – between ammonia and other effects

This chapter shows the importance of integrating thinking on agricultural ammonia and other pollutants and effects. Measures to reduce ammonia emissions can have both positive and negative effects on other pollutants, environmental problems, animal welfare etc. For instance, as ammonia losses decrease due to improved application of manure in the field, there are also less indirect emissions of N_2O due to less deposition of ammonia. On the other hand, nitrate leaching is likely to increase as more nitrogen is effectively applied in the soil. This can however be counteracted due to increased crop yields as more nitrogen is available for the crops. There is a need for policy perspectives to consider trade-offs in order to avoid shifting nitrogen emissions from one area of the environment into another.

Table 24 summarises some of the co-benefits (win-wins) between ammonia reduction measures and other pollutants and effects. For instance, covering slurry, manure and urine not only reduces ammonia emissions but also emissions of methane. Covered storage, as well as low nitrogen feed and low emission housing, are important measures to reduce ammonia emissions but also has the advantage of providing a better housing environment and animal health.

Table 24. Overview of some of the co-benefits (win-wins) between ammonia and other pollutants and effects.

Measures reducing both ammonia and methane emissions	• Covered slurry, manure and urine storage (with a plastic sheet). • Digestion of manure (extracting biogas from slurries). • Acidification of slurry. • Air purification with Regenerative Termic Oxidation (RTO). • Storing manure at low temperatures.
Measures reducing both ammonia and nitrous oxide emissions	• Coverage of slurry stores (avoid porous crusts, e.g straw). • Cover solid manure heaps (with a plastic sheet). • Low ammonia application of manure (rapid incorporation). • Digestion of manure (extracting biogas from slurries).
Measures reducing both ammonia and other positive effects	• Low nitrogen feed, low emission housing, covered storage and using peat during storage of solid manure also provide better housing environment and animal health. • Using peat during storage of solid manure also has the advantage of providing more easily spreadable manure. • Improved utilization of manure and fertilizers, low ammonia application of manure and re-use of ammonia from air purification result in lower production of mineral fertilizers. • Biogas produced from the digestion of manure replaces fossil energy.

Some measures to reduce ammonia emissions may increase other pollutants or have an impact on other negative environmental effects, see Table 25. For instance, air purification demands a higher energy consumption and may also increase emissions of nitrous oxides. Furthermore, measures to reduce other pollutants, e.g. animal feeding strategies to reduce methane emissions, may result in increased emissions of ammonia.

Table 25. Overview of some of the measures which reduce one pollutant but increase the other, or is associated with other negative effects.

Measures to reduce ammonia	• Using peat during storage of solid manure is disadvantageous when it comes to climate change benefits and other environmental effects of increased peat extraction. • Acidification of slurry discourages the development of biogas production (digestion of manure), which is even more effective regarding the reduction of greenhouse gases. • Air purification may increase emissions of nitrous oxides. Another disadvantage is that mechanical ventilation rather than natural ventilation is needed, hence demands higher energy consumption. • Manure incorporation means higher fuel consumption.
Measures to reduce methane	• Some animal feeding strategies can increase N excretion, hence increases ammonia emissions. • Active aeration of stored manure generally increases ammonia emissions.

4.2 Policy challenges

Through the Gothenburg Protocol and the NEC directive, Sweden has committed to reduce ammonia emissions by 15 % by 2020 and by 17 % by 2030 compared with the base year 2005. According to the latest SMED inventory (SEPA, 2017), total ammonia emissions in Sweden have been reduced by 2.3 ktonnes since 2005 (from 62.6 ktonnes to 60.3 ktonnes), i.e. a reduction by about 4 %. Ammonia emissions need to be reduced further (by about 8,4 ktonnes until 2030) in order to achieve the pollution target (52 ktonnes).

The largest reduction potential for ammonia emissions is in the agricultural sector. Efforts should primarily concentrate on cost-effective, practical and feasible measures, e.g. low nitrogen feed, covered storage and low ammonia emission spreading techniques. A great challenge with agricultural policies is to decrease negative effects, while at the same time maintain or increase food production.

