

## WHY IS ACIDIFICATION OF SLURRY A SUCCESS ONLY IN DENMARK? TRANSFER OF ENVIRONMENTAL TECHNOLOGY ACROSS BOARDERS

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### Abstract

*The EU countries are trying to reduce the ammonia emission towards the 2020 and the 2030 targets in the Clean Air agreement. In order to do so, the countries need to implement a range of technologies. The Danish ammonia emission has been reduced by 40% from 1980 to 2015, but more is required. Several technologies have been used in the buildings, in the storage and when applying manure. One technology now used widely in Denmark (20% of all slurry) is acidification of slurry where the application of sulphuric acid reduces the ammonia emission. However, the technology has hardly been used in other EU countries. The main reasons for the low uptake in other countries are; the cost level, lack of implementation in local regulation combined with potentially unwanted side effects such as increased phosphorus (P) mobility in soils and surplus sulphur (S) fertilisation, as well as, uncertainty about safety. For a technology to be accepted in a “non-native” country, national farm scale tests are required as the technology acceptance. It is shown that regulatory requirements help companies producing these technologies and without these requirements the companies might struggle financially as the demand for new technologies is low.*

**Keywords:** Acidification, costs, ammonia emission, technology transfer, regulation

### 1. Introduction

The NEC Directive (2001/81/EC) (National Emission Ceiling) sets a ceiling for the national emissions for a number of atmospheric pollutants including ammonia (NH<sub>3</sub>) from most European countries. The aim of reducing NH<sub>3</sub> emissions is to limit eutrophication of ecosystems in order to improve the protection of the environment and human health.

For the EU 28 countries, the emissions were 3,591 kt NH<sub>3</sub> in 2013, compared with the emission in 1990 of 5,028 kt NH<sub>3</sub> (EAA, 2010). The reduction in NH<sub>3</sub> emissions since 1990 has been 43% in Denmark, 17% in Germany and the EU average is 29% (EAA, 2015). The largest emitters in 2013 were France, Germany and Spain and they also had an increase in emissions from 2013 to 2014.

The EU target is a further reduction of 6% in 2020 and 19% in 2030 for EU28 compared to the 2005 levels (Directive 2016/2284) and (EC, 2013) (see figure 1). The largest reductions requirements in the first period of the Clean Air agreement towards 2020 are found in Denmark (24%) and Finland (20%), whereas the largest reduction in the second period between 2020 and 2030 are found in Germany (24%), Croatia (24%) and Hungary (22%). In other words, a number of countries will still be looking for new technologies which can help them to reach their targets both in 2020 and 2030.

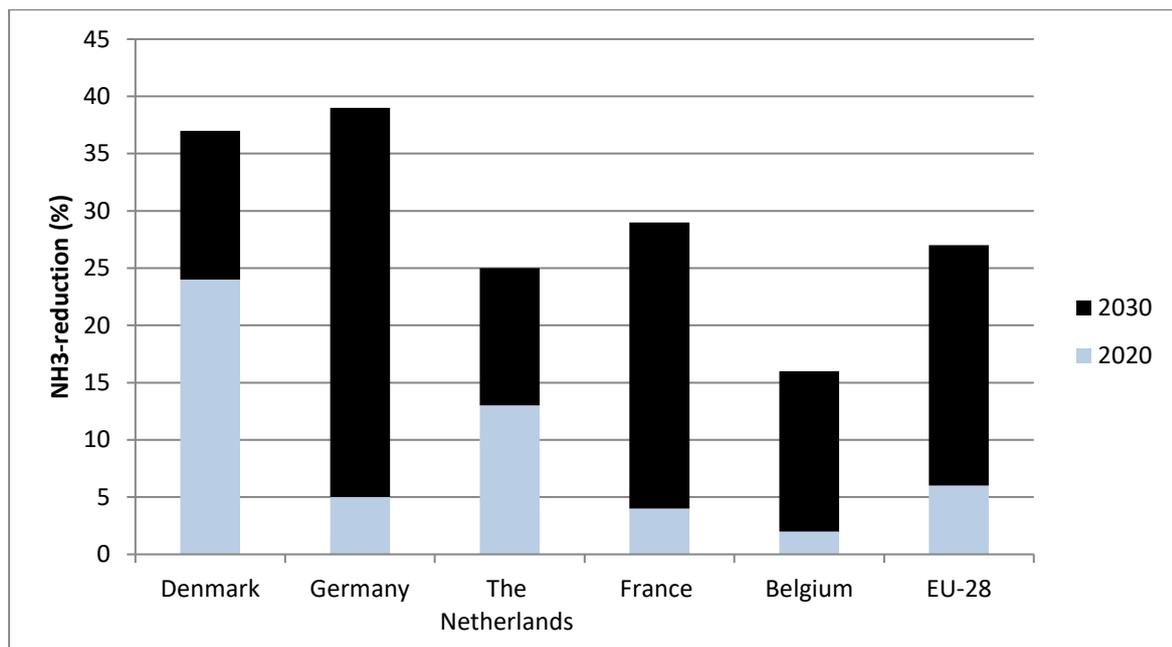
Agriculture was responsible for 93% of NH<sub>3</sub> emissions in 2007 and the reduction in emissions within the agricultural sector is primarily due to a reduction in livestock numbers (especially cattle) since 1990, changes in the handling and management of organic manures, improved feeding and the decreased use of nitrogenous fertilisers.

