Nordic Council of Ministers

NORDIC NITROGEN AND AGRICULTURE

Policy, measures and recommendations to reduce environmental impact

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Sofie Hellsten, Tommy Dalgaard, Katri Rankinen, Kjetil Tørseth, Airi Kulmala, Eila Turtola, Filip Moldan, Kajsa Pira, Kristoffer Piil, Lars Bakken, Marianne Bechmann and Stina Olofsson

TemaNord 2017:547

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ISBN 978-92-893-5086-0 (PRINT)
ISBN 978-92-893-5087-7 (PDF)
ISBN 978-92-893-5088-4 (EPUB)
http://dx.doi.org/10.6027/TN2017-547

TemaNord 2017:547
ISSN 0908-6692

Standard: PDF/UA-1
ISO 14289-1

Cover photo: unsplash.com / Tommi Saltiola

Print: Rosendahls
Printed in Denmark

5041 0457
Ecolabelled Printed Matter
Rosendahls

Nordic co-operation

Nordic co-operation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, the Faroe Islands, Greenland, and Åland.

Nordic co-operation has firm traditions in politics, the economy, and culture. It plays an important role in European and international collaboration, and aims at creating a strong Nordic community in a strong Europe.

Nordic co-operation seeks to safeguard Nordic and regional interests and principles in the global community. Shared Nordic values help the region solidify its position as one of the world's most innovative and competitive.

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Preface

Increasing attention is now given, nationally and internationally, to the importance of understanding and managing other global cycles of elements in addition to carbon, including nitrogen. Work on planetary boundaries has identified overloading the nitrogen cycle as one of the most critical problems. A particular challenge is that reactive nitrogen (N_r) is involved in a cascade of different environmental effects, from local air pollution to eutrophication, acidification and climate change. These problems are often managed by different and not always coordinated policies and instruments. Recent studies and projects, such as the European Nitrogen Assessment, and newly initiated projects by the OECD, have looked at how more coherent and integrated policies could be better targeted and more cost-effective. The Convention on Long-Range Transboundary Air Pollution (CLRTAP) has established a Task Force on Reactive Nitrogen (TFRN) to look scientifically at the whole cycle of reactive nitrogen, as a background for policy development.

The use of fertiliser in agriculture, together with NO_x from fossil fuel combustion, is a major anthropogenic source of reactive nitrogen, and requires special attention and analysis; around two thirds or more of N_r from human sources is related to agriculture, from fertiliser, fixation by crop plants or feed imports.

This report builds on earlier work by the Nordic Council of Ministers on these issues, in particular TemaNord2015:570 "Nordic agriculture air and climate", and is also a follow-up of TemaNord2013:558 "Agriculture and environment in the Nordic countries".

The report provides an overview of main sources, pathways and impacts of reactive nitrogen in the Nordic countries, including knowledge gaps. It reviews ongoing national and international policy efforts to control reactive nitrogen, and looks at trends and developments, including results of control policies, in flows of reactive nitrogen in the Nordic countries.

On this basis the report suggests further work to close knowledge gaps, and recommends possible control strategies and policy instruments for reactive nitrogen, in order to design and implement better integrated, more effective and more cost-effective policies.

The project was funded by the Environment and Economy Group (MEG) of the Nordic Council of Ministers (NCM) and was carried out by a Nordic network of researchers, led by the Swedish Environmental Research Institute (IVL).

June 2017

Signe Krarup
Chair, the Working Group on Economy and Environment
under the Nordic Council of Ministers

Summary

The aim of this study was to provide recommendations on:

- Strategies and policy instruments to achieve cost effective abatement of reactive nitrogen from agriculture in the Nordic countries.
- The need for further work to describe the effects of integrated, cost effective control strategies for reduction of loss of reactive nitrogen in the Nordic countries under varying climate and soil conditions.

This report is based on a literature review performed by Sofie Hellsten, Tommy Dalgaard, Katri Rankinen and Kjetil Tørseth (see Appendix 3). Additional input was also obtained from discussions at a workshop held in Gothenburg in January 2017, with 11 participants from the Nordic countries with different backgrounds within the field of nitrogen and agriculture (See Appendix 1). The current study has contributed to encourage Nordic collaboration regarding nitrogen and agriculture.

Main conclusions and recommendations

The Nordic countries have, during the last 20 years, introduced efficient measures to reduce nitrogen loss to the environment. Still, N losses are relatively high as compared to the policy targets set, despite the regulatory framework applicable to the agricultural sector at EU and national level. The Nordic countries are at very different stages with regard to nitrogen abatement. Denmark for instance has already cut nitrogen losses by 50%.

Especially, adequate policies and regulations for manure management are important to reduce the impact of reactive nitrogen (ammonia, nitrate and nitrous oxide) from farming systems in the Nordic countries. What further research can be recommended, and what is the way forward for policy development: Stricter laws and regulations, economic instrument and incentives, or more voluntary and advisory efforts? Furthermore, it is important to discuss how to separate and consider the emissions and uncertainties due to weather events and other factors which cannot be controlled by farmers.

We have identified a few key policy actions:

- The focus in the Nordic countries should be on implementing the most cost effective, practical and feasible measures first. As long as these practical and feasible measures (which do not cause other negative environmental effects) are not fully implemented, more demanding and costly approaches should not be the first priority.
- For reduction of ammonia emissions from agriculture, we noted that low nitrogen feed, covered slurry and manure storages and low ammonia emission spreading techniques, are among the most cost-effective, practical and feasible abatement measures to implement.
- In some cases, it may be relevant to extend current rules and regulation e.g. regarding new livestock houses, and coverage of manure tanks and spreading of manure, slurry and digested manure. However, the effects (economic and on other pollutants and environmental effects) need to be considered and further investigated.
- We recommend that some of the current farm-regulations are simplified.
- We recommend scientifically based voluntary actions, in line with the Swedish advisory program "Focus on nutrients" to be continued and further developed, and that similar approaches are also implemented in other Nordic countries.
- Important success criteria for advisory actions and changed farming behaviour are voluntary measures and repeated farm visits, relating to how measures will influence farm economy (positively or negatively) and feedback to farmers regarding the environmental progress (e.g. through the press) to make the farmers proud of their achievements.
- We also recommend more, scientifically based information campaigns about the effects of changed consumption behaviour, towards reduced nitrogen and greenhouse gas emissions, highlighting the environmental benefits.
- We believe N balances, and the distribution of surplus N to different types of losses, may be more relevant as a basis for policy instrument on large (landscape and regional) scales rather than on a small (field) scale.

We have identified a few key policy challenges:

- A great challenge with agri-environmental policies is to decrease negative effects, while at the same time maintain or increase food production.
- When assessing technical abatement measures, a holistic policy approach, not only considering the direct mitigating effect and costs but also other benefits and effects of the actual measure, is important.
- In addition to technical measures, system change measures, e.g. reduction of food waste, increasing the overall efficiency in the food chain, or promotion of

consumption patterns with lower nitrogen footprints, could help to further reduce overall nitrogen losses.

- An important policy challenge is to consider the effect of emissions produced in other countries due to increased import. Measures to reduce nutrient losses from agriculture are ineffective in a global perspective if the production is carried out in other countries with as large or larger environmental effects.
- An important dilemma that needs to be discussed politically is the question of carbon sequestration and the fact that digestion of manure to produce biogas may have negative implications and lead to lower C content in soils if the digest is not returned into the soils as fertiliser. Holistic approaches are needed for the use of bio-based energy sources to reduce the use of fossil fuels and mitigate greenhouse gas emissions.
- We need to produce more with less in the future. Precise farming with modern technology should be highlighted. In this way higher yields with lower nitrogen losses, and net greenhouse gas emissions etc. can be obtained.

We have identified a few key knowledge gaps where further research is needed:

- From a policy perspective, to further motivate abatement of nitrogen losses from agriculture, it is important to identify knowledge gaps as well as possible overlaps and gaps in existing policies on reactive nitrogen.
- The complex interactions, synergies and trade-offs between different pollutants and environmental effects demand relevant assessment tools and more research to find the right balance between potential conflicting interests, including e.g. emission savings, other environmental effects, costs, and ethical values.
- There is a need to improve the understanding of the efficiency of voluntary efforts and advisory actions.
- Nordic research groups are in a strong position to take on research in novel approaches to mitigate ammonia, nitous oxides and nitrate losses from agricultural land, while developing a significant and more sustainable bioeconomy.
- An evaluation of the balance between targeting of mitigation measures and the transaction costs is lacking.
- There is a gap to define, evaluate and compare e.g. biodiversity versus water protection effects, mitigation measures for climate change versus water protection targets, etc.
- There are large potentials for the development of the Nordic agriculture-based bioeconomy including integration of environmental protection schemes and a better utilisation of nitrogen in the whole production chain.
- The back up from the scientific community within the field of nitrogen research is an important contributor to the prominent position of the Nordic countries in different policy bodies within the EU as well as within the Convention on Long

Range Transboundary Air Pollution (CLRTAP). Therefore, it is important to continue to exchange information and experience between the Nordic countries on measures and policy strategies to reduce nitrogen losses from agriculture.

1. Introduction

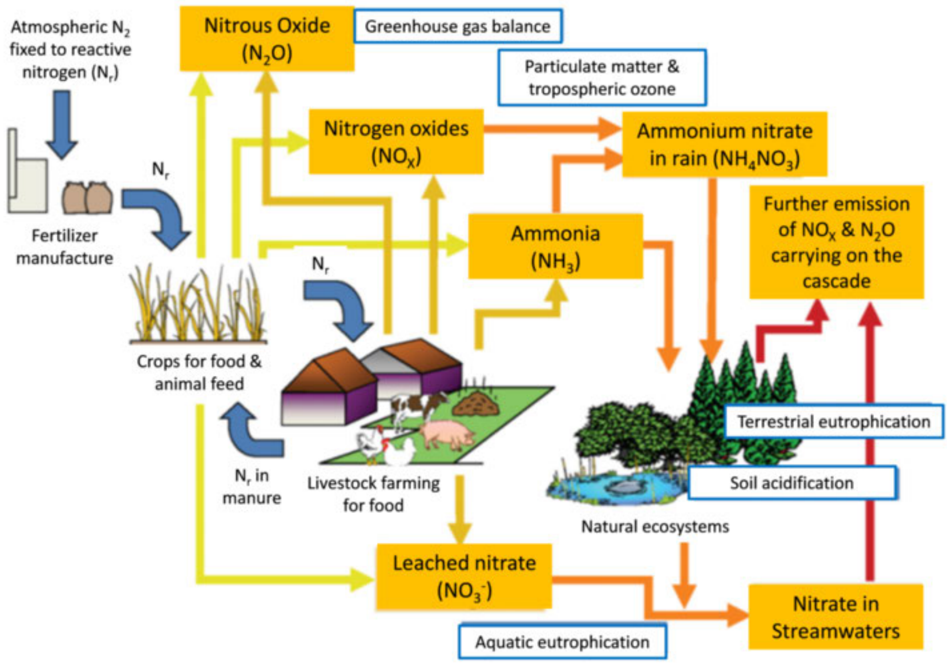
The growth of plants is not possible without readily available reactive nitrogen (Nr[1]), and livestock and humans are dependent on N protein supplies through diet. The availability of Nr for food production has increased significantly over the last century, and the impacts of nitrogen compounds on the environment have increased correspondingly. Agriculture is thus a major contributor to nitrogen emissions. Other sources of Nr exist as well, in particular related to energy production and transport. Considering the cost of producing Nr and the negative effects when emitted/lost to sensitive ecosystems, there are obvious benefits in managing Nr fluxes. There are many regulations in place to reduce the impacts of Nr, but still, fluxes are large compared with natural background levels, and the management of nitrogen needs to be improved in the future.

Human activity has drastically increased the amount of reactive nitrogen (Nr) in the environment over the past century. Nitrogen, being an essential nutrient, was in demand for increased food production to support the growing global population numbers. The Haber-Bosch process, which captures atmospheric nitrogen (N2) to form reactive nitrogen (Nr), made it possible to intensify agriculture. In addition, energy production (mainly fossil fuel combustion) has contributed to the availability of Nr through the formation of nitrogen oxides. About 70% of anthropogenic global N emissions to the atmosphere are a consequence of food production. From 1860 to 1995, Nr production increased from ~15 Tg N in 1860 to 156 Tg N in 1995, a factor 10 increase. In 2005, numbers had further increased to 187 Tg N yr-1 (Galloway *et al.*, 2008).

The production of fertilisers is the largest source of reactive nitrogen in Europe, and its use is associated with releases of Nr with potential harmful effects through emissions of ammonia (NH_3), nitrate (NO_3^-) and nitrous oxide (N_2O), see Figure 1. Organic compounds like manures or root nodules of leguminous also take part in the nitrogen cycle along with easily dissolved nitrates or ammonium-nitrates. By reactions in soil, organic nitrogen will be mobilised to ammonium and nitrates, named here as reactive nitrogen.

[1] Reactive nitrogen (Nr) includes all forms of nitrogen that are biologically, photochemically, and radiatively active. These reactive forms are those capable of cascading through the environment and causing an impact through smog, acid rain, biodiversity loss, etc. (Galloway 2004; 2008. See also http://www.n-print.org/node/5).

Figure 1: A simplified view of the human impact on the nitrogen cycle and the associated cascading effects. Blue arrows show intended anthropogenic Nr flows, while the other arrows show unintended flows



Source: Sutton *et al.* (2011).

Regardless of the origin, mineral fertiliser or organic compound, reactive nitrogen can have cascading impacts, since it can be converted to any other N species in favourable conditions (Galloway, 2003). Therefore, one atom of reactive nitrogen may take part in many environmental effects, see Figure 1. This cascading effect of nitrogen highlights the importance of a holistic policy approach to abate the effects of losses of reactive nitrogen to the environment. Reactive nitrogen will also have a direct impact on the carbon cycle, and can have global-scale effects on atmospheric fluxes of carbon dioxide (CO_2) and methane (CH_4).

Reactive nitrogen, if not used by crops, may contribute to several environmental problems, affecting ecosystems, climate and human health; see blue boxes in Figure 1. Environmental effects include:

- Nitrogen leaching in soil and groundwater.
- Eutrophication and acidification of terrestrial ecosystems.
- Eutrophication of marine ecosystems.
- Global warming (N_2O emissions and other effects of nitrogen).
- Effects of nitrogen on human health (particulate matter and tropospheric ozone formation).

Galloway *et al.* (2008), in their assessment of the global nitrogen cycle, conclude that it is critical to get a better understanding of emission rates. While there is a relatively good understanding of NO_x emissions from fossil fuel combustion, it is less so from biomass burning and soil emissions. The largest uncertainties are in the NH_3 emission rates, from all sources, on all scales. There are also critical questions about the fate and impact of the N deposited to terrestrial, freshwater, and marine areas.

Through emissions of gaseous ammonia to the atmosphere, long-range transport of nitrogen may cause impacts even in remote ecosystems, for instance in the Nordic countries, and this has led to international pollution abatement agreements. Nr availability is commonly a factor 10 higher than preindustrial levels. Hence understanding the Nordic nitrogen losses from agriculture in combination with the long-range transport of air pollutants will provide further strength for this issue at national and European levels, as well as global air pollution policy. The challenge in managing the use of nitrogen is thus to maximise the benefits of the nutrient in its use at the first stage (e.g. fertilisation) while minimising the unwanted consequences of Nr.

Despite the awareness and the policy measures in place (see chapter 4.1 and 4.2 below), there is still a need to improve the management of reactive nitrogen. This study has identified common issues as well as differences in current abatement approaches across the Nordic countries. The respective regulations and policies regarding manure management differ, and there is a need to further explore how to learn from alternative approaches in reducing the impact of reactive nitrogen from farming systems in the Nordic countries.

1.1 Aim of the project

The aim of this project was to provide recommendations on:

- Strategies and policy instruments to achieve cost effective abatement of reactive nitrogen from agriculture in the Nordic countries.
- The need for further work to understand the effects of integrated, cost effective control strategies for reduction of loss of reactive nitrogen in the Nordic countries under varying climate and soil conditions.

In January 2017 a workshop was carried out "Nitrogen and agriculture in the Nordic countries – Causes and effects, measures and recommendations" (see Appendix 1). The discussions from the workshop are presented in this report within gray boxes. These discussions are based on the knowledge and views of the 11 people who participated in the workshop. All participants from the workshop have contributed to the report, including some additional persons (see Appendix 3 and Chapter 6).

This project only included experts from Sweden, Denmark, Norway and Finland. The main focus of the report is nitrogen from the agricultural sector, hence reactive nitrogen from other sources are only discussed briefly.