Relevant cost data need to be provided together with mitigating effects to make an integrated assessment to support decision making. Table 26 shows some examples of feasible measures which have the potential to reduce ammonia emissions in Sweden, showing their reduction potential and cost. The data are mainly based on SBA (2010). Implementing these four measures (low nitrogen feed for pigs, coverage of all urine containers, doubling the use of peat during storage, applying low emission spreading techniques for urine and expanding the geographical area regulating manure incorporation within 4 hours) would result in an emission reduction of 3,5 ktonnes, at a cost of about 19 million SEK, which is not even half way to the emission target for 2030. Further measures than those suggested in Table 26 are therefore needed.

Table 26 only considers lowering the crude protein for pigs (due to lack of data regarding reduction levels and costs for other livestock). However, lowering the crude protein further both for pigs, dairy cows and poultry, to its optimal level (without decreasing productivity) provides one of the most cost effective ways to reduce ammonia emissions during housing, storage and manure application. Another efficient abatement measure not included below is to use more efficient covers for slurry compared with natural crusts.

As long as the most practical and feasible measures (which do not compromise productivity or other negative environmental effects) are not fully applied, a further focus on the more demanding approaches might not be needed, such as acidification of slurry or low emission techniques in new and largely rebuilt pig and poultry houses, e.g. air purification.

Table 26. Overview of cost-effective feasible measures which have the potential to reduce ammonia emissions in Sweden, mainly based on SBA (2010).

Measure	Scenario	Reduction & cost	Comment
low nitrogen feed	Lowering the crude protein from 14.5 % to 12.5 % for pigs.	About 1 ktonnes / yr of ammonia emissions in Sweden at a maximum cost of 5 million SEK (0.5 million €).	Lowering the crude protein further also for other livestock has a great potential to reduce ammonia emissions.
covered storage	All urine containers are applied with a cover that reduces 90 % of the ammonia emission.	About 870 tonnes / yr of ammonia emissions in Sweden at a cost of about 8.1 million SEK (0.85 million €)/ yr.	Applying more effective covers also for slurry and manure has a great potential to reduce emissions further.
using peat during storage of solid manure	Doubling the use of peat (from year 2010) as suggested by SBA (2010).	About 800 tonnes / yr of ammonia emissions in Sweden at a cost of about 2.9 million SEK (0.3 million €).	Increasing the use of peat even more has a great potential to reduce emissions further. However negative effects of peat extraction need to be considered.
low ammonia emission spreading	Extending the area regulating manure incorporation within 4 hours (also including digested manure). Spreading of urine with low emission spreading techniques.	About 850 tonnes / yr of ammonia emissions in Sweden at a cost of about 2.8 million SEK (0.3 million €).	Extending both the area and including digested manure as well as urine has a great potential to reduce ammonia emissions.

The GAINS model scenarios can be used as a tool to calculate the cost and pollution reduction effect of different abatement strategies. The model calculates costs per unit of activity (e.g. number of livestock or tons of fertilizer use), or costs per unit of removed pollutant (NH_3).

Wagner et al. (2012) have applied three ammonia reduction ambition levels and a cost optimised scenario (the MID scenario, Amann et al. (2011)) to calculate the cost and emission reduction for Sweden through to 2020. The following measures were considered (at different ambition levels): low nitrogen feed, housing adaptions for new housing, covered storage and low emission application of manure and urea. The cost optimised scenario (MID) was most effective, reducing emissions by 25 % between 2010 and 2020.

It is important to show that substantial economic and environmental benefits can be gained from reducing ammonia emissions. Measures should not be too expensive to the farmers, and may in some cases even pay for themselves, e.g. thanks to the reduction in cost of mineral nitrogen fertiliser due to savings of nitrogen within the farming system. In this context it is also important to show that environmental, health and agronomic benefits outweigh the costs, e.g. reduced greenhouse gases, odour and losses of other pollutants (e.g. methane) and reduced energy consumption, as manufacturing of ammonia-based fertilizers are associated with energy use, see Section 3.1.