To reduce ammonia emissions from livestock manure, the Directive calls on EU Member States to encourage the use of modern agricultural machinery techniques including; livestock feeding, low emission storage and housing systems, and limitations on the use of mineral fertilizer (EC, 2015). It also includes low emission spreading technologies such as the spreading of slurries to grassland by using a trailing hose, a trailing shoe, or through shallow or deep injection. According to a study by the European Commission, using advanced agricultural machinery techniques for the spreading of manure in fact offers the highest benefit-to-cost ratio when compared to other potential reduction measures (CEMA, 2015 and EC, 2016).

A number of similar technologies are being used in many EU countries, e.g. the injection of slurry on the fields and the cover of storage of the slurry are used in e.g. the Netherlands and Denmark, but only to a limited extent in Germany and France. A technology like acidification of slurry is used almost only in Denmark. Acidification is based on the idea of lowering the pH-value by adding an acid to the slurry which reduces the emission of ammonia from the slurry. The acidification can be applied either in a tank near the stable, in the slurry storage or during land application. Acidification is applied to almost 20% of all slurry in Denmark.

The purpose of this paper is to describe and analyse how a technology like acidification has become a success in Denmark, and why the technology has not been adopted in other EU countries with similar challenges. The paper focuses on the different steps of the implementation including the trials and tests, the regulation and the economic incentives to implement the technology. The aim is that this analysis will also provide a guideline for what is required for a successful technology transfer from one country to another within this field. This is important as at the national level there is also a focus on the export opportunities for companies producing innovative environmental technologies.

The countries included in the analysis are countries which have included acidification in previous analyses of measures and technologies or have carried out tests relating to acidification (Netherlands and Germany). The sources are mainly written reports concerning the trials and possible implementation together with presentations and verbal comments from experts from the International Workshop held in Vejle in 2016 (MST, 2016).



**Figure 1. NH<sub>3</sub> reduction requirement in the Clean Air Package for 2020 and 2030 compared to 2005 emission levels for selected countries and EU-28.**

Source: EC (2013).

## **2. Key issues related to implementation of new environmental technology**

Transfer of technology (TOT), is the process of transferring technology from the place of its origination to wider distribution among more people and places. Horizontal transfer is the movement of technologies from one area to another whereas the vertical movement is closer linked to the whole chain from production to consumer.

Whereas technology transfer can involve the dissemination of highly complex technology from capital-intensive origins to low-capital recipients, it can also involve appropriate technology, not necessarily high-tech or expensive, that is better disseminated, yielding robustness or better results.

Many analyses look at technology transfer between developed and developing countries and barriers between cultural very different countries (e.g. Metz and Turkson, 2000). A major part of technology transfer impact in terms of money happens between developed countries (Reddy and Zhao, 1989), but relative few have looked at transfer of environmental technologies between developed countries (Johnson and Lybecker, 2009). Johnson and Lybecker (2009) point out some key issues such as uncertainty of the new process and that the speed depends on the cost-effectiveness of the new technology. Their review also finds that the incentives to adopt new technologies are greater with market based tools than with regulatory tools just as they point out that new technologies frequently challenge existing legal systems. With respect to the technology transfer a low “technological distance” between the exporting and receiving country should help the transfer as is the case here where the transfer is between western European countries. Government interest is linked to the potential markets in larger economies especially for countries with a small home market. A key issue for the new technology is to meet the three fold promise: reduce environmental footprint, increase economic competitiveness and social benefits (Kanda et al., 2013). In Montalvo (2008) some key dimensions have been outlined in relation to innovations in cleaner technologies at firm level. These dimensions are: government policy, economics, markets, communities and social pressure, attitudes and social values, technological opportunities and technological capabilities and organizational capabilities. The analysis made in this paper has looked at some key aspects linked to this technology, which are discussed below. They are:

1. Is the technology effective and tested at farm scale under relevant conditions?
2. Is the new technology cheaper (per unit or per reduction requirement) than other technologies?