The current project was initiated by the Environment and Economy Group (MEG) at the Nordic Council of Ministers (NCM). The study follows up on the earlier NCM-report "Agriculture and environment in the Nordic countries" (TemaNord 2013:558, Prestvik *et al.*, 2013). The project also builds on the work in the previous NCM-report "Nordic agriculture air and climate" (TemaNord 2015:570, Antman *et al.*, 2015; Pira *et al.*, 2016). One of the main findings from these studies was the importance of exchanging experience on practices and knowledge between the Nordic countries to provide solutions to reduce harmful environmental impacts from agriculture.

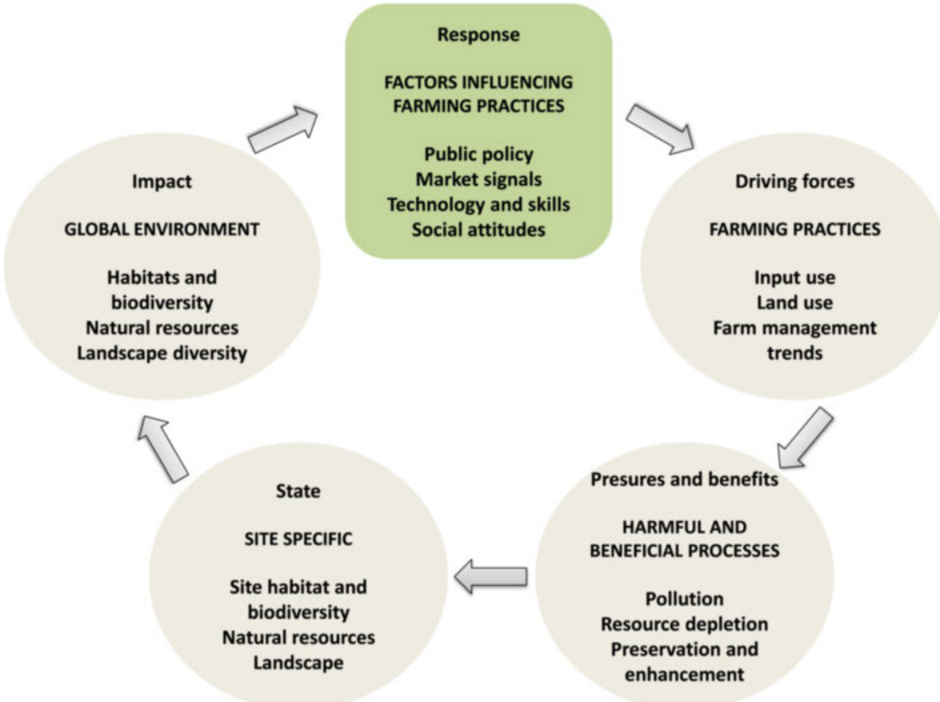
2. Impact assessment and N balances

As also mentioned by the OECD (2000, 2011), the N balance is an important indicator for the environmental impact and performance of agriculture. It is useful together with measures for the Nitrogen Use Efficiency, to compare different farming systems and countries. However, to link to specific environmental impacts on air, water and climate, distributions of the N balance into the specific flows of nitrogen between the production sectors and these three main compartments of the environment are needed. New methods for this linking have been developed and adapted to selected Nordic countries, and can be used both for ex ante and ex post evaluation of N policies. Finally, the combined assessment of both driving forces, pressures, state, impacts and responses are important to include in an iterative development and assessment of agri-environmental policies.

2.1 Impact of N mitigation measures

A common approach for impact assessment of N mitigation measures is the European Environmental Agency DPSIR-framework (EEA, 2005), see Figure 2. This approach includes indicators for Driving forces (D), Pressures (P), State and Impacts (S, I) and Responses (R), and this framework can also be followed to evaluate the effect of nitrogen mitigation measures over time in a certain region or country.

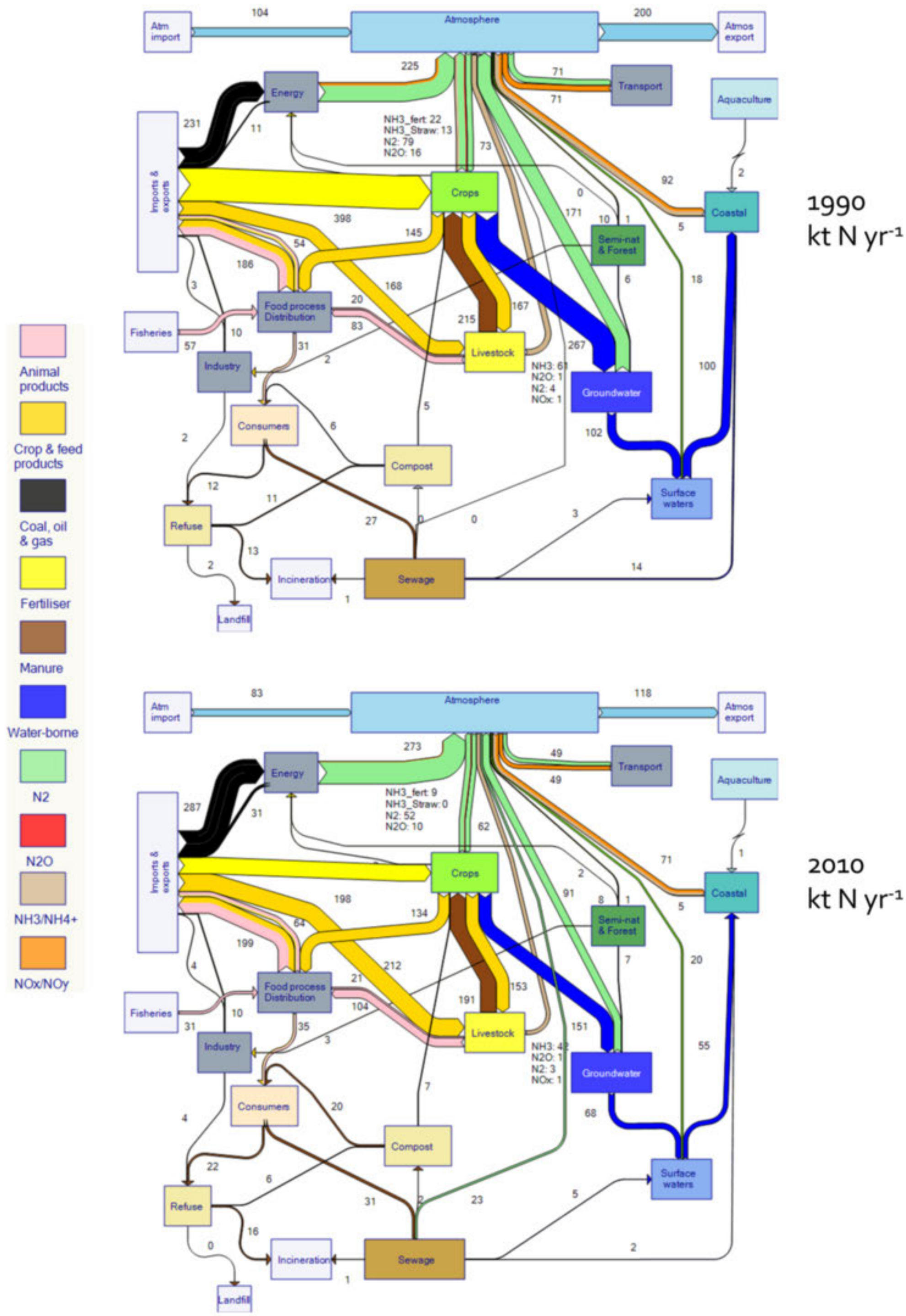
Figure 2: The EEA (2005) DPSIR framework for Environmental Impact Assessment



For example in Denmark, the use of fertilisers has been a major driver (D) for N emissions (P) with environmental as well as health impacts (S, I), leading to a political response (R) with a series of political action plans to mitigate the unwanted effects of N, while keeping a sustainable agricultural production (Dalgaard *et al.*, 2014).

A key indicator to follow the impacts of such N mitigation measures in the N cascade is a tool to assess the N balance in the form of defined N inputs, outputs and flows. Methods for this approach are provided by the Expert Panel on N budgets (http://www.clrtap-tfrn.org/epnb) under the United Nations UN-ECE Task Force on Reactive Nitrogen (TFRN). As an example Hutchings *et al.* (2014) used such methodology to assess effects on the N flows in Denmark from 1990 to 2010 (Figure 3), showing significant reductions in fertiliser input and thereby to N losses to the water and atmospheric spheres.

Figure 3: The N balance, N inputs and N flows (kt N yr-1) assessed for Denmark 1990 (above) and 2010 (below)



Source: Hutchings *et al.*, 2014.

2.2 Perspectives on national N budgets in the Nordic countries

One of the ambitions of TFRN is to help the represented countries to construct their respective National Nitrogen Budgets (NNB). National N budgets capture all major flows and stores of Nr in each country as exemplified in Figure 3 for Denmark. In an NNB, the level of detail applied to individual flows ideally will be in direct proportion to their size. Some are dealt with as agglomerates, and others may even be neglected. So far the most advanced calculations are available for Switzerland (Heldstab *et al.*, 2010) and for Germany (Umweltbundesamt, 2009), followed by Denmark (Hutchings *et al.*, 2014).

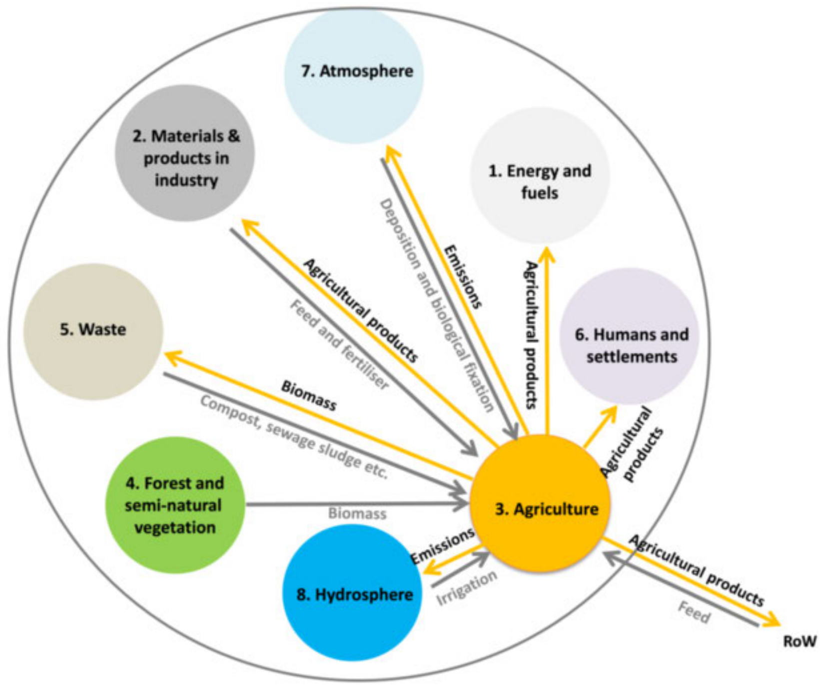
Leip *et al.* (2011) have undertaken the task of mapping major flows of N across Europe, based on national N budgets available (CH, D, NL, F, UK and CZ) which they unified and complemented with their own calculations using available databases and models. The biggest difficulty in undertaking this task has been the lack of NNBs from most of the EU-27 countries and the fact that the available NNBs were neither calculated with a harmonised methodology nor for the same years.

The TFRN Expert Panel on Nitrogen Budgets (EPNB) has recently completed the task to provide a comprehensive methodology on how national N budgets should be constructed[2] (UNECE, 2013). The national budgets divide reactive N flows into eight major areas: Energy & fuels, Materials & products in industry, Agriculture, Forests & semi-natural vegetation, Waste, Humans & settlements, Atmosphere and Hydrosphere (Figure 4). The ambition is that the countries will, to the extent possible, use the EPNB methodology and make the national calculations comparable and readily available for European compilation beyond that of Leip *et al.* (2011).

The relative importance of the individual parts of an NNB varies, typically with Agriculture and Energy & fuels competing for the largest category. Nordic countries are specific in several respects. The agricultural sector is by far largest in Denmark, compared with Sweden, Norway and Finland. The energy and fuel mix is also specific, with the four Nordic countries having a particularly high share of total energy need supplied by hydropower, nuclear power and renewable sources. On the other hand, fishery and forestry make relatively larger contribution to the NNB compared with the European average and in Sweden and Finland, the leaching of Nr has quite a significant component of organic nitrogen, both in relative and absolute terms. Of the Nordic countries there are several publications on various parts of the NNB (e.g. Salo *et al.*, 2007, Bleken and Bakken, 1997). The Swedish programme "Greppa näringen" (http://www.greppa.nu/), to take another example, has a comprehensive approach to construct nitrogen budgets at the farm level for several thousand individual farms across the whole country. But so far only Denmark has published a comprehensive NNB (Hutchings *et al.*, 2014). The work to construct NBBs using the EPNB methodology remains, however, to be undertaken by all four countries.

[2] See http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20160921_public.pdf

Figure 4: Nitrogen flows between Agriculture and the other pools of a National Nitrogen Budget (NNB)



Source: Winiwarter and EPNB (2016).

To provide a short overview of how the NNB of the four Nordic countries compare is complicated by the fact that, except for Denmark, the individual national budgets are not available. However, it is relatively safe to assume, that for all four countries the main inputs of Nr are import of N fertiliser, import of crop products as animal feed, import of fuels, N deposition and biological nitrogen fixation. As outputs the likely largest N flows are through emissions of NH_3, NO_2 and N_2O, through leaching to coastal waters and in Denmark through export of agricultural products. Some of the more easily available posts in such a comparison are summarised in Table 1.

Table 1: Major inputs and outputs in the national nitrogen budget (NNB) for 2014 (kg of N/ha/yr)

	Denmark	Finland	Sweden	Norway
Input				
N-deposition[1)]	12	2.7	3.6	2.2
Fertiliser import	45[2)]			
Fodder import	48[2)]			
Fuel import	65[2)]			
BNF[3)]	9.2[2)]			
Output				
NH_3[1)]	14	0.9	1.0	0.6
NO_2[1)]	7.7	1.2	0.9	1.1
N_2O	4.9[2)]			
Leaching	12[2)]			
Export	45[2)]			

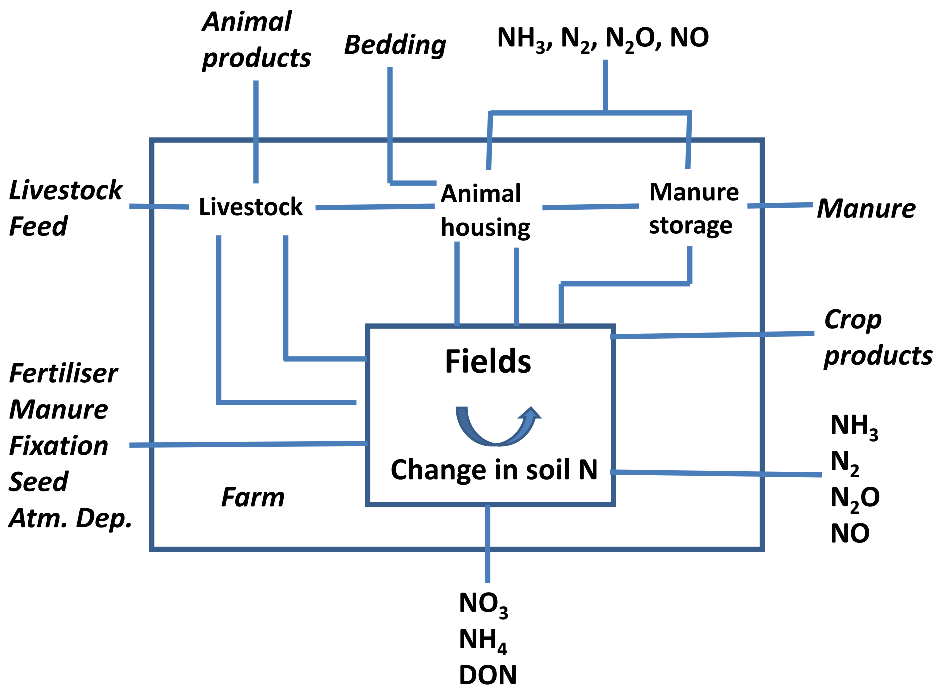
Note: All figures are only presented for Denmark, which is the only Nordic country presently to have calculated an NNB.

Source: [1)] EMEP (2016).
[2)] Hutchings *et al.* (2014).
[3)] Biological N-fixation.

Figure 5 shows a schematic picture of the main nitrogen flows and losses in an agricultural system. The change in soil N in Figure 5 can also be referred to as "the gross nitrogen balance", i.e. the potential surplus of nitrogen on agricultural land. This is estimated by calculating the balance between nitrogen inputs, and nitrogen outputs from the agricultural system per hectare of agricultural land. A surplus indicates potential environmental problems, while a deficit may indicate a decline in soil nutrient status.