Previous cost estimates of ammonia abatement and nitrogen oxides abatement indicate that most of the low cost measures for NOx emissions have already been taken, while many of the low-cost measures for ammonia mitigation have yet to be taken (van Grinsven et al., 2013). Ammonia experts have concluded that (expressed as kg of nitrogen), abatement of ammonia emissions is rather cheap, compared with further abatement of nitrogen oxides (NO_x) (Reis et al., 2015). Hence, technical measures within the agricultural sector, e.g. those presented in Table 26, are more cost effective compared with nitrogen reductions within other sectors already subject to more stringent regulations.

Further ways to reduce ammonia emissions would be to decrease the Swedish production of meat and dairy products, either through reduced meat and dairy consumption, or through increased import of these products. However, importing agricultural products may not result in an overall reduction in ammonia emissions, as the emissions are just transferred elsewhere. Measures to reduce meat and dairy consumption, and measures to reduce food waste, on the other hand, have a great potential to reduce overall emissions of ammonia, see Table 27.

Table 27. Summary of measures to reduce meat consumption and food waste.

Measures to reduce meat consumption (SBA, 2013b)	• Meat VAT. • Environmental labelling. • Information campaigns. • Regulation of public procurement.
Measures to reduce food waste	• Food waste from industry, restaurants food shops and households can be more efficiently surcharged (Schmidt et al., 2012). • Improved food packaging and food storage may improve the life span of a food product. • Information campaigns. • A general increase in food prices.

In Sweden there has been an increase in the consumption of relatively more expensive but also more emission-intensive products such as meat and cheese. The annual meat consumption reached its highest level in 2011, 87 kg meat per person (SBA, 2013c). Meat consumption is believed to be influenced by factors such as increased income, development of “new” meat products, new diets and also influences from other countries. Since 1995 the proportion of Swedish meat consumed has decreased, and the import of meat has slowly increased (SBA, 2013c). Hence, an important policy challenge is to consider the effect of emissions derived in other countries due to increased import.

The EU milk quotas were abolished in 2015 and EU predicts a lower milk price, hence the milk production in Sweden is expected to decrease. This may result in lower national emissions from agriculture, but in fact the emissions are just “exported” and may even increase if more high emitting dairy-farms expand. Measures to reduce nutrient losses from agriculture are ineffective if the production is carried out elsewhere with as large or larger environmental effects.

4.3 Policy efforts to reduce ammonia emissions

Adequate regulations and policies regarding manure management are important to reduce the impact of reactive nitrogen from farming systems in Sweden. Recently a Nordic report summarises policy efforts to reduce nitrogen losses from agriculture in the Nordic countries (Hellsten et al., 2017). In Denmark, which has more stringent rules and regulations compared with Sweden, ammonia emissions have been reduced by 42 % during 1990-2015, compared with an 8 % reduction in Sweden (EEA, 2017).

There is a need to further explore how to increase the use of abatement measures to reduce ammonia emissions. A great challenge with agricultural policies is to decrease negative effects, while at the same time maintain or increase food production. This chapter summarises suggestions on policy efforts to increase the use of abatement measures in Swedish agriculture.

4.3.1 Information and counselling

Information and counselling is a policy effort which is generally considered to be easy to bring through and associated with rather low (governmental) costs, and no costs for the farmers. It may however be difficult to follow up the effect of the policy effort. The policy effort is particularly effective if the counselling reveals economical incitements and increased profitability for the farmer.

The information campaigen "Greppa näringen" (Focus on nutrients), has been running in Sweden since 2001. The information campaign focuses on increasing nutrient management efficiency by increasing awareness and knowledge. "Greppa näringen" puts the farmer in focus and the core of the information campaign is education and individual on-farm advisory visits. Agrifood (2015) concluded that the advising visits within "Focus on nutrients" had reduced N leaching and also led to increased yields. However, environmental support schemes have also contributed to the improvement. Without the support schemes the advisory efforts within "Focus on nutrients" would probably not have been as successful.

Pira et al. (2016) recommended political action to launch an information campaign to change consumption behaviour, e.g. regarding food waste and the consumption of emission intensive products, and, highlighting the benefits for the environment, health and global equality. Targeted measures could be used to raise public awareness of a more sustainable agricultural and food system. However, as previously mentioned, it may be difficult to follow up the effect of this type of information campaign.