3. Does the regulation allow the new technology to replace other technologies to fulfil requirements and can it be implemented in current regulation?
4. Is the technology easy to use and safe?
5. Are the potential side effects analysed in detail and are the perceived side-effects acceptable by the society (consumer and regulator)?

The paper will look at the implementation of acidification in Denmark and in other EU countries (mainly the Netherlands and Germany) based on the five aspects listed above in order to see which elements have contributed to a low implementation of this technology in other EU countries.

### **3. Acidification in Denmark**

Acidification in the stables based on adding sulphur acid reduces the ammonia emission in the whole chain from stable to application and it is used on more than 200 farms in Denmark. The technology has been accepted since 2009 and today in 2016 around 140 farms use the tank acidification near the stables, 75 farms use the application linked to the storage and 110 farms use the field application. In total, 6.6 million tonnes of slurry is acidified or around 20% of all slurry in Denmark.

The development of the acidification concept in Denmark started with the company Staring in 2001 to Infarm and then to JH acidification in the buildings known in Denmark as tank acidification. New companies provide acidification in the slurry tank (storage acidification) (Harsø Maskiner and Ørum Smeden) and field acidification during application (Biocover and Kyndestoft Maskinfabrik) (from 2009).

The systems sold are used evenly on pig and dairy farms. An important aspect is that the Infarm concept was listed on the BAT (Best Available Technology) list of possible required technologies when expanding a livestock farm from 2009 (see appendix 1). Using this technology will reduce ammonia emission so much that other alternatives need not to be used. Dairy farmers have said that they were interested because they could avoid using injection if they used acidification (Jacobsen, 2015). The requirement when applying slurry in Denmark is to use injection on fields with grass, but dairy farmers can avoid this by using acidification. Another gain is that slurry tanks on farms which use acidification in the stables do not need to be covered as is the standard requirement on many pig farms to ensure low emissions from the storage.

The first tanks are now more than ten years old and the problems of possible erosion of concrete, which was feared, have not been observed. All slurry tanks in Denmark are inspected every 10 years (5 years if close to streams). No damage to concrete has been observed.

Ammonia emission has been tested several times and the effects are around 60-70% by applying slurry acidification to slurry inside livestock buildings (see appendix 1). Trials with the acidification of slurry during land application of manure have showed a lower, but still, a significant reduction of ammonia emissions and so it is an alternative to injection. Recent Danish trails in New Zealand have supported these findings (Sommer et al., 2016).

When applying acid to the slurry in the building, the acid is stored in a safe tank outside the stables and the acidified slurry is either pumped back into the stables or directly to the large slurry tank. The acid is applied daily and there are different approaches to ensure how much is applied and the level of acid in the tank.

Acid application in slurry storage is done through a pump and it can in some cases, provide foam at the top of the slurry tank which is why the tank cannot be full when the application of acid starts.

Application of acid in the fields requires less investments and the work in many places is carried out by contractors. The acid is placed in a very secure container at the front of the tractor and provides a counterbalance. The field trial have shown an ammonia emission reduction of up to 50% (25% is the guaranteed effect) depending on the situation and type of slurry (see appendix 1). Again the amount of acid used has an impact on the reduction obtained.

Danish findings indicate that acidified slurry can improve biogas production when the share of acidified slurry in the biogas reactor is below 20-30%, whereas it reduces the gas production when the concentration is over 30%. Using the solid fraction from the separation of acidified slurry seems to boost biogas production significantly (over 30%) compared to untreated slurry. Options regarding the use of other acids such as lactic acid will be investigated (Jonassen, 2016; Hjorth, 2016)

## **Economics**

The total costs per Livestock Unit drops from 107 € per LSU/year for small farms with 200 LSU to 50 € per LSU per year for farms with 500 LSU (Aaes et al., 2009 and MST,

2009). The system is, therefore, relatively expensive on small farms. The cost, in relation to the reduction in NH<sub>3</sub>-N, is 3-7 € per kg NH<sub>3</sub>-N. The costs are calculated to be around 1.5 DKK per finished pig per year using acid in the stables or 40 € per cow per year.

As Denmark used to have sup-optimal nitrogen norms, the marginal value of nitrogen was higher than the price of nitrogen. Recent economic analyses show a gain of up to 2 € per ha (with sunny conditions), but can in some cases show a loss of up to 22 € per ha (Birkmose, 2016). The economic gain comes when there is an increase in yield of 0.13 tonnes per hectare. The costs are around 33 € per ha, where the additional application is 20 € per ha and the use of acid is 13 € per ha, based on 3 litres per ton slurry. With higher use of acid, the need for a lime application increases. The acid application in a slurry tank costs typically from 0.5 - 1.5 € per ton of slurry. For the field system, the cost of application in the field is around 0.7 € per ton, which means that it can compete with injection as a hose application and can be cheaper than injection in the field. For organic farms, the use of lactic acid seems to be an interesting option which is now being analysed more closely. For farms in Europe the cost could be around 15 € per ha. This is based on lower purchase of mineral fertiliser, but the yield is not increased.