Eurostat have calculated the gross nitrogen balance for Denmark, Sweden, Norway and Finland during 1995 until 2014, see Table 2. The estimated output depends mainly on the yields of crops and fodder, while inputs consist of fertilisers and manure, atmospheric deposition, biological fixation and seeds and planting material. In Sweden, Norway and Finland, the main nitrogen input to agricultural soils are mineral fertilisers (46–55% of the nitrogen input), but in Denmark, the main nitrogen input is manure (about 48%).

Figure 5: A schematic picture of the main nitrogen flows and losses in an agricultural system



Source: Eurostat (2011).

The calculation indicates that Denmark and Norway have a higher nitrogen surplus (80 and 94 kg N per ha per year respectively for year 2014), compared with Sweden and Finland (32 and 47 kg N per ha per year respectively). Although Norway has the highest nitrogen surplus (which indicates potential environmental problems through nitrogen losses to water and air from agricultural soils), the agricultural area in Norway is small. In Denmark on the other hand, more than 60% of the land area is being farmed However, in addition, Norway has a significant fish farm industry. In all four countries the nitrogen surplus has decreased since 1995, particularly in Denmark where it has decreased by almost 50%. This indicates that the nitrogen use efficiency has increased in all Nordic countries during the past 20 years.

Table 2: Gross nitrogen balance (kg N per ha of utiliser agricultural area), 1995, 2000, 2005 and 2010–2014

	1995	2000	2005	2010	2011	2012	2013	2014
Denmark	156	132	111	90	88	83	87	80
Finland	79	55	48	56	49	46	45	47
Sweden	57	50	41	38	37	27	30	32
Norway	104	90	98	84	99	91	104	94

Source: Eurostat (online data code: aei_pr_gnb).

During the workshop we discussed how to connect N balances to N losses and water quality. We believe N losses and N balances are difficult to connect at the farm level, as losses depend on a range of factors that are not included in the N balance. For instance, N losses are dependent on changes in soil organic matter pools and weather conditions – both via a direct effect on runoff volumes and leaching but also via the yield level. Due to these factors, some crops, such as maize, have a high leaching, despite balances that are close to neutral. In general, it should be kept in mind, that the effect of some effective mitigation measures does not affect N balances. One additional example is catch crops, which do not change the N balance, but are effective in reducing leaching. Nonetheless, load estimates can be correlated to N balances in very large data sets that integrates large scales and long time periods (Finland) or by using models (Sweden) to give policy recommendations. We believe N balances may act more accurately as a policy instrument on large (landscape) scale rather than on a small (field) scale. They can show the differences between geographical conditions, and be an indicator of the overall nutrient use efficiency in the agricultural system.

Different target balances could be set to different livestock production systems, crops, soil types etc. Providing the target balances for different crops/soil types are correctly set, they can be used on farm level as advisory tools.

We noted that there are differences in the Nordic countries when calculating N-balances or when determining fertilisation levels. For instance, in Finland, only the soluble fraction of N is taken into account, i.e. not the total N of manure as in e.g. Denmark. Furthermore, no nitrogen fixation is taken into account. The correlation between losses and balances differ from country to country because different things are compared. Due to the different applications applied to calculate N-balances, it is difficult to compare the N balances between the countries.

We also discussed how to link the effect in the environmental impact with the nitrogen use, i.e. linking responses and impact to pressures. Can empirical and/or model based balances be used to identify and target the problem fields? This could include the development of:

- Farm type specific assessment or risk analysis.
- Health-check of the N-balance as one important sustainability indicator for the performance at, for instance, the field, stock, farm, watershed, regional, national and even transnational level (the Baltic Sea as one Nordic context example).
- Actions to improve the yield level and checking the fertilisation practices if the field N balance deviates negatively from the target.
- Improvement of user friendly assessment models, not necessarily focusing on the N-balance alone, but also including other relevant issues.

What is done if you do not apply with the targets, i.e. how do you link to policy responses? How are the regulations or the measures revised based on observed effects?

- Links to cross compliance and conditional links to agricultural EU and national support schemes. (However, Norway, Iceland and Greenland are not members of the EU.)
- Fines or taxes linked to non-compliance.
- Supported agri-environmental measures, i.e. payment for mitigation actions, such as catch crops in Norway, Finland, Sweden, and Denmark (the later also per regulation), have positive environmental effects.

During the workshop we identified a number of knowledge gaps, and areas where further research is needed:

- There are some interesting gaps to address in relation to the link to greenhouse gas emissions, e.g. in relation to N_2O emissions (see Section 3.3. and Bakken (2017) in Appendix 2).
- There are important gaps in relation to N in groundwater, and the link to agricultural practices.
- Understanding the gap between science messages and actual policy.
- Too little information exchange between countries – lessons to learn! Maybe things are done just for historic reasons, although other things might be better, simply because you are not aware of good practices and ideas from other countries.
- Improvements for consistent emission inventories across countries are needed.
- Topics around nitrate leaching and N-balance and ammonia loss are better understood, as the link between types of losses and GHG emissions.
- Ammonia emission information lacks; especially for Finland.
- Technological end-of pipe solutions vs. input reduction measures.
- Natural vs. geoengineering systems (with high risks).
- High intensity small area vs. low intensity large area farming.
- Farm type: How does it correlate with the different types of N losses?
- How can Nitrogen Use Efficiency (NUE) be used? (together with N balances).
- How can geographical targeting be assessed?
- Information exchange between countries, e.g. emission matrixes.
- Development potential for a strong and sustainable bioeconomy in the Nordic countries, including a better integration of links between production and environmental impact.

3. Measures, synergies and trade-offs

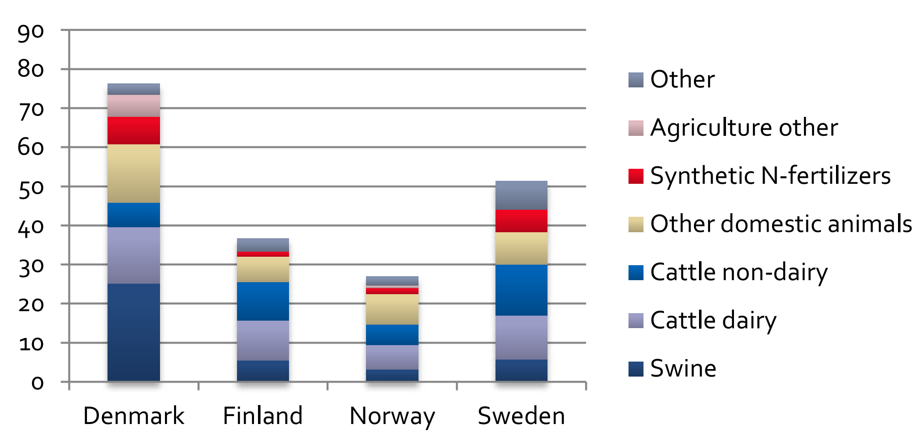
During the last 20 years, the Nordic countries have introduced efficient measures to reduce nitrogen loss to the environment. Still, N losses are relatively high as compared to the policy targets set, despite the regulatory framework applicable to the agricultural sector at EU and national level to restrict adverse environmental impacts. The Nordic countries are at very different stages with regard to nitrogen abatement. Denmark for instance has already cut nitrogen losses by 50%. All the Nordic countries have regulations on the spreading, storing and use of manure, with Denmark having the most stringent regulations.

In addition to technical measures, system change measures, e.g. reducing food waste, increasing the overall efficiency in the food chain or changed diets towards food or products with lower nitrogen footprints, also has a great potential to reduce overall nitrogen losses in the Nordic countries.

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, other environmental effects, costs and ethical values.

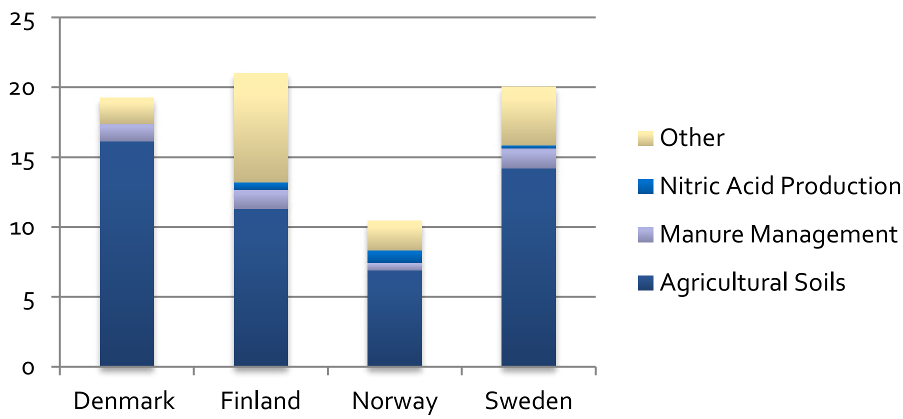
Agriculture is an important source of reactive nitrogen through emissions of ammonia (NH_3), nitrate (NO_3^-) and nitrous oxide (N_2O). Agriculture is the main source of ammonia emissions in the Nordic countries (about 96% in Denmark, and approximately 90% on average in Finland, Norway and Sweden), see Figure 6. Regarding emissions of nitrous oxide, agricultural soils and manure management are the dominant sources (about 60–90%) in the Nordic countries, see Figure 7.

Figure 6: Ammonia emissions (thousand tonnes) in Denmark, Finland, Norway and Sweden during 201



Source: Antman *et al.* (2015), based on EMEP and CLRTAP.

Figure 7: Nitrous oxide emissions (thousand tonnes) in Denmark, Finland, Norway and Sweden during 2012



Source: Antman *et al.* (2015), based on UNFCCC.

All the Nordic countries have regulations on the spreading, storing and use of manure, with Denmark having the most stringent regulations, see Chapter 4. Over the past 30 years Denmark has managed to decrease the nitrogen load to marine waters by 50%, as well as turning an overall trend of increasing nitrogen content in groundwater to a decreasing trend. This has been done mainly by improving the nutrient utilisation efficiency in agriculture as well as setting restrictions on the use of nitrogen fertiliser, which further gives the farmer an incentive to improve nitrogen use efficency. In Finland, the nitrogen load from agriculture to waters has not decreased in recent years, despite considerable reductions in fertiliser use.

In Norway, the main focus in agriculture has been on reducing phosphorus losses and not as much on nitrogen. Therefore the estimated losses of nitrogen from agricultural areas to marine waters increased by 11% from 1990 to 2011 (Selvik *et al.*, 2012).

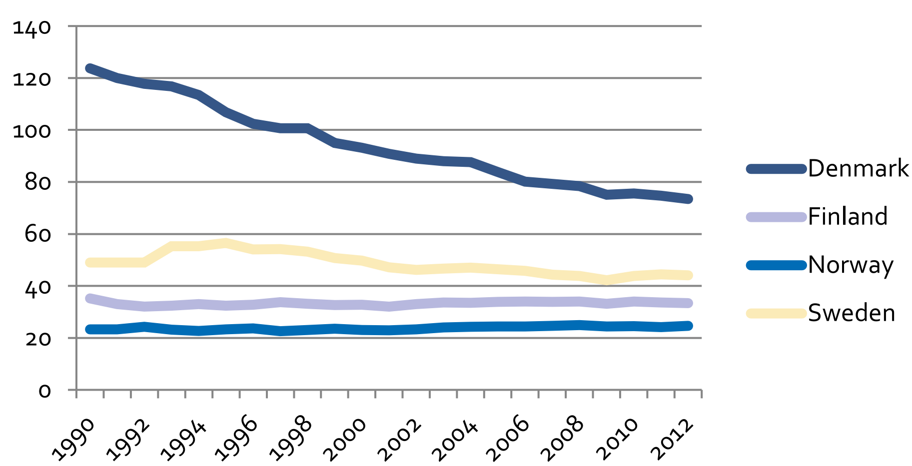
Nitrogen losses from agriculture in the Nordic countries are still sometimes high (see Figure 8 & Figure 9), despite the abatement measures applicable to the agricultural sector at EU and national level that aim to restrict adverse environmental impacts of agricultural activities. Denmark has had the largest reduction in emissions of both ammonia and nitrous oxides since 1990. Sweden has had a small reduction, while Finland and Norway are almost at the same level as in 1990. Furthermore, projections indicate relatively small emission reductions in the coming years (e.g. Grönroos, 2014; SEPA, 2015). It is therefore 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 implemented, but these measures are not always viable, and the reasons for not applying these measures need to be identified and further investigated.

The Nordic countries are at different stages with regard to nitrogen abatement. In Denmark, many of the most feasible measures have already been implemented and Denmark has already cut nitrogen losses by 50%.

Although Denmark has higher nitrogen losses compared with the other Nordic countries, Denmark also has the highest agricultural productivity and the largest agricultural area. Due to the high agricultural production in Denmark, with 63% of the land area being farmed, the targets set for the Water Framework Directive are sometimes exceeded, hence further reductions are still needed.

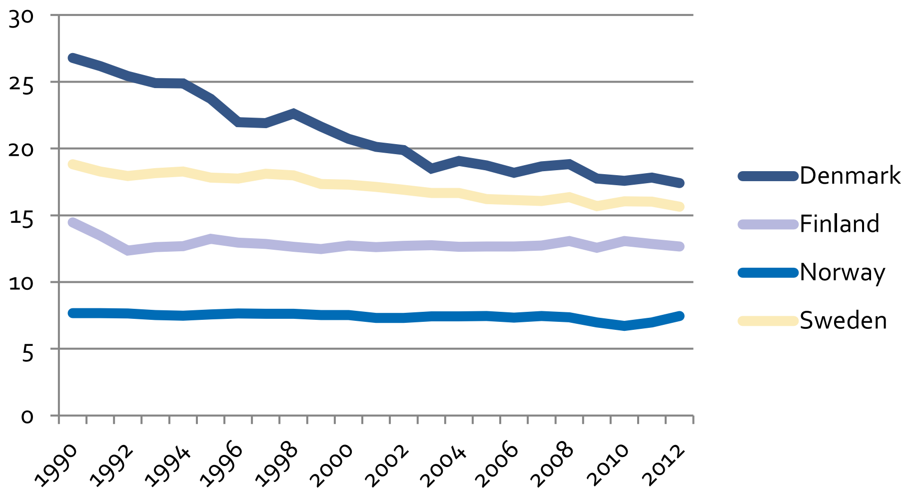
Nordic animal housing and manure removal systems differ in certain respects from agricultural systems applied in other countries as a result of tradition, climate and animal welfare. Therefore some of the abatement measures recommended internationally may not be suitable for Nordic agricultural systems. Furthermore, although the Nordic region is culturally, socially and economically homogeneous, diverse geological and climatic conditions affect certain types of agricultural production. For instance, incorporation of organic manure in spring may sometimes be difficult in Sweden and Finland due to clay soils, where there is only limited time for different practices, while this problem is not as evident in e.g. Denmark. Hence during some conditions a measure may not always be suitable.

Figure 8: Ammonia emissions (thousand tonnes) in Denmark, Finland, Norway and Sweden during 1990–2012



Source: Antman *et al.* (2015), based on EMEP & CLRTAP.

Figure 9: Nitrous oxide emissions (thousand tonnes) from agriculture in Denmark, Finland, Norway and Sweden during 1990–2012



Source: Antman *et al.* (2015), based on UNFCCC.

A number of livestock housing and manure removal systems in the Nordic countries are already designed in such a way that they produce lower nitrogen outputs compared with conventional systems in other European countries. Inversely, European countries moving towards improved animal welfare may glance at the livestock housing systems in the Nordic countries, and knowledge on emissions of reactive nitrogen from farming activities in the Nordic countries are therefore important.

During the workshop we discussed costs and capitalisation in relation to measures to reduce nitrogen losses, i.e. that land prices might be affected by policy measures to regulate nitrogen losses. Another interesting cost-dimension refers to the regional differences regarding effect and ability to implement the measure. For instance, in Finland, the voluntary agri-environmental programme is not always able to target the measures in an environmentally optimal way.

Cost- effectiveness is per definition always linked to the achievement of a certain target, you can compare the cost-effectiveness of two measures or policies against the same target. This is very important as the costs of implementing a measure is most often marginally increasing – the first wetland or kg nitrogen application reduction is much cheaper than the last.

We also discussed the possibility to measure the cost-effectiveness for achieving the nutrient load reductions at the recipient, rather than as the cost-effectiveness related to the implementation of the measure at the field. If we target the mitigation measures to areas where they are more effective, the implementation might be more cost effective. For instance the cost to the North Sea may be 1 SEK/reduced kg N, while for the Baltic Sea 5 SEK/ reduced kg N and to a specific fiord 10 SEK/ reduced kg N. Hasler et al. (2015) illustrates that targeting according to both effects and costs might lead to large reductions in the total costs of achieving a reduction target.