Further information and counselling could e.g. be aimed at the following areas:

- Change consumption behaviour, highlighting the benefits for the environment, health and global equality.
- Regarding the advantages of applying low nitrogen feed.
- Regarding the advantages and effects of using peat during storage of manure.
- To encourage use of acidifying substances to reduce pH of liquid manure.

4.3.2 Rules and regulations

Rules and regulations are effective policy instruments with low (governmental) costs. However, the cost for the farmer may be large and may influence profitability, competition etc. A problem may be that the farmer is not provided with incentives to reduce emissions further than stated in the regulations. Rules and regulations also require means to administrate and follow up the regulations.

Sweden has regulations on the spreading, storing and use of manure (SBA, 2015). Swedish regulations consider regional differences, and therefore different regulations apply depending on where you are in the country. Southern Sweden, and so called sensitive areas (close to water bodies and coastlines) are associated with more stringent regulations, see Figure 6.

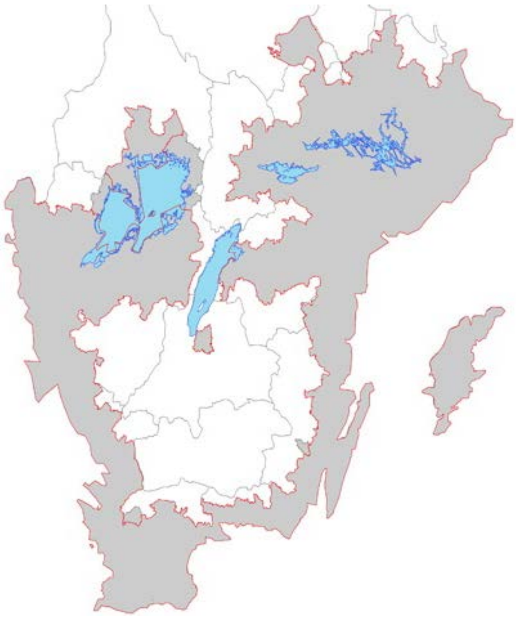


Figure 6. Sensitive areas in Sweden (gray areas). The red line shows the former areal extend of the sensitive areas (before 2014). Administrative boarders (counties) are also shown. Source: www.jordbruksverket.se (Växtnäring).

All livestock farms in Sweden must have sufficient manure storage (6 to 10 months' storage capacity) in order to avoid spreading manure during inappropriate times of the year. The size of the storage depends on number of livestock and location of the farm. In southern Sweden requirements for coverage of slurry and urine tanks (a floating cover or equivalent) apply. There are also regional, specific rules for when manure spreading should occur, and how quickly the manure should be incorporated into the soil. In the sensitive areas in the most southerly parts (Figure 6), there are restrictions on type of spreading techniques that should be used. In these areas it is not permitted to spread more manure than the equivalent of 170 kg of nitrogen per hectare and year. Further restrictions apply for winter oilseed crops (sown during the autumn) and other winter crops where the maximum load is 60 kg and 40 kg of nitrogen per hectare respectively.

Current manure management regulations could be extended also to include:

- Current regulations on coverage of slurry could be extended also to include digested manure.
- Type of cover could be regulated to encourage more effective covers, at least for new or expanding buildings.
- Regulations that manure spread on bare soil should be incorporated within 4 hours could be extended also to include digested manure.
- The geographical area for regulations on manure application could be extended.

New rules and regulations could be:

- Rules and regulations regarding new livestock houses.
- Setting rules demanding air purification in conjunction with permissions for new or expanded operations.

4.3.3 Investment support

Investment support systems can be a very effective policy effort, because it provides the farmer with clear economic incentives to bring through a particular measure. A disadvantage is the (governmental) cost of the investment support. Investment support in Sweden is currently provided within the Rural development program, see Table 2. In addition, investment support is also provided to manure digestion plants for biogas production (SEA, 2016).

Table 28. An overview of support schemes and environmental investments within the Swedish Rural development program.