From a societal perspective, acidification provides a relatively low cost reduction of both ammonia and CO<sub>2</sub>. In the economic analysis with respect to climate measures it has been assumed that acidification reduces methane emission by 50% and the effect is 17.6 and 29.8 kg CO<sub>2</sub>e per ton slurry of cattle and pigs (Dubgaard et al., 2013). As seen from table 1, acidification is not the cheapest per kg NH<sub>3</sub>-N for smaller reductions, but for larger reductions it is competitive. Cooling also reduces methane emissions and so it is the most cost efficient CO<sub>2</sub> reduction measure of the ones listed in Table 1. No other side-effects are included in the calculation in Table 1.

**Table 1. Cost-effectiveness of reducing ammonia emission in Denmark**

| Measures      | Effect (%) | Costs per year per pig (DKK per unit) | Cost per kg NH <sub>3</sub> -N (DDK/ kg NH <sub>3</sub> -N) | Costs including side effects (DKK/kg CO <sub>2</sub> ) <sup>1)</sup> |
|---------------|------------|---------------------------------------|---|--|
| Acidification | 70         | 15-18                                 | 50 - 70   | Negative   |
| Feeding       | 0-20       | 0 - 8                                 | 0 - 90  | Around 0   |
| Cooling       | 20-40      | 0 - 9                                 | 0 - 60  | Negative   |
| Air cleaning  | 25-80      | 3- 15                                 | 50 - 80   | Positive   |

Source: <sup>1)</sup>Dubgaard et al., 2013 and <sup>2)</sup>Aaes et al., 2009

- 1) The CO<sub>2</sub> cost including side effects which include the lower ammonia emission at 41 DKK pr. kg N. 1 € = 7.45 DKK
- 2) Note: Other environmental side effects are not included in the analysis.

As the acidification system in Denmark has been through the EU approved analysis approach (VERA), it should be accepted and used in other EU countries (Germany and The Netherlands). (VERA is the Verification of Environmental Technologies for Agricultural Production, see: <http://www.vera-verification.eu/>). The SyreN system have a VERA approval from 2012 and the most recent for the Acidification in the stables is from 2016 (MST, 2015b).

## 4. Adaptation of acidification in the EU

Most of the analyses carried out with respect to acidification in the EU outside Denmark have been done in the Netherlands and Germany, why these countries are in focus when looking at the possible implementation in other EU-countries. Comments from experts from other EU-countries given at the International workshop in Vejle in 2016 are also included in order to get a broader description of the considerations made (MST, 2016).

### 4.1. The Netherlands

As in Denmark the Netherlands have a large reduction requirement towards 2020 and they have also reduced the ammonia emissions considerably since 2005. Regarding acidification, reports say that the focus in relation to approval has been on the effect of ammonia emissions, the safety during the handling of the acid, and the soil impact (Huijsman et al., 1994 ; Groenestein et al., 2011). On the other hand, corrosion of metal and concrete and odour emissions did not seem to be a problem in the evaluations made. The acidification

approach used in The Netherlands was based on nitric acid which would give too large a nitrogen supply on certain farms. A key factor in the 1990'ties was the fact that acidification was not approved by the government as a technology to be used as an ammonia reducing technology (Huijsman et al., 1994). The reason for the disapproval was that the actual use of the acid could not be checked before surface spreading by government agencies. Furthermore, farmers in The Netherlands were obliged to have their outside manure storage tanks covered in order to reduce the ammonia emissions from these storage tanks (Huijsman et al., 1994 and 2015). Acidification could not replace the need for this cost. The cost of acidification of slurry prior to spreading was more expensive than disc injection of the slurry which was an accepted technology by the government.

More recently the Dutch dairy cattle sector tried to achieve an ammonia reduction by taking feeding measures, but in 2008, it was found that this was not enough to get the desired reductions in ammonia emissions. This gave a renewed interest in acidification of cattle slurry. The Dutch government wants to forbid the use of the trailing hose application on peat and clay soils, and only allow disc injection in order to reduce the ammonia emissions during spreading as is the case with other soil types. By using acidified cattle slurry instead of crude slurry in a trailing hose, the ammonia emission could be further reduced and meet the requirements of the government (Huijsman et al., 2015). Tests of acidification of cattle slurry with sulphuric acid based on the INFARM approach (building acidification) have been carried out. Field trials did indicate an average ammonia emission reduction of 7-24% compared to the non-acidified slurry, which is a lower effect than in the Danish trails (Huijsmans et al., 2015). The effects were based on application of 2 and 4 l H<sub>2</sub>SO<sub>4</sub> per m<sup>3</sup> slurry and the recommendation is to use no more than 4 l per m<sup>3</sup>. The cost aspect has not been analysed in the Dutch reports.