Targeting of mitigation measures have also been discussed in Bechmann et al. (2016a), who highlighted that although targeting may be more efficient, it often results in higher transaction costs due to administration, advice services and control. We concluded that there is no linear relation between cost and benefits, as it depends on the specific case. In agreement with Bechmann et al. (2016a) we acknowledge that an evaluation of the balance between targeting of mitigation measures and the transaction costs is lacking.

3.1 Measures to reduce ammonia emissions

Agriculture is the main source of ammonia (NH_3) emissions in the Nordic countries (about 90% or more). The agricultural sector also has the largest potential to reduce emissions of ammonia.

Ammonia emissions mainly occur as a result of volatilisation from livestock excreta. The complexity of ammonia is that measures need to consider potential downstream emissions as nitrogen conserved at each manure management stage (animal feed and housing, manure storage and application of manure and mineral fertilisers to the fields) is available for ammonia volatilisation in the next stage.

The UNECE Task Force on Reactive Nitrogen has recently summarised a guidance document regarding options for ammonia mitigation (UNECE, 2014; Bittman *et al.*, 2014). This document is based on international research on farming systems that may not necessarily be applicable to Nordic conditions. Animal housing and manure removal systems in the Nordic countries differ in certain respects from agricultural systems applied in other countries as a result of tradition, climate and animal welfare.

Table 3 provides an overview of measures to reduce ammonia emissions in the Nordic countries. A more detailed description of abatement measures applied in the Nordic countries can be found in Antman *et al.* (2015). The most cost effective abatement measures regarding reduction of ammonia emissions are manure application techniques that limit ammonia volatilisation, feeding strategies and low emission manure storage (covered storages), see Table 3.

Grönroos (2014) have assessed different measures to reduce ammonia emissions from agriculture in Finland. 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. Grönroos (2014) concluded the following recommendations:

- Improved implementation of feeding recommendations via farm-specific advisory. (If needed the feeding recommendations can be updated)
- Application: Slurry and urine should be spread mainly with injection. Trail hoses could be used for spreading to growing crops. Solid manure and slurry and urine should be incorporated as soon as possible following spreading, and no longer than after 12 hours. Broadband spreading should be banned.

- Storage: Slurry storages should be covered with floating covers (as a minimum requirement), but preferably with solid, tight roofs. Urine tanks should always be covered with tight roofs.

For Norway, the reduction in ammonia-emissions by changed application method is estimated to 1,500–2,000 tonnes/yr, which is the most efficient measure to reduce ammonia-emissions (Bechmann *et al.*, 2016b).

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, see Table 3. Some housing measures such as air purification and reducing pH of liquid manure, are more expensive.

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):

- Low emission application of manures and fertilisers to land.
- Animal feeding strategies to reduce nitrogen excretion.
- Low emission techniques for all new stores.
- Strategies to improve nitrogen use efficiencies and reduce nitrogen surpluses.
- Low emission techniques in new and largely rebuilt pig and poultry housing.

Table 3: Overview of measures to reduce ammonia emissions. The costs are primarily based on cost estimates from Sweden and Denmark. Updated from Hellsten (2017)

Measure	Reduction potential	Cost per kg N reduced	Comment
Low nitrogen feed	About 20%	-0.5–0.5 EUR (van Vuuren *et al.*, 2015).	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%	0–20 EUR[1)] (Bittman *et al.*, 2014; 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. Lowest costs and highest effect for new stables. This measure could be increased by rules and regulations regarding new livestock houses.
Air purification	About 60% (assuming about 20% of the ventilation capacity)	2.5–17 EUR (NIRAS Kons, 2009)	Options to treat the air ventilated from animal housing, e.g. acid scrubbers to treat the exhaust air. 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	0.5–5 EUR (SBA, 2010)	Reduce the exposure of stored manure to air, e.g. concrete lid, plastic floating sheet, peat (see below), straw or natural crust. The reduction emission potential lies in applying more effective covers than natural crusts. Stricter regulation regarding cover of slurry, urine containers and also digested manure could be an effective measure.
Low ammonia application of manure	45–90% depending on type of manure & time after spreading (< 4 h)	About 0.5–1 EUR (SBA, 2010)	Means to distribute manure to minimise surface exposure, i.e. by placing it underneath the soil, e.g. band application, shallow injection or direct incorporation. Stricter regulations for both slurry, urine and digested manure could be an effective measure.
Low emission application of urea			Refers either to appropriate timing and dose of application or to the substitution of urea by other chemical forms of fertilisers 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, see above.
Using peat during storage of solid manure	About 50%	About 0.5 EUR (SBA, 2010)	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. This measure could be increased by providing information and counselling, to facilitate contacts with peat producers or by offering subsidies for farmers using peat.
Acidification of the slurry	About 80% during storage and 70% during spreading	3–14 EUR (NIRAS Kons, 2009)	Reducing pH of slurry is difficult to implement in some countries, as liquid manure systems are required. Furthermore, the development of biogas production is discouraged. Although methane emissions are being reduced, this measure is disadvantageous for biogas production, which is even more effective regarding GHG. In Denmark acidification is particularly carried out in connection with application. Information activities and subsidies could be possible instruments to encourage the use of acidifying substances.

Note: [1)] Includes expensive measures such as air purification.

3.2 Measures to reduce nitrate leaching

Table 4 provides an overview of measures to reduce nitrate leaching in the Nordic countries.

Table 4: Overview of measures and costs to reduce nitrate leaching in the Nordic countries, mainly based on Bechmann *et al.* (2016a) and SBA (2013)

Measure	Cost per kg N reduced to the sea	Comment
Catch crops	1–3 EUR (5–19 DKK), (Eriksen *et al.*, 2014)	Shows the cost for farmers for reduction of N loss to the sea. If changes in the crop rotation are required the cost will be higher, 21–32 EUR/kg (157 DKK/kg N).
Wetlands (re-establishment and construction)	4 EUR (31–33 DKK), (Eriksen *et al.*, 2014) 5–8 EUR (49–80 SEK) (SLU, 2010)	May act as nitrogen (and phosphorus) traps. Denmark plan to build many small ponds (constructed wetlands) to reduce leaching.
Management of manure (see also Table 3)	42–840 EUR (420–8370 SEK) for a kg of reduced N leaching to the Baltic Sea (Agrifood, 2015).	Advisory services and education exist in each country regarding improved utilisation of manure and fertiliser, e.g. the advisory Program "Focus on nutrients" in Sweden. Denmark[1)] has strong restrictions in N application compared with Sweden, Norway and Finland.
Combined catch crops and spring tillage	10 EUR (96 SEK), (SLU, 2010)	Reduce nutrient leaching during October to March. A catch crop is grown between two main crops and take up the plant nutrients left in the soil after harvest, hence reduces leaching. Spring tillage is associated with a lower risk of nutrient leaching than during autumn, but may increase the use of pesticides during the growing season (depending on crop sequences on the field and type of pesticides that are available for use).
Controlled drainage		The farmer controls the runoff from the arable land by raising or lowering the ground water level using installed wells. Hence nitrogen leaching to surface water can be reduced.
Digestion of manure		Makes the nutrients more easily accessible for the plants, but digested manure is also more easily leached.
Extensive ley/ cultivated grasslands		Contribute to reduced plant nutrient losses and erosion.

Note: [1)] It is not in all aspects stronger restrictions in Denmark than the other Nordic countries. Some countries have or have had exceptions in the Nitrates Directive (Denmark, Germany, Belgium, Ireland, Austria, Holland and France). It is generally the embankment exception is adding up to 230 or 250 kg N / ha.

A recent report (Bechmann *et al.*, 2016a) targets water management for agriculture in the Nordic countries. The authors concluded that the agricultural mitigation measures implemented in Sweden, Denmark, Norway and Finland have many similarities, despite natural and institutional differences between the countries.

During the workshop discussions it was evident that the effectiveness of measures to reduce nitrate leaching depends regionally. For instance, in Finland, controlled drainage has been seen as a good measure to reduce both leaching and emissions of N_2O from peat soils while Denmark on the other hand, has had mixed experience regarding the effectiveness of controlled drainage. This is likely due to the different soil conditions that apply. In Finland, cultivation of peatland is more common, and controlled drainage may also be an important measure to reduce losses of nitrogen from acidic sulfate soils. In Finland, it is suggested that peat soils should preferably be kept under grass cultivation than under cereals or other annual crops to reduce losses.

Regarding optimisation of N fertilisation with inorganic fertilisers, at least in Finland, it is evident from the data of N balances that there are large differences in the N use efficiency between different farms. We suppose that all farmers cannot optimize the N fertilisation according to their conditions, there may be problems with soil structure, the response may be low etc.

We also discussed nitrification inhibitors as a measure to reduce nitrate leaching that may be used more frequently in the future (not included in Table 4). Nitrification inhibitors are compounds that can reduce the rate at which ammonium is converted to nitrate. This can reduce N losses through denitrification and leaching. They must be applied when spreading, as they degrade in tanks.

Digestion of manure to produce biogas makes the nutrients more easily accessible for the plants, but digested manure is also more easily leached. Digestion of manure may lead to lower C in soils if the digest is not used as a fertiliser on fields (if it is not decomposed anyhow). An important question is that if we want to sequester carbon, how does it affect the soil? Holistic approaches are needed for the use of bio-based energy sources to reduce the use of fossil fuels and mitigate greenhouse gas emissions. We concluded that this is an essential dilemma that needs to be discussed politically.

3.3 Measures to reduce emissions of nitrous oxide

N_2O emissions from agricultural soils depends on process rates (nitrification and denitrification), and their product stoichiometry (see Lars Bakken (2017), see Appendix 2). Table 5 provides an overview of measures to reduce emissions of N_2O from agricultural soils.

Table 5: Overview of measures to reduce nitrous oxide (N2O), mainly based on SBA (2010) and JTI (2014

Measure	Comment
Effective use of manure and fertilisers	Particularly regarding spreading, i.e. adjust time and amount of manure to the need of crops. In a Nordic climate, we believe that we can safely say that timing wise, spring application is more efficient that autumn application.
Avoid porous crusts, e.g. straw	Porous crusts during storage of slurry, urine and digested manure may increase the risk of emissions of N_2O (using e.g. a plastic sheet is better). However, it may depend on situation and sometimes a crust is better than nothing. Covering solid manure heaps with a plastic sheet may reduce emissions of N_2O.
Rapid incorporation of manure after application	Likely reduces losses of nitrous oxide. Some methods for low ammonia application of manure may however increase emissions of nitrous oxide, but from a holistic perspective it is still advantageous regarding greenhouse gases.
Digestion of manure	Anaerobic digestion does not result in significant N_2O production, while aerobic digestion (either as compost or as aerated slurries), will emit large amounts of N_2O. However, both potentially reduce N_2O emission after application to soil. Digestion makes the nutrients more easily accessible for the plants and therefore likely also reduces losses of nitrous oxide. However apply a long digestion process, and cool the digested manure or collect the gas to avoid emissions of N_2O.
Catch crops	Reduce nutrient leaching, and likely also reduces losses of nitrous oxide (but may increase the use of pesticides).
Spring tillage	Spring tillage likely reduces losses of nitrous oxide (as long as the soil is not compacted).

Traditional approaches to mitigate emissions (IPCC recommendations for instance) have targeted the process rates, rather than the stoichiometry. Typical examples are:

- Reduced fertiliser levels (thus reducing the rates of nitrification and possibly denitrification).
- Optimizing fertiliser levels to match the assimilation by crops (thus reducing off-season nitrate leaching and denitrification in the soil and downstream).
- Digestion of manure prior to incorporating into the soil (reducing the amounts of available C, thus denitrification).
- Spring tillage (reducing off-season nitrification and denitrification).
- Adequate soil drainage and good soil structure (to minimize denitrification).

However, no-tillage or reduced tillage can increase N_2O emissions. This is true if it is done for just a few years and later the situation can be different (Sheehy *et al.*, 2013; van Kessel *et al.*, 2013).

3.3.1 Mitigating N_2O emissions, novel approaches

The mitigations targeting of process rates are safely anchored in "good agronomic practice", their merits are plausible, and the priority of such measures is understandable considering our limited understanding in the past regarding of the product stoichiometry and its regulation, both in single cells, communities and soils. Today, we are less ignorant however, thanks to recent progress in the study of the ecology and regulatory biology of the organisms involved, and a range of novel mitigation options are emerging, as listed in Table 6.

Table 6: Novel mitigations of N2O emission, targeting the ecology and regulatory biology of N transformations. The options are listed with decreasing realism

Measure	Comment	References
Increasing soil pH	Enhancing the rate of N2OR expression in denitrification, thus reducing N2O/N2 product ratio.Optional materials to increase soil pH: limestone, mafic minerals, biochar.	Qu *et al.* (2014) Russenes *et al.* (2016) McMillan *et al.* (2016) Cayuela *et al.* (2014)
Partial inhibition of nitrification	Reducing the proportion of bacterial ammonia oxidation (versus archaeal), thus reducing the N2O/NO3- product ratio of nitrification.Minimising the risks for anoxic spells induced by ammonium/urea fertilisers due to fast nitrification.	Hink *et al.* (2016) Huang *et al.* (2014) Ruser and Schulz (2015)
Inocculations of legumes with N2O reducing symbionts	Enhance N2O reduction in nodules and the soil; using symbionts which reduce N2O.	Itakura *et al.* 2013
Plant growth promoting rhizobacteria (PGPR) with high N2OR activity	PGPR with truncated denitrification (only N2OR) will effectively reduce the N2O/N2 product ratio of denitrification.	Gao *et al.* (2016)

We acknowledge that novel approaches to reduce N2O emissions targeting the product stoichiometry, would require more research prior to implementation, both for elaborations and for validation of their effects on N2O emissions in realistic agronomic field experiments. But Nordic investment in this research is strongly recommended for several reasons:

- By reducing the N2O/NO3- and N2O/N2 product ratios of nitrification and denitrification, we can achieve substantial reductions without reducing the crop yields in high intensity farming. We need to identify the specific changes in practice for farmers and how these ratios can be changed. The modes of action are transparent, contrasting a number of more traditional agronomic approaches which are based on massive empirical evidence only.
- Nordic research groups are in a strong position to take on this research, with a number of pioneering groups who would be able to make significant progress by coordinating and focusing their research on novel mitigation strategies.

3.4 System change measures

In addition to technical measures (described in Sections 3.1–3.3), system change measures such as precision agriculture, reduction of food waste, increasing the overall efficiency in the food chain, or promotion of consumption patterns with lower nitrogen footprints, could help to further reduce overall nitrogen losses. Also policies affecting structural changes in farm size may have an impact on emission reductions, if more efficient measures that are only applicable to larger farms can be applied.

Some of the system change measures can be achieved at farm level as a voluntary effort, encouraged by advisory programs and knowledge e.g. precision farming, i.e. applying optimum fertilisation rates and adaption to the need and circumstances (soil, weather, vegetation, water etc.), inter cropping and choosing a crop sequence which is advantages for reduction of nitrate leaching, which are all measures that may result in less nitrogen losses from the field.

Other system changes may require policy interaction, such as regulations on reducing N fertilisers below current recommendations, to reduce the nitrogen inputs to the agricultural system. Other examples of system changes that involve policy interaction are e.g. measures to reduce food waste (e.g. improved food packaging and storage) or information campaigns to promote changes in consumption patterns. However, generally it is more cost effective to control the production rather than the consumption. Hence, pricing the products to reflect the emission and environmental costs may be an effective way to change consumption patterns towards products with lower nitrogen footprints. This may, on the other hand, have implications on profitability and competition for the farmer.

For instance, if the import of meat and dairy products would increase, and the Nordic production of these products was reduced, nitrogen losses from agriculture in the Nordic countries would decrease. However, importing agricultural products may not result in an overall reduction in nitrogen losses, as the emissions are just transferred elsewhere. Furthermore, production carried out elsewhere may even be associated with larger nitrogen footprints and environmental effects.

An interesting example comes from the milk sector. The EU milk quotas were abolished in 2015 and the EU predicts a lower milk price. Hence the milk production in e.g. Sweden is expected to decrease, because the milk sector cannot compete with the lower prices. 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 on the cost of exiting farms with a lower emission. Consequently, measures to reduce nutrient losses from agriculture are ineffective if the production is carried out elsewhere with larger environmental effects.

3.5 Synergies and trade-offs – between different pollutants and effects

This section shows the importance of integrating thinking on agricultural nitrogen losses and other pollutants and effects. Measures to reduce one pollutant 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 can 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, and a lower need to use mineral fertilisers.

Table 7 summarises some of the synergies (win-wins) between nitrogen reduction measures and other pollutants and effects. For instance, covering slurry, manure and urine storages not only reduces ammonia emissions but also emissions of methane.