Environmental support schemes	Cultivation of ley. Catch crops, spring cultivation. Riparian buffer zones. Maintenance of ponds and wetlands.
Environmental investments	Construction of wetlands. Different investments for improved water quality. Two step ditch. Controlled drainage.

Pira et al. (2016) noted that current support systems for agriculture mainly have favoured intensive and large-scale farming and that growth in production has been central to agricultural policy, while other interests have not been considered as important. One reason may be that large scale farmers are better represented through interest organisations. Livestock intensification may have advantages regarding the implementation of some abatement strategies. On the other hand, intensive farming may generate problems related to e.g. the need to redistribute large amounts of bulky organic waste. Small farms on the other hand, may be less dependent on external inputs and outputs and are likely to use local resources which can lead to lower emissions.

Potential areas where an investment support could be considered to reduce ammonia emissions:

- To encourage the use of acidifying substances in Sweden.
- A peat contribution could be provided to farmers with solid manure systems using at least 50 % peat as litter.
- Policy efforts should consider that small-scale farmers may have to receive financial or technical assistance in order to implement measures.

5 Recommendations and further work

A great challenge with agricultural policies is to decrease negative effects, while at the same time maintain or increase food production. There is a need for policy perspectives to move more towards a holistic approach, hence when evaluating measures to reduce ammonia within agriculture, the effect on other pollutants and effects also need to be considered. Relevant cost data need to be provided together with mitigating effects and co-benefits and trade-offs with other environmental effects to make an integrated assessment to support decision making.

The most cost effective ammonia abatement measures in Sweden are low nitrogen feed, low ammonia application of manure, and low emission manure storage (covering slurry and adding peat to manure). Measures to reduce housing emissions, e.g. designing the stable to reduce the surface and time manure is exposed to air, are also rather cost effective, particularly for new stables. For instance, implementing low nitrogen feed for pigs, coverage of all urine containers, doubling the use of peat during storage, applying low emission spreading techniques for urine and expanding the geographical area regulating manure incorporation within 4 hours would result in an emission reduction of 3,5 ktonnes per year at a cost of about 19 million SEK (2 million €), see Table 26.

An important policy challenge with a great potential to reduce overall emissions of ammonia is measures to reduce meat and dairy consumption and measures to reduce food waste. In this context it is also important to consider the effect of emissions derived in other countries due to increased import.

Recommended policy action:

- Ammonia experts have concluded that (expressed as kg of nitrogen), abatement of ammonia emissions is rather cheap, compared with further abatement of nitrogen oxides (NO_X). In order to reduce overall nitrogen losses, policy efforts should be targeted at technical measures within the agricultural sector, which are more cost effective compared with nitrogen reductions within other sectors already subject to more stringent regulations.
- Main focus should be on implementing the most cost effective, practical and feasible measures (e.g. low protein feeding and low ammonia emission storage and spreading of manure). As long as the most practical and feasible measures (which do not compromise other negative environmental effects) are not fully applied, a further focus on the more demanding approaches might not be needed, such as acidification of slurry or low emission techniques in new and largely rebuilt pig and poultry houses, e.g. air purification.

- Policy makers should consider that small-scale farmers may have to receive financial or technical assistance in order to implement measures.
- The advisory Program "Greppa näringen" (Focus on Nutrients), in combination with support schemes and environmental investments within the Swedish Rural Development Program, has proven to be successful and should continue.
- An information campaign regarding changes in consumption behaviour should be launched, highlighting the benefits for the environment, health and global equality.
- In addition to the current rules and regulations, the regulations could be extended. However the effect (economic and on other pollutants and effects) need to be considered and further investigated first. Suggestions on new or extended rules and regulations:
    - Current regulations on coverage of slurry could be extended also to include digested manure.
    - Type of cover could be regulated to encourage more effective covers.
    - Regulations that manure spread on bare soil should be incorporated within 4 hours could be extended also to include digested manure.
    - The geographical area for regulations on manure application could be extended.
    - Rules and regulations regarding new livestock houses could be more stringent compared with existing livestock houses.
    - Setting rules demanding air purification in conjunction with permissions for new or expanded operations.