#### **4.2. Other EU countries**

Germany has had some trials with acidified slurry and the focus has been on the consequence of excess application of Sulphur to soils in Germany. The Danish Biocover concept is accepted as a technology in some of the 16 states in Germany, but not all (personal comment from BioCover). All new livestock farms in Slesvig-Holstein need to have air cleaning and so acidification does not replace this investment. Germany is, furthermore, concerned about the safety when handling and transporting concentrated acids and so they will be looking for an alternative to sulphuric acid (Hjorth, 2016).

In Belgium, several farmers have been interested in acidification if the conditions are right (personal comment from Biocover). The technology focus in Belgium is on applying manure with low emission techniques such as injection and quick ploughing, whereas acidification is perceived as expensive and also the use of chemicals and the potential negative effect on pH in soils is a minus (Pers. Communication, Filip Raymaekers, DLV).

In France, a new project called "Agr'Air" calls for pilot projects aimed at disseminating technologies and practices that can contribute to the reduction of ammonia emissions and / or emissions of fine particles. Within this proposal, it might be possible to establish acidification systems in France as there has been a great interest in applying the technology in France. The French approach is not based on a BAT list and there has been a low focus on NH<sub>3</sub> emissions for many years. A list of 10 technologies has been proposed and this includes improved feeding, cover of storage, as well as injection, as measures (ADEME, 2013).

The Swiss regulation does not allow farmers to have acid outside on the farm so acidification in that setup is not relevant even though the storage seems to be very safe. Safety seems to be their biggest concern according to Swiss members of the acidification conference in Denmark 2016 (MST, 2016).

In the UK, the AHDB Pork company has been to Denmark and has seen the system setup (acidification in buildings). English farmers have so far not done much to reduce ammonia emissions and so e.g. air cleaning is not used widely as it is costly and does not provide any financial benefits for the farmer (Penlington, 2015). The UK experience based on their visit in Denmark was that it did not require more labour. The number of flies around the building was reduced as well as the odour was reduced. It was found that there were cost savings from not having to cover their stores, as well as, they could apply less slurry per ha due to the higher N and P availability.

Sweden will have a test site in the Baltic acidification program (so will Estland, Poland, Letland and Estonia and Germany (Baltic Slurry, 2016)). The project runs from 2016 to 2018 and is led by JTI in Sweden. It is too early to say what will be the implications of this project, but it does indicate an interest in testing the acidification technology.

Slurry acidification will be accepted as a BAT technology in the coming EU-BREF (Best Available Technique Reference) document. At that point, more countries will probably be looking with interest for adaptation and implementation of the technology (BREF, 2016). The BREF report states that the driving force is that reduced emissions, significantly improve air quality in the animal houses, providing improved animal welfare, and a better

working environment. Farmers in Denmark are required to adopt low-emission measures to obtain an environmental permit to expand their production capacity. The higher N content of slurry generates economic benefits due to the lower use of mineral fertilisers in Denmark. The use of slurry acidification during land spreading facilitates the application of the acidification technique, since it is not dependent on alterations within the pig housing (BREF, 2016).

The findings from the countries are summarized in Table 2. The findings show that in The Netherlands uncertainty regarding implementation in regulation, control with actual use and negative side effects on P losses have been the deciding factors. In Germany, the risk of over application of Sulphur (S) has been the main concern. For several countries, the limited number of local test farms and local users has been a problem and the VERA approval system has not been enough to ensure that a technology assessment in one country can be used in other EU countries (see Table 2). This would indicate that the technology transfer from one country to another can be costly for the company behind the technology as they have to pay for local trials. It will be interesting to see to what extent e.g. Belgium, France and the Baltic countries will take on the acidification technology as they will do so only if they have an assessment of the side effects.