Some measures to reduce pollutants may increase other pollutants or have an impact on other negative environmental effects, see Table 8. For instance, animal feeding strategies to reduce methane emissions may result in increased emissions of ammonia. Furthermore, the conditions reducing methane-emissions may counteract N_2O-emissions, e.g. establishment of a natural crust cover on the storage for swine slurry reduce emissions of methane while increasing emissions of N_2O, but the size of these emissions are not quantified (Bechmann *et al.*, 2016b).

Using catchment scale economic-hydrological optimisation models Konrad *et al.* (2015) and Nainggolan *et al.* (2015) have demonstrated that both trade-offs and synergies between two pollutants such as nitrogen loading to the sea and greenhouse gases (GHG) emissions can be obtained when implementing measures with both effects at the optimal locations. Hereby abatement costs of the two pollutants can be reduced at the same time, but the effects might also be neutral or even conflicting.

Table 7: Overview of synergies between different pollutants and effects (updated from Hellsten *et al.* (2017))

Measure	Synergy
Measures reducing both ammonia and methane emissions	Covered slurry, manure and urine storage (with a plastic sheet or with permanent roofs). Digestion of manure (extracting biogas from slurries). Acidification of the 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).
Measures reducing ammonia and having other positive effects	Low nitrogen feed, low emission housing and covered storage 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, better housing environment and animal health. Improved utilisation of manure and fertilisers, low ammonia application of manure and re-use of ammonia from air purification result in lower production of mineral fertilisers (reduction of greenhouse gas).
Measures reducing both nitrate leaching and nitrous oxide emissions	Catch crops. Spring tillage. Reduced tillage. Digestion of manure.
Measures reducing both nitrate leaching and other positive effects	Extensive ley/cultivated grasslands also decrease the risk of erosion. Reduced tillage, means less fuel. Erosion control. Digestion of manure (biogas production) increase the production of renewable energy, decrease greenhouse gas emissions from manure and reduce leaching of nutrients. Spring tillage is also a good soil erosion measure.

Table 8: Measures which reduce one pollutant but increase the other, or is associated with other negative environmental effects (updated from Hellsten *et al.* (2017))

Measure	Trade-off
Measures to reduce ammonia	Using peat during storage of solid manure is disadvantageous when it comes to climate change effects and other environmental effects of increased peat extraction. Acidification of slurry discourages the development of biogas production, which is even more effective regarding the reduction of greenhouse gases. (However this is not the case when acidification is done in field immediately prior to application.) Air purification may increase emissions of N_2O. Air purification, demands mechanical ventilation rather than natural ventilation, hence demands higher energy consumption. Manure incorporation means higher fuel consumption.
Measures to reduce nitrate leaching	Wetlands may increase emissions of methane and N_2O. Controlled drainages on arable may increase emissions of N_2O. Spring tillage, reduced tillage and catch crops may increase the use of pesticides. No till, spring tillage may increase PO_4 losses with surface run-off. Spring tillage and reduced tillage can increase N_2O emissions (compacting the soil). A more compact soil increase emissions. A good soil structure (to avoid standing water) is important for reduced emissions of N_2O.
Measures to reduce N_2O	Spring tillage, reduced tillage and catch crops may increase the use of pesticides. Structural liming may increase release of CO_2. Improved soil drainage may increase N leaching.
Measures to reduce methane	Some animal feeding strategies can increase N excretion, hence increases ammonia emissions. Active aeration (composting) of stored manure generally increases ammonia emissions.

There is a need for policy perspectives to move more towards a holistic approach, hence when evaluating mitigation measures within agriculture, the effect on other pollutants and effects also needs to be considered. During the workshop, we concluded that synergies are not a problem, but trade-offs are! It is, however, important also to be aware of the positive side-effects of different measures, when evaluating their effectiveness, cost and overall environmental impact.

Table 8 clearly shows that it is important to consider trade-offs in order to avoid shifting nitrogen emissions from one area of the environment into another. But how can we assess trade-offs between N effects and other types of effects? How do we decide what is the priority order of targets? For instance: How do we conclude what is the best way forward: using peat during storage of solid manure to reduce ammonia emissions, or is it better to prioritise the negative effects of peat extraction? The first step is to fill the knowledge gaps regarding the environmental effects of the different measures. But even if we do have all the knowledge regarding effects, how and who decides what is best to prioritise? Hence, the greatest challenge regarding trade-offs are how to weigh the different effects to each other. Regarding GHG (greenhouse gases) the measure is CO_2-equivalents, but there is nothing like "nitrogen damage equivalents". We concluded that summarising synergies and trade-offs in a table is a good start. The tables presented in this report are not complete, but they summarise the majority and the most important synergies and trade-offs when it comes to nitrogen mitigation in the agricultural sector.

Apparently there is a gap to define, evaluate and compare e.g. biodiversity versus groundwater effects. Abatement costs and private benefits from the production of crops and livestock might be easy to measure using available market prices, but it might be more difficult to measure and include the value of the ecosystem services and goods that do not have a price, such as the effects on biodiversity, groundwater contamination/protection etc.

There is a need for tools to assess combined effects of measures to reduce pollution to air and water, e.g. the GAINS model (Klimont and Winiwarter, 2015), and the FarmAC/Farm-N models are examples of tools to evaluate combined effects (Dalgaard *et al.* 2014; 2017). The TargetEconN model developed for the Limfjords and Odense catchments in Denmark (Konrad *et al.*, 2015) and the BALTCOST model for the Baltic sea (Hasler *et al.*, 2014, applied for both N, P and GHG in Nainggolan *et al.*, 2015) are also such examples.

4. Agricultural and environmental policies

Adequate policies and regulations regarding manure management are important to reduce the impact of reactive nitrogen from farming systems in the Nordic countries. 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 to further explore how to increase the use of abatement measures to reduce nitrogen losses from agriculture.

Implementation of measures may occur on a mandatory or voluntary basis. There are several international policies applied in the agricultural sector, which have partly different targets and follow-up indicators. On a national level, there are surprisingly large differences between the regulatory frameworks in the Nordic countries applied to implement measures.

There is a need for policy perspectives to move more towards a holistic approach. Furthermore, identification of knowledge gaps as well as possible overlaps and gaps in existing policies on reactive nitrogen in the Nordic countries are needed.

4.1 International agri-environmental policy

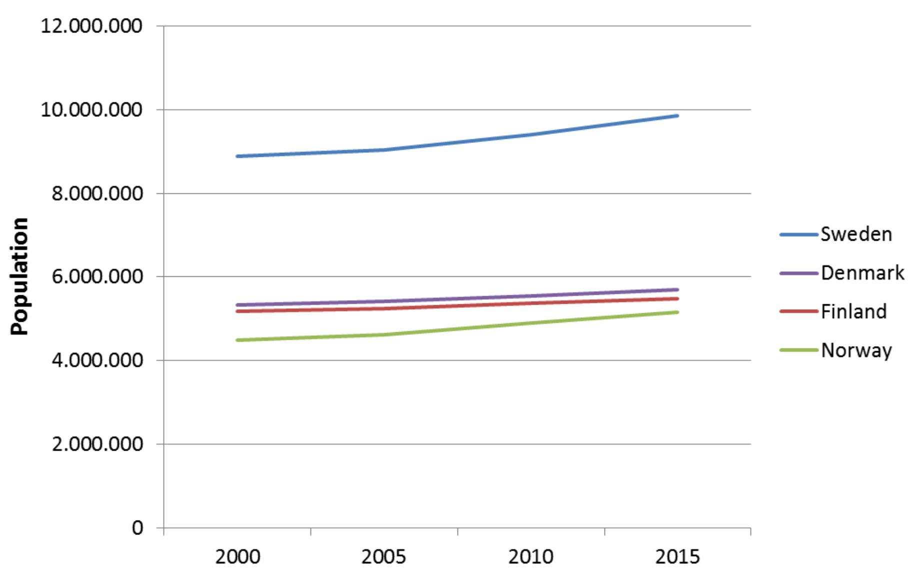
Nitrogen emissions are trans-boundary and can be transported long distances from other countries. Therefore, international cooperation is important to reduce negative environmental impacts. Several international agreements have been adopted in recent decades e.g. the Gothenburg Protocol, the National Emission Ceilings Directive (2001/81/EG), the Helsinki Commission's (HELCOM's) Baltic Sea Action PLAN (BSAP) and the Nitrates Directive (91/676/EEC). The Agenda 2000 and the reform of the Common Agricultural Policy (CAP), including greening of CAP in 2015. Agricultural activities, and especially the use of animal manure and fertilisers, are affected by five categories of EU policies and measures (Oenema *et al.*, 2012):

- The EU Water Framework Directive, Nitrates Directive and Groundwater Directive.
- Air and climate change related EU directives (National Emission Ceilings Directive, the Directive on Ambient Air Quality, the Directive on Industrial Emissions, and policies related to the Kyoto protocol).
- Nature conservation legislation, including the EU Birds and Habitats directives.
- Animal welfare regulations.

The UN Convention on Long Range Transboundary Air Pollution (CLRTAP) has set up EPMAN, the Expert Panel on Mitigating Agricultural Nitrogen under the Task Force on Reactive Nitrogen (TFRN). Other important nitrogen initiatives include the European Nitrogen Assessment (Sutton *et al.*, 2011), which presented sources, effects and policy perspectives of reactive nitrogen in Europe. Currently an OECD-project is assessing the use of different policy instruments to manage the unwanted release of nitrogen.

European policies have been successful in reducing nitrogen emissions e.g. from power generation and road transport. At the same time the population in the Nordic countries has increased (Figure 10). However, policy options to reduce reactive nitrogen from the agricultural sector have so far not been subject to equally stringent regulations. Cost-effectiveness analyses have shown that technical measures within the agricultural sector are more cost effective compared with other sectors which have been subject to more stringent regulations (Hasler *et al.*, 2014; Reis *et al.*, 2015). It is also important to take synergy effects into account in order to avoid shifting nitrogen emissions from one area of the environment into another (see Section 3.5).

Figure 10: Population development in the Nordic countries from year 2000



The Nitrates Directive (1991) aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices in Nitrate Vulnerable Zones (NVZs). These zones are land areas that contribute to nitrate pollution and which drain into polluted waters or waters at risk of pollution. Good Agricultural Practice includes measures such as:

- Limiting the periods when nitrogen fertilisers can be applied on land.
- Measures limiting the conditions for fertiliser application.
- Requirement for a minimum storage capacity for livestock manure.
- Crop rotations, soil winter cover, and catch crops.

The Nitrates Directive forms an integral part of the Water Framework Directive (2000) and is one of the key instruments in the protection of waters against agricultural pressures. The Water Framework Directive (WFD) aims at a good ecological status of water bodies in Europe. It is based on the concept of the natural geographical and hydrological unit, the river basin, to which management plans should be designed.

HELCOM Baltic Sea Action Plan (BSAP) aims to restore the good ecological status of the Baltic marine environment by 2021. For this reason, HELCOM has adopted the following ecological objectives to describe the characteristics of a Baltic Sea, which is unaffected by eutrophication:

- Concentrations of nutrients close to natural levels.
- Clear water.
- Natural level of algal blooms.
- Natural distribution and occurrence of plants and animals.
- Natural oxygen levels.

Environmental measures in agriculture have gained a more prominent role also in the different schemes under the EU common agricultural policy (CAP). The original objectives of CAP in 1962 were to provide affordable food for EU citizens and a fair standard of living for farmers. In the CAP reform in 1992 farmers were encouraged to be more environmentally friendly. That coincided with the 1992 Rio Earth Summit, which launched the principle of sustainable development. A new CAP reform in 2003 cut the link between subsidies and production. Farmers started to receive an income support payment, on condition that they look after the farmland and fulfil environmental, animal welfare and food safety standards. From 2015 and onwards, agri-environmental measures are complemented with greening payments funded directly by the EU. The payments require crop diversification and maintaining an ecological focus area and permanent grassland.

Nowadays the schemes of CAP include various conditions aiming at environmental protection and sustainable agricultural production. These conditions require beneficiaries to take certain measures without a separate compensation.

4.2 National agri-environmental policy

Table 9 provides a summary of current policy controls in the Nordic countries. Bechmann *et al.* (2016a) noted that, although there are many similarities regarding agricultural mitigation measures implemented in the four countries, there are large differences between the instruments used in the agricultural policy. In Denmark, general command-and-control-measures (rules and regulations) are dominating. Most of the measures have been implemented as legislations, but with a recent shift towards a more geographically differentiated and voluntary framework (Dalgaard *et al.*, 2014). In Finland and Norway more regionally adapted incentive-based policies are used. In Sweden, agricultural mitigation measures are based on legislation, information campaigns and subsidies.

Farmers in Denmark, Sweden and Finland can get support for a number of voluntary measures within the Rural Development Programmes (RDP). Most of the measures are within (RDP), however, for Denmark, large parts of agricultural mandatory measures have been outside the RDP.

Actions related to the Nitrates Directive have a high priority in all four countries, because the directive is binding even for Norway. Within the HELCOM countries, measures to prevent nitrogen leaching have very high priority, because most of the countries have reduction conditions set in the Baltic Sea Action Plan. Furthermore, the Water Directive sets high priorities for nitrogen abatement for countries that border the sea. However, the ammonia targets and reductions set in the Gothenburg Protocol and the EU National Emissions Ceilings (NEC) Directive are rather low. This is likely to have significance for the ammonia mitigation strategies applied in the Nordic countries.

Pira *et al.* (2016) recommended that measures should be taken to reduce the gap between the Nordic countries regarding the usage of technical measures for emission reductions. Furthermore, a platform to share experiences should be set up. The current project has contributed to facilitate the collaboration between nitrogen experts from the different Nordic countries with special focus on nitrogen from agriculture. Nordic countries have often acted together in international fora and our results can be important in this context. The sustainability of far northern ecosystems represents a special responsibility of the Nordic countries and the Nordic conditions might be of less priority for other European countries.

Table 9: Summary of current policy controls in the Nordic countries

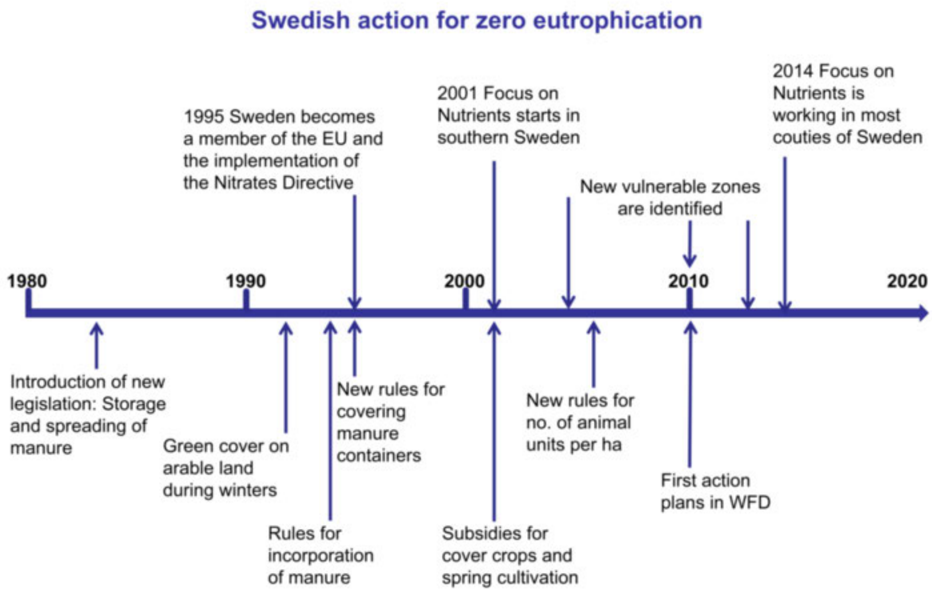
Information and counselling	Rules and regulations	Investment support
Sweden		
The advisory Program "Focus on nutrients" (Greppa näringen") focuses on increasing nutrient management efficiency by increasing awareness and knowledge. The campaign is characterised by voluntary participation, farm specific measures, repeated farm visits and follow-up on each farm.	Regulations regarding the spreading, storing and use of manure consider regional differences. All livestock farms must have sufficient manure storage. In southern Sweden requirements for coverage of slurry and urine tanks apply. Regional, specific rules for when manure spreading should occur, and how quickly the manure should be incorporated into the soil apply. The sensitive areas also have restrictions on type of spreading techniques. In southern Sweden, 50–60% of arable land shall be under vegetative cover during the autumn and winter.	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
Norway		
The agricultural advisory service conveys information on best management practices including reduced tillage, grassed buffers and waterways and sedimentation ponds. They are also the main actor making fertiliser plans.	The rules and regulations consist of production grants requiring fertiliser and pesticide plans; national and regional environmental programmes with subsidies for measures to reduce nutrient losses and rules for when, how and where to spread manure.	Environmental support schemes: -Tillage in spring instead of autumn -Reduced tillage -Catch crops, spring cultivation -Riparian buffer zones -Maintenance of ponds and wetlands Environmental investments: -Construction of sedimentation ponds -Hydrotechnical installations to reduce surface runoff -Manure storage

Information and counselling	Rules and regulations	Investment support
Denmark		
Information on manure handling, animal housing and optimized feed practice. Information regarding fertiliser norms and buffer zones (restrictions) near sensitive areas. Program for catchment advisors (oplands-konsulenter), to promote, suggest and facilitate local solutions to meet requirements for catchment based N leaching reductions from agriculture. Information about organic farming and other types of environmentally friendly systems: both at the consumer side (e.g. for branding and local food chains), and at the producer side (e.g. for new types of manufacturing and about conversion).	Rules for storage of slurry and manure (e.g. minimum storage capacity, no runoff from manure heaps and mandatory slurry tank floating barriers). Rules for how and when manure spreading should occur (e.g. broadcasting banned, and ban on winter spreading of slurry for spring crops). Mandatory fertiliser and crop rotation plans (min. proportion of area with winter crops and catch crops). Ban on autumn soil tillage before spring crops. Voluntary buffer zones around sensitive areas.	Subsidies to: -Promote better manure handling and animal housing (BAT) -Establish strategic wetlands -Low-N grasslands in environmentally sensitive areas -More organic farming, extensification and afforestation
Finland		
Many environmental projects, e.g. - TEHO, TEHO+ (2008-2014; http://www.ymparisto.fi/tehoplus) - JÄRKI (2009 -; www.jarki.fi) - LOHKO, LOHKO II (2015 -; www.mtk.fi/lohko) - Supported advisory services (Råd 2020; http://www.mavi.fi/sv/stod-och-service/radgivare/neuvo2020/ Sidor/default.aspx)	Regulations regarding the spreading, storing and use of manure or organic fertiliser products. Larger animal units need to have environmental permits. Stricter upper limits for N fertilisation for those who have joined the Finnish Agri-Environmental Programme, otherwise according to the Nitrates Directive. Also municipal environmental protection regulations (e.g. manure spreading).	- Investment support e.g. for livestock farming investments and for investments that improve the status of the environment e.g. investments to improve the efficiency of manure management, subsurface drainage and controlled subsurface drainage, Support for non-productive investments e.g. construction of wetlands

4.2.1 Sweden – Agri-environmental policy

Sweden has regulations on the spreading, storing and use of manure (SBA, 2015). Legislation on storage and spreading of manure were introduced already in the 1980's. Since then further and expanded rules have been introduced, see Figure 11.