Further work should concentrate on:

- The SMED inventory is better adapted to Swedish agricultural conditions, but the GAINS model scenarios are more flexible for calculating and changing abatement measures, and to include the cost of different abatement measures. Understanding the differences between SMED and GAINS, both regarding inventories and forecasts, in order to reduce uncertainties in the Swedish ammonia calculation, e.g. why the livestock numbers in the SMED-inventory and the GAINS-inventory are different. Furthermore, the differences in forecasts, particularly the latest SMED-forecast (done in 2015) which is at the same level as GAINS MTFR-scenario for year 2030, need to be explored further.
- The complex interactions, synergies and trade-offs between different pollutants and environmental effects demands more research to find the right balance between potential conflicting interest, including e.g. emission savings, ethical values, costs and other environmental effects. Economy and profitability are important factors affecting type of production system and abatement measures chosen and design of support system for agriculture.
- From a policy perspective, in order to further motivate abatement of ammonia from agriculture, it is important to identify knowledge gaps as well as possible overlaps and gaps in existing policies on reactive nitrogen.

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Appendix 1. Overview of ammonia inventory methodology for SMED and GAINS.

SMED methodology

An overview of the SMED-methodology to estimate ammonia emissions is provided in SEPA (2017). Ammonia emissions during 1990-2014 have been recalculated in the latest SMED inventory for ammonia (SEPA, 2017), hence the emissions are different from those reported in SEPA (2016).

Statistical sources within SMED's national ammonia inventory (SEPA, 2017):

- Livestock data have mainly been collected from the Farm register of the Swedish Board of Agriculture. For slaughter chicken, horses and furred animals other statistical sources have been used.
- Information about fertilisers and manure (e.g. type of fertiliser and manure, amount, storage method and method of spreading) are based on telephone interviews with random holdings, carried out every second year by Statistics Sweden.
- Data on manure and nitrogen production are based on nutrient balance calculations and are compiled by the Swedish Board of Agriculture. Milk production per dairy cow (which affect nitrogen excretion) were obtained from the Swedish Dairy Association.
- Emission factors of ammonia during housing, storage and spreading of manure have been obtained from the Swedish University of Agricultural Sciences and from the Swedish Institute of Agricultural and Environmental Engineering (JTI). Emission factors from mineral fertilizers were obtained from the EMEP/EEA Emission Inventory Guidebook 2013.

SMED calculates emissions based on type of livestock, emission stage, emission factor and type of manure management (SEPA, 2017). Abatement measures are therefore indirectly taken into consideration based on statistics, surveys and emission factors applied. For instance, housing emissions are calculated based on the equation below.

Housing = D * N * V * P

D – Livestock population

N – production of nitrogen per livestock and year (kg)

V – N volatilization rate during housing (%)

P – housing period (%)

GAINS methodology

Statistical sources within the GAINS-model have been validated by national experts and future scenarios are based on national projections and work of international organizations (FOA, EFMA, IFA and OECD) (Klimont and Winiwarter, 2011).

The GAINS approach calculates emissions based on livestock category, abatement technique, emission stage, livestock population, emission factor, reduction potential of abatement technique and implementation rate of the abatement technique (Klimont and Winiwarter, 2011). The emission factors therefore depend on type and implementation rate of abatement.

$$\mathbf{Housing = D * \sum_{a} [(V * N (1 - R_a) * I_a]}$$

D – Livestock population

N – nitrogen excretion during housing (kg)

V – N volatilization rate during housing (%)