**Table 2. Technology assessment of acidification in different EU-countries**

| <b>Key questions</b>   | <b>Denmark</b>  | <b>The Netherlands</b>                              | <b>Germany</b>          | <b>Other EU countries</b>                    |
|--|---|---|-------------------------|--|
| Is it cheaper than other technologies used for NH <sub>3</sub> reductions? | Yes<br>(for some farmers)   | No  | Perhaps                 | Not at the moment                            |
| Does acidification reduce ammonia emission?                                | Yes   | Yes   | Yes                     | Yes  |
| Does it replace other technology investments?                              | Yes<br>(injection on dairy farms)   | No  | No                      | Depending on legislation                     |
| Is it safe for humans and the environment ?                                | Yes<br>Yes  | Yes<br>Unsure                                       | Yes<br>Unsure           | Unsure                                       |
| Local test results?  | Yes   | Some  | Some                    | No   |
| Can it be implemented in current regulation?                               | Yes   | No  | No                      | No   |
| Other issues regarding regulation  | Low N-norms has helped  | Risk regarding whether farmers will actually use it | Focus on other measures | Focus on other measures                      |
| Side effects of using acidification  | S and P are not seen as a major problem   | Risk of P losses (low soils)                        | Risk of S contamination |  |
| Company perspective  | Producers of the technology are not doing very well financially and export is difficult |   |                         | No local companies to promote the technology |

## 5. Discussion and Conclusion

Acidification (sulfuric acid, or lactic acid) does give a lower ammonia emission of up to 80%. The results show slightly higher N<sub>2</sub>O emissions and lower methane emission from some acids, whereas the CO<sub>2</sub> emission is often unchanged (Fangueiro et al., 2016) (see appendix 2). Findings show an increase in the mineral fertilizer equivalent for the slurry when applied in the field. In some cases, acidification can increase biogas production. A major

problem is the safe handling of the acid which seems to have been solved in the Danish technology approach to acidification, but it is a key issue in many countries.

The key issues analysed in this paper with respect to the implementation of acidification show that regulation needs to support the implementation for it to be a success. Acidification might have unwanted side effects as too high Sulphur levels (Germany) and might lead to high P-losses (Netherlands). The paper also argues that for technologies to be successful local trials are required.

For the farmers' the costs are important and the review suggest that the costs can be up to 15 € per ha, but in the Danish case there are economic advantages when the N-application was below optimum. In case a stricter regulation is implemented in other EU countries acidification might be worth testing.

The findings suggest that new environmental technologies are more likely to be developed in countries with ambitious ammonia targets and clear technology descriptions, whereas countries like e.g. France, with less focus on NH<sub>3</sub> losses, are likely to have fewer producers of new environmental technologies, and fewer advisors and farmers interested in testing new technologies. On the other hand, changes in Danish regulation with higher N-norms, combined with general low farm income, have shown that the demand for such technologies can drop quickly.

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### **References**

ADME (2013) Analyse du potentiel de 10 actions de réduction des émissions d'ammoniac des levages français aux horizons 2020 et 2030. Report.

[http://www.ademe.fr/sites/default/files/assets/documents/analysepotentiieldedixactionsreductionemissionsammoniaclevagesfrancais\\_2020-2030\\_rapport\\_2013.pdf](http://www.ademe.fr/sites/default/files/assets/documents/analysepotentiieldedixactionsreductionemissionsammoniaclevagesfrancais_2020-2030_rapport_2013.pdf)

- Aaes, O, Andersen, J.M., Gyldenkerne, S., Hansen, A.G., Jacobsen, B. H., Kjær, H., Pedersen, P og Poulsen, H.D. (2008): Evaluering af det generelle ammoniakkrav, maj 2008. Published by Miljøstyrelsen. Offentliggjort i maj 2009.
- BREF (2016) Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs.  
[http://eippcb.jrc.ec.europa.eu/reference/BREF/IRPP\\_Final\\_Draft\\_082015\\_bw.pdf](http://eippcb.jrc.ec.europa.eu/reference/BREF/IRPP_Final_Draft_082015_bw.pdf)
- Baltic Slurry (2016). Reducing nitrogen loss from livestock production by promoting the use of slurry acidification techniques in the Baltic Sea Region. <http://balticsslurry.eu/about-the-project/>
- Birkmose, T. (2016). Business economics and results from field trials with acidified slurry. Presentation. [Seminar on acidification on the 28-29<sup>th</sup> of September, Vejle, Denmark.](#)
- CEMA (2015). Reduction targets for ammonia emissions from agriculture. Memo.  
<http://www.cema-agri.org/page/reduction-targets-ammonia-emissions-agriculture>
- Dubgaard, A.; Laugesen, F.M.; Ståhl, E.E.; Bang, J.R.; Schou, E.; Jacobsen, B.; Ørum, J.E. og Jensen, J.D. (2013). Analyse af omkostningseffektiviteten ved drivhusgasreducerende tiltag i relation til landbruget. Rapport 221. Institut for Fødevarer og Ressourceøkonomi, KU.
- EC (2013). Clear Air package. [http://ec.europa.eu/environment/air/clean\\_air\\_policy.htm](http://ec.europa.eu/environment/air/clean_air_policy.htm)
- EC(2015). Proposal for a Directive of the European Parliament and of the Council on the reduction of national emissions of certain atmospheric pollutants and amending Directive 2003/35/EC - Comments from delegations  
<http://data.consilium.europa.eu/doc/document/ST-13044-2015-INIT/en/pdf>
- Eurostat (2015). Agriculture - ammonia emission statistics.  
[http://ec.europa.eu/eurostat/statistics-explained/index.php/Agriculture\\_-\\_ammonia\\_emission\\_statistics#Ammonia\\_emissions.27\\_targets](http://ec.europa.eu/eurostat/statistics-explained/index.php/Agriculture_-_ammonia_emission_statistics#Ammonia_emissions.27_targets)
- EC (2016). Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC

- EEA (2016). NEC Directive reporting status 2015. <http://www.eea.europa.eu/themes/air/national-emission-ceilings/nec-directive-reporting-status-2015>
- Fangueiro D, Hjorth M, Gioelli F. (2015) Acidification of animal slurry - a review. *J Environ Manage.* 149:46-56. doi: 10.1016/j.jenvman.2014.10.001.
- Groenestein, C.M; M.C.J. Smits; J.F.M. Huijsmans and O. Oenema (2011). Measures to reduce ammonia emissions from livestock manures; now, soon and later. Report 488. Wageningen, NL
- Hansen, J.; Mikkelsen, M.H.; Albrektsen, R.; Dubgaard, A. og Jacobsen, B.H. (2015). Scenarier for ammoniakemissionen fra Danmark i 2020 og 2030. [Scenarios for ammonia emission in Denmark 2020 and 2030]. IFRO report no. 230. Department of Food and Resource Economics, University of Copenhagen. 52 p. (in Danish).
- Hjorth, M. (2016). Replacement of sulfuric acid. Presentation at MST seminar on Acidification in Vejle, Denmark.
- Huijsmans, J.F.M., J.M.G. Hol and H.A. van Schooten, (2015). Toediening van aangezuurde mest met een sleepvoetenmachine op grasland. Wageningen UR Plant Research International.
- Huijsmans, J.F.M., E.M. Mulder & D.W. Bussink, (1994). Acidification of slurry just before field application to reduce ammonia emission. International Conference on Agricultural Engineering, Milano, 29th August - 1st September 1994, p. 4-5.
- Jacobsen, B.H. (2015). Why is acidification a success only in Denmark? Abstract paper for Manure Resource conference in Ghent.
- Jacobsen et al. (2015). White paper on nutrient regulation in selected member states. Report. INEMAD project
- Jacobsen, B.H.; Laugesen, F.M. and Dubgaard, A. (2014). Farm and socioeconomic perspective on the economics of biogas. *Jour. Int. Farm Management.* Vol. 3, No. 3, DOI: 10.5836/ijam/2014-03-02
- Jacobsen B. H. (2012) Reducing ammonia emission using the BATNEEC concept in Denmark. *Journal of Food Economics.* Vol. 9. (3) pp. 166-176.
- Jacobsen, B.H. (2012). Reducing ammonia emission in Europe – cost, regulation and targets with focus on Denmark. *Journal of Agricultural Science and Technology A.* Volume 2, Number 3. ISSN: 2161-6256).
- Johnson, D. K. N. and Lybecker, K. M. (2009). Challenges to Technology Transfer: A Literature Review of the Constraints on Environmental Technology Dissemination.

Colorado College Working Paper No. 2009-07. Available at SSRN:

<https://ssrn.com/abstract=1456222> or <http://dx.doi.org/10.2139/ssrn.1456222>

Jonassen, K. (2016). Ammonia emission reduction during in house slurry acidification.

Danish Environmental Agency. Presentation in Vejle.

Kanda, W.; Hjelm, O. and Mejfa-Dugand, S. (2013). Promoting the export of environmental technologies: governmental initiatives in selected countries. Linköping University, Sweden.

Metz, B. and Turkson, J.K. (2000). The diffusion of energy technology in the rural areas of developing countries. In The International Transfer of Technology (2000). IPCC. Cambridge University Press, Cambridge, UK.

<http://www.ipcc.ch/ipccreports/sres/tectran/index.php?idp=202>

MST (2009). Svovlsyrebehandling af gylle I slagtesvinestald. BAT blad.

<http://mst.dk/media/mst/66973/SI-St->

[01%20forsuring%20slagtesvin%20BAT%20blad%20-%20endelig.pdf](http://mst.dk/media/mst/66973/SI-St-01%20forsuring%20slagtesvin%20BAT%20blad%20-%20endelig.pdf)

MST(2015a). List of technologies. Environmental Protecting Agency. Ministry of Environment.

<http://eng.mst.dk/topics/agriculture/environmental-technologies-for-livestock-holdings/list-of-environmental-technologies/>

MST (2015b). VERA certification of JH acid.