Figure 11: Time-line of Swedish action for zero eutrophication. WFD – Water Framework Directive



Source: Stina Olofsson, Swedish Board of Agriculture, Appendix 2.

2001 the advisory Program "Focus on nutrients" (Greppa näringen) started, in order to meet government environmental objectives regarding eutrophication, a non-toxic environment and reduced climate impact. The information campaign focuses on increasing nutrient management efficiency by increasing awareness and knowledge. "Focus on nutrients" puts the farmer in focus and the core of the information campaign is education and individual on-farm advisory visits. The campaign is characterised by voluntary participation, farm specific measures, repeated farm visits and follow-up on each farm. The programme is run as a co-operation between the Swedish Board of Agriculture, the Federation of Swedish farmers, County administrative boards and advisory firms. See also Section 4.5.1.

In addition to "Focus on nutrients", support schemes and environmental investments are also included within the Rural development program, see Table 10.

Table 10: An overview of support schemes and environmental investments within the Swedish Rural development program

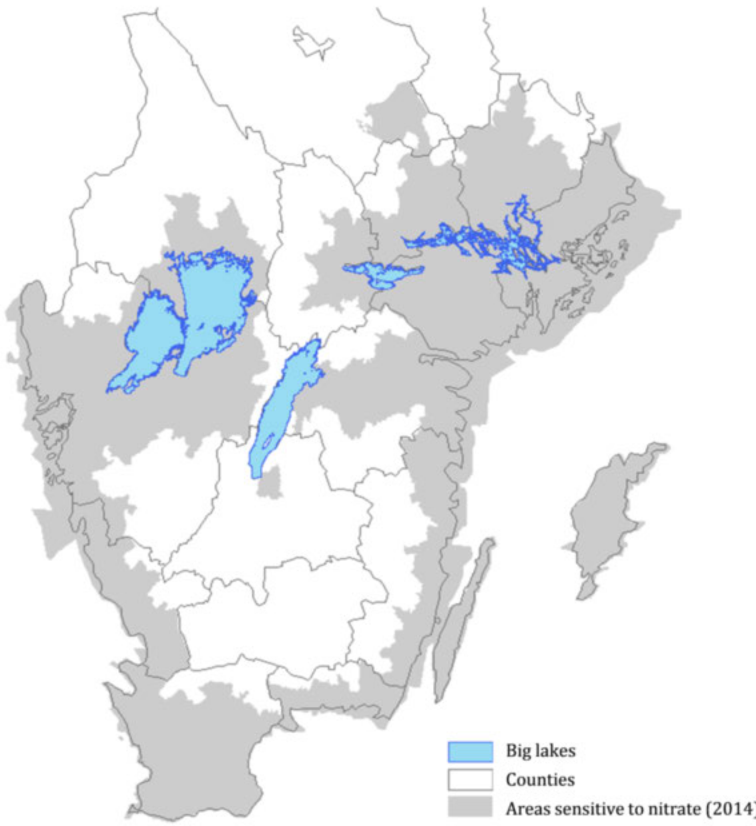
Investment support	Measure
Environmental support schemes	Cultivation of ley. Catch crops, spring cultivation. Riparian buffer zones. Maintenance of ponds and wetlands.
Environmental investments	Construction of wetlands. Different investments for improved water quality. Two step ditch. Controlled drainage.

The programme "Focus on nutrients" has shown to be successful. During a 10-year period, the transport of nitrogen to rivers in Sweden has decreased by 20–30%. The decrease was greatest in the regions where most measures had been done and in areas where "Focus on nutrients" had been ongoing (Fölster *et al.*, 2012). 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. Fölster *et al.* (2012) noted that combining the two measures catch crops and spring tillage, best explains the improvements, and both these measures are supported withing the environmental support schemes.

A more recent report (Agrifood, 2015) concluded that the advising visits within "Focus on nutrients" had reduced N leaching and also led to increased yields. "Focus on nutrients" is funded by the Swedish Rural Development Program.

Current Swedish regulations regarding the spreading, storing and use of manure 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 12.

Figure 12: Sensitive areas in Sweden (NVZ) (gray areas)



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 12), there are also restrictions on type of spreading techniques that should be used. The spreading of manure and other organic fertilisers is limited by its content of phosphorus that may not exceed 22 kg per hectare available land, counted as a five-year average. In southern Sweden, the rules state that 50–60% of arable land shall be under vegetative cover during the autumn and winter.

4.2.2 *Denmark – Agri-environmental policy*

The past century, significant expansion of Danish agricultural production and N inputs have led to a parallel increase in agricultural N surpluses, and an increased N leaching (Hansen *et al.*, 2011; Dalgaard *et al.*, 2014). With more than 60% of the land farmed and a 7,500 km long coastline with shallow estuaries and coastal waters, this has resulted in severe environmental problems, and according to the EU Nitrate Directive, Denmark has designated the whole territory as nitrate vulnerable.

From 1985 and onwards the following series of political action plans to mitigate losses of N and other nutrients were implemented (updated from Dalgaard *et al.*, 2005, 2014; Kronvang *et al.*, 2008; Mikkelsen *et al.*, 2010):

- 1985 Action Plan on nitrogen, phosphorus and organic matter (NPo).
- 1987 Action Plan for the Aquatic Environment I (AP-I).
- 1991 Action Plan for Sustainable Agriculture.
- 1998, 2000 Action Plan for the Aquatic Environment II (AP-II).
- 2001 Ammonia Action Plan.
- 2004 Action Plan for the Aquatic Environment III (AP-III).
- 2009 Green Growth Plan.
- 2011/2014 1st Generation River Basin Management Plans, implementing the EU Water Framework Directive (WFD).
- 2016 New Danish Agri-Environmental Policy and 2nd Generation River Basin Management Plans.

In summary, these action plans included the types of measures listed in Table 11, which according to Dalgaard *et al.* (2014) can be classified into either Command and Control measures (C&C), Marked-Based Regulation (MBR) or Information and Voluntary Action (IVA).

C&C is the classic regulation type, where a certain action or pollution practice is forbidden by law, controlled by the authorities, and fined if the law is violated. In contrast, MBRs includes all types of Marked-Based Regulation and Governmental Expenditure that directly affect the market and thereby the economic optimum for production and hence pollution. This category covers both:

- Market-Based Instruments where the management and pollution behavior are regulated via market incentives, typically via a green tax (for example N-taxation) under the polluter pays principle (Carter, 2007). (N taxation is not implemented in Denmark, but there is a pesticide tax as well as a tax on phosphorus in fodder).
- Other types of Market-Based Regulation (for example N quotas combined with manure trading possibilities).
- Governmental Expenditure, that in the form of subsidies affects the market in a similar way to taxes, but by encouragement rather than inhibition. Governmental

expenditure is not necessarily under the polluter pays principle (for example, most of the EU agri-environmental policy measures are under this category, as they are designed to promote environmentally friendly production practices, but financed by the EU member states budgets and not via a specific farm tax; Buller *et al.*, 2000).

Finally, the remaining types of policy measures are classified as Information and Voluntary Action (IVA). This includes knowledge production and communication of information about more sustainable N-management practices and technologies via research and extension services (which may be subsidised), and actions by "individuals or organisations doing things to protect the environment that are neither required by law nor encouraged by financial incentive", and which "the government can encourage through a range of communicative strategies" (Carter, 2007).

The initial action plans were based on both national and international political initiatives (Dalgaard *et al.*, 2014): Already in 1972 Denmark, France, Iceland, Norway, Portugal, Spain, and Sweden signed the Oslo Convention, prohibiting the direct dumping of harmful substances at sea. After the inclusion of among others the United Kingdom, the Netherlands and Germany, this treaty was amended in 1981 and is today included in the OSPAR (1992) "Convention for the Protection of the Marine Environment of the North-East Atlantic". The Danish action plans have subsequently been used to implement the EU Nitrates Directive of 1991 (The Council of the European Communities 1991), and the Water Framework Directive (WFD) in year 2000 (The European Parliament and the Council of the European Union 2000). Moreover, at an international level the ambitions of reducing nutrient loads to the environment are also important parts of treaties in relation to the HELCOM Baltic Marine Environment Protection Commission (The Helsinki Commission 2008), The Marine Strategy Framework Directive (The European Parliament and the Council 2008), and the, from 1983 and onwards enforced, UN Convention on Long-range Transboundary Air Pollution (CLRTAP).

Table 11: Selected examples of N policy measures, implemented over the past 30 years with the Danish N action plans (extended from Dalgaard *et al*,. 2014). Geographically targeted types are marked as localised (in brackets)

Year	N measures imposed:	C&C[1]	MBR[2]	IVA[3]
1985	-Max. stock density.	X	-	-
	-Mandatory slurry tank floating barriers.	X	-	-
	-No runoff from silage clamps and manure heaps.	X	-	-
	-Min. slurry capacity and ban on winter spreading of slurry for spring crops (including subsidies to invest in slurry tanks etc.).	X	(X)	-
1987	-Mandatory fertiliser and crop rotation plans.	X	-	-
	-Min. proportion of area with winter crops.	X	-	-
	-Mandatory manure application within 12 hours.	X	-	-
1991	-Statutory norms for manure N utilisation.	X	-	-
	-Max. N applied to crops equaling econ. optimum.	X	(X)	-
	-Subsidies to low-N grasslands in environmentally sensitive areas.	-	(localised)	(X)
1998	-Max. N applied 10% below economic optimum.	X	(X)	-
	-6% mandatory catch crops.	X	-	-
	-Subsidies to more organic farming, new wetlands, extensification and afforestation.	-	(localised)	(X)
2001	-Promotion of low excretion livestock feeding.	-	-	X
2004	-More catch crops	X	-	-
	-Tightened ammonia restriction (e.g. broadcasting banned), and special restrictions near sensitive nature areas.	(localised)	-	X
	-Subsidies to promote better manure handling and animal housing (BAT).		X	X
		-		
2009	-Buffer zones around streams, lakes and NH_4 sensitive habitats.	(localised)	-	-
	-More catch crops (≈14%) mitigating less set aside.			
	-Tax on mineral P in feed.	X	-	-
	-Max. N applied ≈15% under economic optimum.			
	-Optimized feed practice promotion.	-	X	-
		X	(X)	-
		-	-	X
2011	Ban on autumn soil tillage before spring crops.	X	-	-
2014	-Subsidies to compulsory 10 m buffer zones along lakes and water courses.	X	X	-
	-More wetlands, and catch-crops in vulnerable estuaries.	(localised)	X	-
2016	-More catch-crops in vulnerable zones.	X	-	-
	-Fertiliser norms set to economic optimum.	X	X	-
	-Buffer zones made voluntary.	-	-	X
	-Subsidies to establish strategic wetlands.	-	-	X

Note: [1)] C&C – Command and Control.
[2)] MBR – Market Based Regulation or Governmental Expenditure.
[3)] IVA – Information and Voluntary Action.

4.2.3 Finland – Agri-environmental policy

Water bodies are an important part of the Finnish countryside and inland waters cover about 10% of the country's total surface area. First concerns of eutrophication, and agriculture's role in promoting it, arose already in the 1960s. Nowadays there is a set of legal instruments to control agricultural nutrient losses (Table 12).

Table 12: Summary of legal instruments to control agricultural nutrient losses in Finland

Year	Plan	Significant element	Target
1960s and 1970		First concerns of the effect of agriculture on water quality.	
1990	National agricultural policy	Advice, obligatory set-aside with the tax on P-fertilises.	Reduce over-production and over fertilisation.
2000	Nitrate Directive	Good agricultural practices, control manure spreading on fields, storing of manure and other organic fertilisers, max N fertilisation levels.	Reduce nitrogen losses to surface and groundwaters.
1995	Finnish Agri-Environmental Programme 1	Conform to the EU's agri-environmental policy. Upper limits for N and P fertilisation.	To reduce suspended sediments and nutrient losses into water bodies by about 20–40%.
1998	Water protection targets to 2005		Eutrophication control.
2000	Finnish Agri-Environmental Programme 2	Increasing crop cover during winter.	More attention to biodiversity.
2000	Environmental permits for livestock housings (based on Environmental Protection Act).		
2000	Municipal environmental protection regulations (based on Environmental Protection Act)	Includes regulations for agriculture, e.g. manure spreading.	
2005	Water protection targets to 2015		Reduction of nutrient loads from Finnish agriculture by a third compared with their levels over the period 2001–2005.
2007	HELCOM Baltic Sea Action Plan	Transboundary pollution; Atmospheric and terrestrial.	Reduction of N load to the Baltic Sea, 1,200 tn N.
2007	Finnish Agri-Environmental Programme 3	Higher reduction in P fertilisation.	
2010	1st Water Management Plan (WPD)	Agri-Environmental programme – the main tool in the agricultural sector	Good ecological status of waters.
2013	Finnish Agri-Environmental Programme 4	Reduced P fertilisation by manure. Catch crops. Increasing crop cover during winter.	More attention to mitigation of climate change.
2016	2nd Water Management Plan (WPD)	Agri-Environmental programme – the main tool in agricultural sector.	Good ecological status of waters.

Nutrient leaching from manure spreading is a growing problem in Finland due to the concentration of livestock farming in certain areas and its separation from crop farming. Manure handling is regulated mainly via the Nitrates Directive andall of the cultivated land area is classified as a nutrient vulnerable zone (NVZ). Furthermore, national environmental legislation has a permission procedure to regulate emissions of substantial operators like intensive large-scale livestock farms.

The agri-environmental programme, that is a part of the Rural development programme, consists of a package of measures related to environmental commitments that aim for environmentally sustainable farming, separate environment contracts that promote water protection in agriculture, biodiversity and genetic diversity in arable land environments and gene bank conservation measures.

The main emphasis of the measures is to reduce nutrient loads into the watercourses and to enhance biodiversity. Within the current agri-environment-climate measure (2015–2020), the climate issues are paid more attention than before. Farmers have been interested in the agri-environmental schemes for as long as they have been available. Nowadays, around nine farmers out of ten have made an environmental commitment for a period of five years.

When joining the agri-environmental program, farmers accept a set of measures concerning balanced use of fertilisers (Table 13). In addition, farmers can select parcel-specific operations, which are:

- Recycling of nutrients and organic matter.
- Incorporation of slurry into the soil.
- Control of runoff waters.
- Environment management grasslands.
- Plant cover on arable land in winter.
- Use of organic cover for horticulture plants and seed potatoes.
- Biodiversity in arable land environments.
- Alternative plant protection for horticulture plants.