R – Reduction efficiency of abatement technique

I – Implementation rate of the abatement technique

Within the GAINS-model, ammonia factors of each manure management stage (housing-->storage-->spreading) are influenced by the nitrogen losses at previous stages. Therefore, the emission factor in the equation above, i.e. EF = N * V, is applied to calculate the emission factor in the following step (storage):

$$\mathbf{EF_{housing} = N_{housing} * V_{housing}}$$

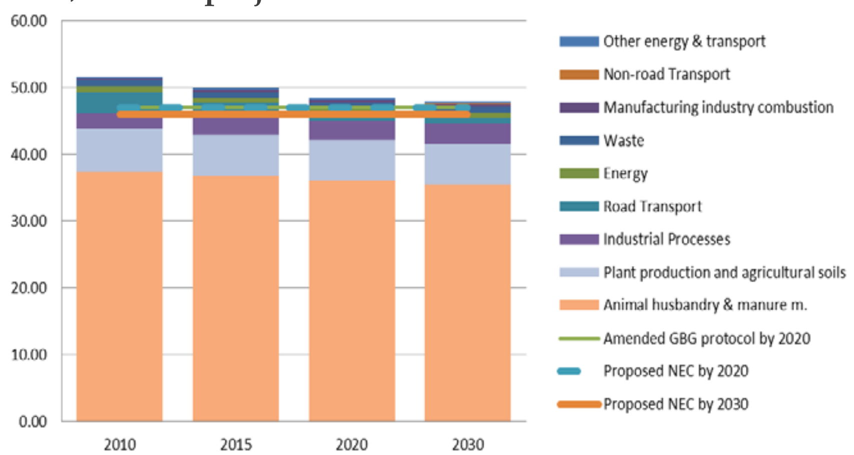
$$\mathbf{EF_{storage} = N_{housing} (1 - V_{housing}) * V_{storage}}$$

EF = Emission factor

Appendix 2. Differences in the SMED projection for 2013 and 2015

The SMED forecasts from 2013 and 2015 are different, see Figure 7. The SMED projection from 2015 has applied a reference scenario "The model scenario", developed by the Swedish Board of Agriculture (SEA, 2014). The model-scenario is based on an economic model, taking into account assumptions on future policies and market development. For instance, the EU milk quotas were abolished in 2015 and EU predicts a lower milk price. Therefore Swedish milk production is expected to decrease until 2035. The model scenario predicts a larger and quicker reduction in ammonia emissions until 2030 compared with the trend-scenario (SEPA, 2015b). The previous SMED projection from 2013 was based on a previous reference scenario, where the production level was assumed to remain at the same level from 2020 to 2030, which means that the current trend (up to 2010), with a steady production decline, was not taken into account. The forecast was, however, assuming an increase in efficiency and productivity, which means that the same production is achieved with fewer livestock, a reduced number of hectares and even less nitrogen supply. This means that despite the locked production between 2020 and 2020, emissions from the agricultural sector are reduced in the forecast, but at a lower rate compared with the current reduction.

a) SMED projection2013



b) SMED projection2015

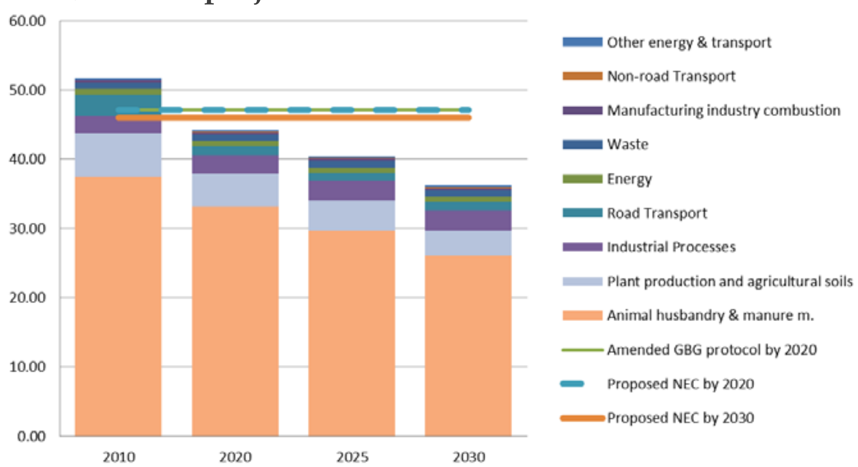


Figure 7. SMED emission projections for Sweden. a) year 2013, b) year 2015. Note that the years on the y-axel are not identical in the two figures. Source: http://cdr.eionet.europa.eu/se/eu/colp93lqa/

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