<http://eng.mst.dk/topics/agriculture/environmental-technologies-for-livestock-holdings/livestock-housing-system/>

MST (2016). Seminar on acidification on the 28-29<sup>th</sup> of September Vejle, Denmark. See presentations at: <http://eng.mst.dk/topics/agriculture/acidification/>

Petersen, S.O; Hutchings, N.J.; Hafner, S.D.; Sommer, S. G.; Hjorth, M. and Jonassen,

K.E.N. (2016). Ammonia abatement by slurry acidification: A pilot-scale study of three finishing pig production periods. Agriculture, Ecosystems and Environment, 216, 258-268.

Pedersen, K.P., Pedersen P., Jensen J.E., Hansen M.N., Sommer S.G. (2008). A whole-farm assessment of the efficiency of slurry acidification in reducing ammonia emissions. European Journal of Agronomy, 28, 148–154.

Penlington, N.(2015). Lower slurry pH to get ahead of emissions rules. Livestock. October issue.

- SEGES (2014). Status, økonomi og overvejelser ved forsuring af gylle [Status, economics and considerations related to acidification]. Danish Farmers Advisory Service.  
[https://projekter.vfl.dk/projekter/erhvervsudviklingsordningen/2015/forbedret\\_naeringsstofudnyttelse\\_2625/sider/status-oekonomi-overvejlser-ved-forsuring-af-gylle\\_pl\\_po\\_15\\_279\\_2625.aspx](https://projekter.vfl.dk/projekter/erhvervsudviklingsordningen/2015/forbedret_naeringsstofudnyttelse_2625/sider/status-oekonomi-overvejlser-ved-forsuring-af-gylle_pl_po_15_279_2625.aspx)
- Sommer, S. et al. (2016). Methane, Nitrous Oxide and Carbon-dioxide emissions from the liquid dairy manure management chain in New Zealand as affected by acidification and separation: a pilot study. Presentation at MST seminar on Acidification in Vejle.
- Stevens, R. J.; Laughlin and J. P. Frost (1989). Effect of acidification with sulphuric acid on the volatilization of ammonia from cow and pig slurries. Journal of Agr. Science. Volume 113, Issue 3 December 1989, pp. 389-395. DOI:  
<https://doi.org/10.1017/S0021859600070106>
- Sørensen, P. and Eriksen, J. (2009). Effects of slurry acidification with sulphuric acid combined with aeration on the turnover and plant availability of nitrogen. Agriculture, ecosystems and Environment, 131, 240-246.

## Appendix 1

Table A1. A summary of the Danish Technology list

| Area         | Technology   | NH3 reduction (%)     | Effect on odour (%) |
|--------------|--|-----------------------|---------------------|
| Buildings    | Cooling  | <30%                  | 0%                  |
|              | <b><i>JH forsuring (acid from a tank outside the building)</i></b> | <b><i>50%-64%</i></b> | <b><i>0%</i></b>    |
|              | Low emission floor   | 17-50%                | 0-30%               |
| Air cleaning | Chemical cleaning  | 89%                   | 0%                  |
|              | Biological cleaning  | 85-90%                | 75-80%              |
| Tank         | Cover  | 50%                   | 0%                  |
|              | <b><i>Ørum og Harsø (acid in storage tank)</i></b>                 | <b><i>25-85%</i></b>  | <b><i>0%</i></b>    |
| Application  | Injection (grass)  | >25%                  | 25%                 |
|              | Injection (soil)   | >85%                  | >80%                |
|              | <b><i>SyreN (acid during application)</i></b>                      | <b><i>40-50%</i></b>  | <b><i>0%</i></b>    |
|              | Smellfighter   | 0?                    | 40%?                |

Source: The Danish Environmental agency (The Danish Technology list) (MST, 2015a)

**Tabel A2. Summary of overall impact of acidification**

|                           |  |
|---------------------------|--|
|                           |  |
| NH <sub>3</sub>           | Reduced by 50-90%  |
| CO <sub>2</sub> emission  | Unchanged  |
| CH <sub>4</sub> emission  | Reduced  |
| N <sub>2</sub> O emission | Increased by up to 20%   |
| Total N matter            | Increased  |
| Crop yields               | Increased 100-150 kg /ha   |
| N-leaching                | Increased (N-pools)  |
| H <sub>2</sub> S          | Probably reduced   |
| Soluble P                 | Increased  |
| Biogas production         | Increased when 0-25%, then decline<br>Increased for solid fraction |
| Organic matter            | Increased  |
| S in soils                | Could be a problem (increase)                                      |
| Working conditions        | Better (cleaner air)–no effect on smell                            |

Source: Fangueiro et al. (2015) and own findings