Environment management grasslands include perennial grass covered areas that are buffer zones, perennial environment grasslands, and nature management fields. The measure regarding biodiversity in arable land environments includes grass for green manure, catch crops, renovation plants and biodiversity fields.

Table 13: Farm scale measures included into the Finnish agri-environmental programme

Measure	Specific
Balanced fertilisation of crops	
Farm environmental planning	parcel-based notes
Filter strips	3 m wide
Upper levels of fertilisation	crop and soil type specific
Soil tests	chemical and soil type
Education day	

Note: More information:https://www.maaseutu.fi/en/rural-development-programme/Brochures_and_publications/Pages/default.aspx

Furthermore, committed farmers can agree on a 5-year environment contract which can be made without an environmental commitment. These contracts comprise measures regarding management of wetlands, management of biodiversity in the agricultural environment and landscape, crane, goose and swan fields, and rearing of local breeds. Farmers can also get support for non-productive investments which are wetland investments and initial clearing and fencing of heritage biotopes and natural pastures. Investment support can also be provided, e.g. regarding manure storage and processing or subsurface drainage. In addition, the Rural development programme includes finances for farm level advising, for example targeting agri-environmental measures and improving animal welfare.

Nitrogen loads from agriculture in Finland increased during 2000–2006, and then decreased by about 10% during 2007–2012. Phosphorus loads peaked already in 1995–1999 and have decreased steadily since then. The decrease was about 20% which reached the original target of the agri-environmental programme but was still not enough for achieving the current official targets of load reduction to the surface waters. Clearing of new fields explained 50% of the increase in nitrogen fluxes to the Baltic Sea between the periods 1995–1999 and 2000–2006 (Rankinen *et al.*, 2015).

4.2.4 Norway – Agri-environmental policy

In Norway, during the 1980s and 1990s, a system of regulation and economic instruments coordinated by local authorities was developed to encourage farming practices that would reduce diffuse source runoff from agricultural land and point discharges from silos and manure storage systems. The system has been amended and adapted over the years. The legislation includes various regulations under the Pollution Control Act and the Land Act. There are rules on the levelling of steep and hilly farmland to prevent runoff, and regulations on manure and silage effluent that are intended both to reduce point discharges from storage facilities and runoff after application of organic fertilisers. Arable farmers must carry out a plan for fertiliser application to avoid a surplus of nutrients, and there are rules limiting the number of livestock that may be kept per unit area of land. Furthermore, subsidies are given to soil tillage methods that reduce erosion and to retention-measures for nutrients and soil particles (grassed buffer zones and sedimentation ponds).

The regulations relating to production subsidies include a number of environmental standards farmers must meet to be entitled to the subsidies, including pesticide journal, fertiliser application plan, and two meter buffer zone along water ways. A farmer who does not comply with the requirements may lose part of the production subsidies. The Agricultural Directorate is responsible for the schemes, but the schemes are coordinated by the county authorities.

In addition, there are two systems of subsidies for environmental measures in agriculture to encourage farmers to reduce nutrient losses from agriculture. The one system is meant to solve specific regional environmental challenges (Regional Environmental Programme, RMP) and the other system is for special measures requiring more long term investments and maintenance (SMIL).

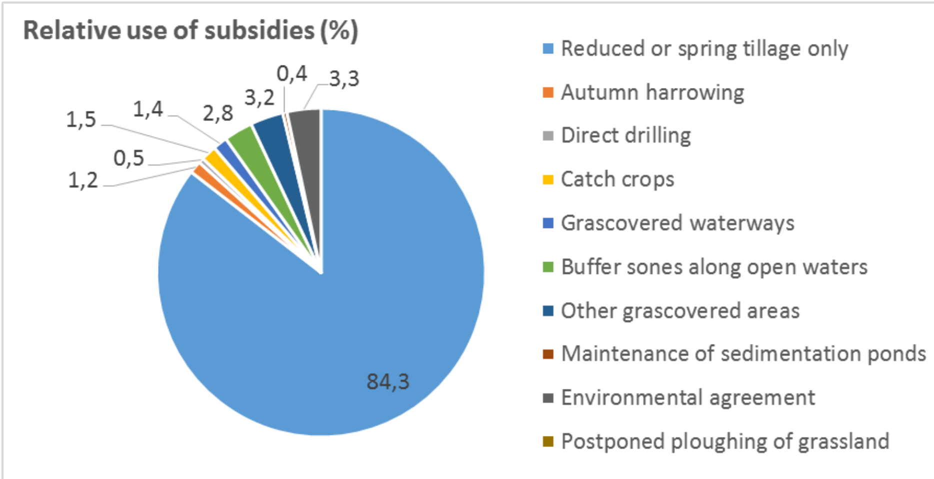
In the SMIL system farmers can for example apply for subsidies to establish constructed wetlands or sedimentation ponds, hydrotechnical installations, waste water treatment facilities or re-open culverted streams. Both investment and maintenance may be paid by subsidies. The local county authorities are responsible for these schemes.

In 2005, the agricultural environmental programme was changed from national to regional level, the regional environmental programme for the agricultural sector (RMP). The county governor authorities can adjust measures to suit regional conditions like the agricultural production system, the main environmental problems in the county, i.e. erosion risk and pollution level. Since 2005, the agri-environmental program has been regional in nature, which means that the county governor is responsible for the management of these schemes and have the freedom to choose level of payments, adjust measures and implement new measures. Practices that may be eligible for subsidies include:

- Changed tillage, stubble/minimum-till rather than bare soil during the winter.
- Buffer zones along streams and lakes.
- Grassed water ways.
- Grass on flood areas.
- Catch crops.
- Manure application in spring and growing season.

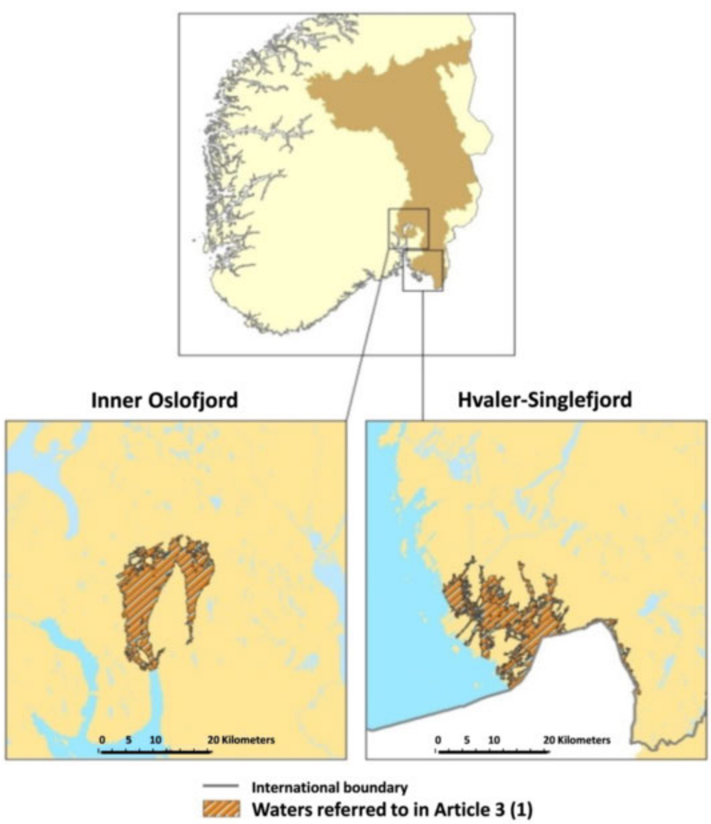
The priority of these grants varies from county to county, and the county governors are responsible for selection of measures and the level of subsidies. At the national level, however, 84% of the grants are used to change soil tillage practices (Figure 11).

Figure 13: The relative use of subsidies in the regional environmental programme in Norway



Nitrate vulnerable zones (NVZ) in Norway are identified in the marine areas in Inner Oslo fiord and in the Glomma estuary. These are vulnerable areas regarding the nitrates directive (Figure 12). In these areas a generally good agricultural practice and specific management plans are required.

Figure 14: Norwegian nitrate vulnerable zones (NVZ) according to the nitrates directive (91/676/EEC, article 3 (1))



The manure regulations require that all livestock farms in Norway must have sufficient manure storage for 8 months in order to avoid spreading manure during inappropriate times of the year (Table 12). The required spreading area for manure is corresponding to 2.5 livestock units ha^{-1} (based on the phosphorus-content of the manure. Both spreading time and methods are regulated. The regulation of organic fertiliser is under revision to accomplish the requirement of reduced emissions to the environment.

Table 14: Regulations for organic manure

Regulations for organic fertiliser
Capacity for manure storage for 8 months
Livestock density; 2.5 LU ha^{-1}
No manure application November 1^{st} – February 15^{th}
Incorporation of manure within 18 hours on arable land

In specific areas, contracts were offered to farmers if they agreed to implement a set of mitigation measures on their farm. These practices included limited nutrient application rates, no ploughing in the autumn, grassed buffer sones along all open waters and constructed wetlands where appropriate. Specific subsidies were given along with the contracts.

In agreement with Bechmann *et al.* (2016a), we noted that, although there are many similarities regarding agricultural mitigation measures implemented in the four Nordic countries, there are large differences between the regulatory frameworks applied in the different countries:

- Better utilisation of manure and other regulation has reduced N loading by up to 50% in Denmark. On the other hand, the fertiliser norm system is expensive and allows low flexibility to farmers.
- The Swedish advisory programme "Focus on nutrients" has been effective in reducing N losses from agriculture. The programme has the benefit of knowledge transfer and flexibility in application via the farmers' visits.
- The Finnish "Agri-Environment program" payment system has succeeded in joining farmers to the programme. It has reduced especially phosphorus loadings from fields.
- In Norway, the legislation on manure management, the Regional Environmental Programme and subsidies for environmental investments successfully motivates farmers to implement measures, mainly regarding phosphorus losses.

We noted that both stringent regulations (as in Denmark), and voluntary and advisory efforts (as in Sweden) have been successful in reducing nitrogen losses from agriculture. However, during the workshop we discussed that the complexity of the regulations (in Denmark) is becoming too high for the farmers to handle. The complexity has been discussed also in Finland on ministery level, but we have not been able to find a reference for that discussion.

We suggest a survey or analysis of the complexity of the regulations in the Nordic countries, to identify if there is a need to simplify them. Instead of increasing the number of pages in the regulation manual even more, there may be a need to simplify the regulations, and still obtain the same level of environmental benefit.

4.3 Policy challenges

Through the NEC directive, Denmark has committed to reduce ammonia emissions by 24%, Finland by 20% and Sweden by 17% until 2030 (compared with the base year 2005). The reduction commitments between 2020 and 2030 are identical in the NEC-directive and the revised Gothenburg Protocol.

Additional measures to reduce ammonia emissions in the Nordic countries are necessary in order to achieve these pollution targets. For instance, in Finland, agricultural ammonia emissions are expected to be about 31.8 kt in 2020, only considering the expected changes in the operational environment, hence without particular actions to reduce emissions (Grönroos, 2014). This corresponds to a reduction of about 8% compared with the target year 2005. However to reach the target for 2020 (13%), an additional reduction of 4.1 kt is required via specific emission reduction measures.

The largest reduction potential for ammonia emissions is in the agricultural sector. Efforts should primarily concentrate on cost-effective, practical and feasible measures, such as those proposed by Grönroos (2014), i.e. 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. A further challenge is not to make the regulatory system too complicated.

Policy Bodies have set up pollution targets, e.g. within the Gothenburg Protocol and the NEC-directive. During the workshop we discussed what the target or the desirable state is. Who will decide? Is it a political decision that we want to achieve, or should we aim at a pristine environment? Different policies may aim notably different targets, from sufficient food production to good ecological status of waters.

Due to different targets, the policies are implemented by different ministries, which may cause conflicts of interest. For example, CAP is clearly an agricultural policy owned usually by the ministry of agricultural matters. On the other hand, e.g. WFD and NEC are environmental legislation owned usually by the ministry of environmental matters.

Another policy challenge refers to emissions derived in other countries. For instance, the climate footprint of Danish agriculture is larger than national areas indicate, e.g. due to areas for soy production in Brazil to feed pigs.

Other interesting policy aspects that we discussed:

- N use efficiency versus N-surplus measurements.
- What limits us in implementing the right policy?
- We noted that technical measures may not be enough to reach the pollution targets, hence also system change may be needed.

We also identified some knowledge gaps:

- Linking management of nitrogen to losses in the whole N cascade, including emissions of greenhouse gasses.
- Adaption to climate change.
- The baseline is more or less unknown.

4.4 Costs of abatement measures

In a policy context, it is important to show that substantial economic and environmental benefits can be gained from reducing nitrogen losses from agriculture. 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 air purification in new and largely rebuilt pig and poultry houses. Measures should not be too expensive to the farmers, and may in some cases even pay for themselves, e.g. through advisory efforts that increase the utilisation of livestock manure and thereby obtain a reduction in the cost of mineral nitrogen fertiliser due to savings of nitrogen within the farming system. For instance, improved nutrient management planning, accounting for real value of nitrogen in manure and based on average yield instead of maximum yield on a field, could be an easy way to reduce nitrogen application with low cost for farmers (e.g. Bechmann *et al.*, 2016b). 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 substances (e.g. methane) and reduced energy consumption, as manufacturing of ammonia-based fertilisers are associated with energy use, see Section 3.5.

One tool to assess different emission reduction scenarios is the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model, developed by the International Institute of Applied Systems Analysis (IIASA). The GAINS tool is applied to conduct integrated assessment model analysis in support of the Gothenburg Protocol (Klimont & Winiwarter, 2015). The model estimates emissions of 10 air pollutants (e.g. ammonia) and 6 GHGs greenhouse gases every 5th year from year 2005 to 2030 based on different scenarios. The GAINS model can therefore be used to reveal win-win policy interventions, as well as trade-offs.

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, Denmark, Finland and Norway 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, and reduced ammonia emissions by 17–29% in the Nordic countries from 2010 to 2020, see Table 15.

Table 15: Ammonia emissions (kt) and reductions (%) for the baseline and the MID scenario described in Amann *et al.* (2011)

	Baseline, 2010	Baseline, 2020		MID-scenario, 2020	
Denmark	59.2	52.5	-11%	48.9	-17%
Finland	33.1	30.4	-8%	25.1	-24%
Sweden	50.6	46.3	-8%	37.7	-25%
Norway	21.8	22.4	3%	15.5	-29%

Hellsten (2017) presented a scenario with four feasible measures (mainly derived from SBA, 2010) which have the potential to reduce ammonia emissions in Sweden:

- Low nitrogen feed for all 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.

Implementing these four measures would result in an emission reduction of 3.5 ktonnes, which is about half way to the emission target of the NEC-directive for 2030. Hence, even further measures are needed, e.g. lowering the crude protein further also for dairy cows and poultry, to its optimal level (without decreasing productivity), or use more efficient covers for slurry compared with natural crusts.

Grönroos (2014) noted that an additional reduction of 4.1 kt is required in Finland via specific emission reduction measures in order to reach the emission targest in Finland until 2020. The combination of enhanced feeding, covering storages and low ammonia spreading techniques were considered to be most efficient.

Previous cost estimates of ammonia abatement and nitrogen oxides abatement indicate that most of the low cost measures for NOx emission 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 can be rather cheap, compared with further abatement of nitrogen oxides (NO_x) (Reis *et al.*, 2015). Hence, technical measures within the agricultural sector are more cost effective compared with nitrogen reduction s within other sectors already subject to more stringent regulations.

We concluded that relevant cost data need to be provided together with mitigating effects to make an integrated assessment to support decision making. However, costs and effects are difficult to compare across Nordic countries due to different conditions in the countries. An effective measure in one country may be difficult or very expensive to implement in another country, due to differences in the farming systems, soil conditions or regulatory frameworks.

Some farmers may be interested in implementing measures to reduce environmental problems, even if it is costly. Hence providing information and knowledge through advisory efforts is important.

We identified a couple of economic barriers from implementing measures:

- Farmers may be facing long term investment costs (maybe > 20 years) from implementing abatement measures, so even if these abatement measures in theory could be implemented tomorrow, capital investments need to be included in the measurement of the costs, see e.g. Eriksen *et al*. (2014).
- The high share of rented land with short-term contracts (particularly in Finland and Norway), may lead to lower investments to maintain the productivity of the land, e.g. less liming or ditching, etc. With short rental contracts farmers cannot expect to get the benefit from their own investments.

4.5 Policy efforts

The dominant policy instruments to reduce nitrogen losses from agriculture in the Nordic countries today consists of financial incentives and regulatory and information measures. Table 9 summarises current policy controls in the Nordic countries and this chapter further discusses policy efforts to increase the use of abatement measures to reduce nitrogen losses from agriculture in the Nordic countries.

4.5.1 Information and advice

Information and voluntary action 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 advice reveals economic incitements and increased profitability for the farmer. Furthermore, increasing knowledge among farmers facilitates for other types of policy efforts to gain acceptance and thus become politically possible to implement.

The information campaign "Focus on nutrients", which has been running in Sweden for many years has contributed to decreasing nitrogen transport from agricultural land to rivers. The information campaign focuses on increasing nutrient management efficiency by increasing awareness and knowledge. "Focus on nutrients" puts the farmer in focus and the core of the information campaign is education and individual on-farm advisory visits. Stina Olofsson (Swedish Board of Agriculture, see Appendix 2), the Project leader of "Focus on nutrients", summarises four important experiences from the programme:

- Repeated visits are the key to influence changed behaviour.
- The advisor always has to relate to how measures taken will influence farm economy.
- It is important to inform farmers about the progress and make them proud of their achievements – preferably through the press.
- To inspire change, the visits need to be voluntary for the farmer.

There have also been agri-environmental projects with farm specific advisory efforts in other countries but they have been short-lived and targeted in smaller areas than "Focus on nutrients".

Examples:

- Similar approaches have been implemented in Norway for specific areas, e.g. the lake Vansjø and Skas-Heigre, where contracts with farmers on environmental behaviour were introduced together with farm visits. However, focus has been on phosphorus and not as much on nitrogen. Furthermore, the Norwegian webpage "Tiltaksveilederen" (www.nibio.no/tiltak) present information on mitigation measures to reduce nutrient losses from agriculture.
- TEHO (2008–2011) and TEHO Plus (2011–2013) in south-west Finland (Launto-Tiuttu *et al.*, 2014), and JÄRKI (2009–2013 and 2014–2018) in southern Finland.
- The new watershed advisory scheme in Denmark, and the work with water councils (Graversgaard *et al.*, 2016). Similar actions were also undertaken in Denmark in the 1990's in campains called "Gylle er guld" ("manure is money").

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 more sustainable agricultural and food system.

4.5.2 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. Rules and regulations also require means to administrate and follow up the regulations. A problem may be that the farmer is not provided with incitements to reduce emissions further than stated in the regulations. Another disadvantage may be that the regulations may be too complicated and expensive.

4.5.3 *Investment and other support*

Investment support systems can be an effective policy effort, because it provides the farmer with clear economic incentives to bring through a particular measure. A disadvantage is the (governmental) administrative cost of the scheme. Investment support is currently provided e.g. for the construction of wetlands in Denmark, Finland and Sweden, and for the maintanence of wetlands in Norway, and for controlled drainage in Sweden and Finland, see Tabel 9 for more examples.

The CAP can be described as having three dimensions: i) market support, ii) income support and iii) rural development. The first two dimensions — market support and income support — are solely funded by the EU budget, whilst the rural development dimension is based on multiannual programming and is co-financed by the member states. In general, to avoid negative side effects of some farming practices, CAP provides incentives to farmers to work in a sustainable and environmentally friendly manner. In Finland, the cost of the agri-environmental programme in the second programme period was 2.3 billion EUR, paid by the EU and Finland. In Sweden, disbursed direct support to agricultural holdings in Sweden within the CAP were 9,502 million SEK in 2014 (SCB, 2016). Environmental support schemes regarding nitrogen (see Table 10) added to 809 million SEK, of which the majority (717 million SEK) was directed towards cultivation of ley.

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 farms 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 manure. 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.

4.5.4 *Taxes and fees*

Market based instruments, such as taxes and fees, are a means to regulate management and pollution behaviour via market incentives under the polluter pays principle (Carter, 2007).

Taxes and fees are fair in the sense that the polluter must compensate for the environmental problems, and it sends a signal to decrease emissions regardless of the initial quantity of emission. Furthermore, the governmental cost is low. However, taxes or charges require administrative systems and the outcome of the policy action may be uncertain. The economic efficiency of market based instruments is believed to be high since it generates financial incentives for both producers and consumers to reduce emissions. However, it is important that the level of tax is balanced and therefore requires precise information about the sensitivity of the price for both supply and demand.

In Sweden, a reintroduction of the tax on mineral fertilisers, which was abolished in 2009, has been discussed in recent years. Considering the cascading effects of nitrogen, N-taxation may be a means to influence the supply of reactive nitrogen into the system. The National Institute of Economic Research (NIER) in Sweden suggests that the tax should be re-implemented, as a means to reduce the use of mineral fertilisers (KI, 2014). NIER refers to the lack of effective policy instruments to reduce the supply of nitrogen through fertilisation. However, in Sweden, the previous nitrogen tax reduced emissions of nitrous oxide by only two percent (the Swedish nitrogen efficiency was already high). The effect of the previous N-taxation in Sweden, and the reasons for abolishing it, need to be assessed further in order to better understand the effectiveness of a new N-taxation.

Also Norway had a tax on mineral fertilisers (1988–2000). In Norway, a reintroduction of the tax of 2.80 NOK per kg of nitrogen has recently been suggested to reduce emissions of nitrous oxide (NOU, 2015:15). However, the effectiveness of the tax compared with other measures has been questioned (Bechman *et al.*, 2016b).

Another interesting policy effort to concider could be tariffs on imports of agricultural products, to promote domestic production of e.g. meat and dairy products. Implementing tariffs increases the domestic price of the agricultural produce, and may result in overall reductions in nitrogen losses from agriculture (provided that the domestic nitrogen losses are lower compared with the imported product). The drawback, however, is that it leads to lower trade.

The Nordic countries need to increase the use of abatement measures to reduce nitrogen losses from agriculture further. But what is the best way forward? Stricter and more stringent regulations or more voluntary and advisory efforts? We concluded that the Nordic countries are very different, and therefore one type of policy may not fit all.

We believe that an important policy challenge is to consider the quality of farming when designing regulations, e.g. farm business development and freedom to their type of farming. There is a big difference depending on type of farming, e.g. dedicated crop farmers, pig producers, dairy producers, part time farmers etc., or small scale farming vs. large scale farming, and organic farming vs. conventional farming.

During the workshop discussion we identified some important areas to address in the future regarding policy strategies:

- Peatland soil management.
- Precision farming with new technology.
- Organic fertiliser products – What is the actual N value? If sewage sludge based fertilisers are used how can the quality of the product be guaranteed (harmful substances, availability of N and P for plants)?
- Taking yield into account as a basis for fertilisation. Using five-year average yield as a basis for nutrient management planning. Low yield levels should not be over-fertilised while for high yielding crops and field parcels often more nutrient inputs can be used without risk to the environment.
- Taking Nitrogen Use Efficiency (NUE) into account as a useful additional metrics.
- Because the organic production type itself has specific regulations, all environmental regulations suitable for conventional farming might not be possible for organic farming. It may also be

relevant to consider small scale farming vs. large scale farming. On the other hand, it is not ideal to create big gaps between production types.

- Nitrogen inhibitors may be an important future abatement measure. Nitrogen inhibitors are relatively harmless, but may be difficult to regulate.
- Possibility to add liming to policy. EU considers it as a basic farmers action, but it is not supported. Structural liming and biochar are allowed.

5. Recommendations and further work

The current study has contributed to encourage Nordic collaboration regarding nitrogen and agriculture. In this chapter we present the main conclusions and recommendations from this study.

5.1 Policy actions

- The focus in the Nordic countries should be on implementing the most cost effective, practical and feasible measures first. As long as these practical and feasible measures (which do not cause other negative environmental effects) are not fully implemented, more demanding and costly approaches should not be the first priority.
- For reduction of ammonia emissions from agriculture, we noted that low nitrogen feed, covered slurry and manure storages and low ammonia emission spreading techniques, are among the most cost-effective, practical and feasible abatement measures to implement.
- In some cases, it may be relevant to extend current rules and regulation e.g. regarding new livestock houses, and coverage of manure tanks and spreading of manure, slurry and digested manure. However, the effects (economic and on other pollutants and environmental effects) need to be considered and further investigated.
- We recommend that some of the current farm-regulations are simplified.
- We recommend scientifically based voluntary actions, in line with the Swedish advisory program "Focus on nutrients" to be continued and further developed, and that similar approaches are also implemented in other Nordic countries.
- Important success criteria for advisory actions and changed farming behaviour are voluntary measures and repeated farm visits, relating to how measures will influence farm economy (positively or negatively) and feedback to farmers regarding the environmental progress (e.g. through the press) to make the farmers proud of their achievements.
- We also recommend more, scientifically based information campaigns about the effects of changed consumption behaviour, towards reduced nitrogen and greenhouse gas emissions, highlighting the environmental benefits.

- We believe N balances, and the distribution of surplus N to different types of losses, may be more relevant as a basis for policy instrument on large (landscape and regional) scales rather than on a small (field) scale.

5.2 Policy challanges

- A great challenge with agri-environmental policies is to decrease negative effects, while at the same time maintain or increase food production.
- When assessing technical abatement measures, a holistic policy approach, not only considering the direct mitigating effect and costs but also other benefits and effects of the actual measure, is important.
- In addition to technical measures, system change measures, e.g. reduction of food waste, increasing the overall efficiency in the food chain, or promotion of consumption patterns with lower nitrogen footprints, could help to further reduce overall nitrogen losses.
- An important policy challenge is to consider the effect of emissions produced in other countries due to increased import. Measures to reduce nutrient losses from agriculture are ineffective in a global perspective if the production is carried out in other countries with as large or larger environmental effects.
- An important dilemma that needs to be discussed politically is the question of carbon sequestration and the fact that digestion of manure to produce biogas may have negative implications and lead to lower C content in soils if the digest is not returned into the soils as fertiliser. Holistic approaches are needed for the use of bio-based energy sources to reduce the use of fossil fuels and mitigate greenhouse gas emissions.
- We need to produce more with less in the future. Precise farming with modern technology should be highlighted. In this way higher yields with lower nitrogen losses, and net greenhouse gas emissions etc. can be obtained.

5.3 Further work

- From a policy perspective, to further motivate abatement of nitrogen losses from agriculture, it is important to identify knowledge gaps as well as possible overlaps and gaps in existing policies on reactive nitrogen.
- The complex interactions, synergies and trade-offs between different pollutants and environmental effects demand relevant assessment tools and more research to find the right balance between potential conflicting interests, including e.g. emission savings, other environmental effects, costs, and ethical values.
- There is a need to improve the understanding of the efficiency of voluntary efforts and advisory actions.

- Nordic research groups are in a strong position to take on research in novel approaches to mitigate ammonia, nitous oxides and nitrate losses from agricultural land, while developing a significant and more sustainable bioeconomy.
- An evaluation of the balance between targeting of mitigation measures and the transaction costs is lacking.
- There is a gap to define, evaluate and compare e.g. biodiversity versus water protection effects, mitigation measures for climate change versus water protection targets, etc.
- There are large potentials for the development of the Nordic agriculture-based bioeconomy including integration of environmental protection schemes and a better utilisation of nitrogen in the whole production chain.
- The back up from the scientific community within the field of nitrogen research is an important contributor to the prominent position of the Nordic countries in different policy bodies within the EU as well as within the Convention on Long Range Transboundary Air Pollution (CLRTAP). Therefore, it is important to continue to exchange information and experience between the Nordic countries on measures and policy strategies to reduce nitrogen losses from agriculture.

6. Acknowledgements

This study has been financed by the Nordic Council of Ministers (NMR) to which the authors are very grateful. The project was initiated by the Environment and Economy Group (MEG) at the Nordic Council of Ministers. The project has made it possible for experts from the four Nordic countries Denmark, Finland, Norway and Sweden to come together and discuss and compare policies and mitigation measures regarding nitrogen and agriculture.

Thank you to the Danish Innovation fund for sponsoring the www.dNmark.org Nitrogen Research Alliance, to Aarhus University and the Ministry of Environment and Food of Denmark for support to the related work under the UN-ECE Task Force on Reactive Nitrogen (TFRN), and the European Union for research support, among other via the H2020 FAIRWAY project on "Farm systems that produce good Water quality for drinking water supplies".

Thank you to the Swedish Environmental Protection Agency, for funding ammonia emission research within the Research Programme SCAC, (Swedish Clean Air & Climate Research Program, www.scac.se), via the project on "Ammonia emissions in Sweden – Inventories, projections and potential for reduction", which has contributed also to this report.

We thank the reviewers at MEG; Øyvind Lone, Ministry of Climate and Environment, Norway, Signe Krarup, Ministry of Environment and Food of Denmark and Fredrik Granath, Swedish Environmental Protection Agency for their review of the report. We also thank Berit Hasler at Aarhus University and Peringe Grennfelt, IVL Swedish Environmental Research Institute för reviewing the report, We highly appreciate the comments and suggestions from all reviewers, which significantly contributed to improving the quality of this report.

We also thank Jens Perus, Centre for Economic Development, Transportation and the Environment, Finland, at MEG for helping out with the administration of the project and the report.

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Sammanfattning

Syftet med den här studien var att ge rekommendationer om:

- Strategier och styrmedel för att uppnå kostnadseffektiv minskning av reaktivt kväve från jordbruket i de nordiska länderna.
- Behovet av ytterligare arbete för att beskriva effekterna av integrerade, kostnadseffektiva strategier för att minska förlusten av reaktivt kväve i de nordiska länderna under varierande klimat och markförhållanden.

Denna rapport baseras i huvudsak på en litteraturstudie genomförd av Sofie Hellsten, Tommy Dalgaard, Katri Rankinen och Kjetil Tørseth (se Appendix 3). Ytterligare underlag till rapporten har inhämtats från diskussioner på en workshop i Göteborg i januari 2017, med 11 deltagare från de nordiska länderna med olika bakgrund inom området kväve och jordbruk (se Appendix 1). Den aktuella studien har bidragit till att förstärka det nordiska samarbetet om kväve och jordbruk.

Huvudsakliga slutsatser och rekommendationer

De nordiska länderna har under de senaste 20 åren infört effektiva åtgärder för att minska kväveutsläpp till omgivningen. Trots detta är kväveförlusterna fortfarande relativt höga jämfört med de politiska mål som satts upp, och trots det regelverk som gäller för jordbrukssektorn på EU-nivå och nationell nivå. De nordiska länderna är på mycket olika stadier när det gäller kväveminskning. Danmark har till exempel redan minskat sina kväveförluster med 50 %.

Framförallt är lämpliga riktlinjer och regler för gödselhanteringen viktiga för att minska effekterna av reaktivt kväve (ammoniak, nitrat och lustgas) från jordbrukssektorn i de nordiska länderna. Vilken ytterligare forskning kan rekommenderas, och vad är vägen framåt för policyutveckling: Strängare lagar och förordningar, ekonomiska styrmedel och incitament, eller mer frivilliga och rådgivande verksamheter? Dessutom är det viktigt att diskutera hur man kan beakta emissioner och osäkerhetsfaktorer som beror på väderförhållanden och andra faktorer som inte kan kontrolleras av jordbrukare.

Vi har identifierat några viktiga politiska åtgärder:

- Fokus i de nordiska länderna bör ligga på att genomföra de mest kostnadseffektiva, praktiska och genomförbara åtgärderna först. Så länge dessa praktiska och genomförbara åtgärder (som inte orsakar andra negativa miljöeffekter) inte genomförs fullt ut, bör inte mer krävande och kostsamma metoder ges hög prioritet.
- För minskningen av ammoniakutsläpp från jordbruket, noterade vi att anpassning av fodret, bästa möjliga teknik för täckning av gödselbehållarna och val av metod vid gödselspridningen, är bland de mest kostnadseffektiva, praktiska och genomförbara åtgärderna att tillämpa.
- I vissa fall kan det vara relevant att utvidga gällande regler (exempelvis för nya djurstallar, gödsellagring och spridningteknik vid spridning av gödsel, slam och rötad gödsel). Effekterna (både ekonomiska och gällande påverkan på andra utsläpp och miljöeffekter) måste dock beaktas och undersökas ytterligare.
- Vi rekommenderar att en del av de nuvarande reglerna och förordningarna för jordbrukssektorn förenklas.
- Vi rekommenderar att vetenskapligt baserade frivilliga åtgärder, i linje med det svenska rådgivningsprogrammet "Greppa Näringen", ska fortsätta och vidareutvecklas, och att liknande metoder genomförs också i andra nordiska länder.
- Viktiga framgångskriterier för rådgivande verksamhet och ändrat beteende bland jordbrukare är frivilliga åtgärder och upprepade besök på gårdar, som relaterar till hur åtgärderna kommer att påverka jordbruksekonomin (positivt eller negativt) och feedback till jordbrukaren avseende miljömässiga framsteg (t.ex. genom pressen) för att göra jordbrukarna stolta över sina prestationer.
- Vi rekommenderar också mer vetenskapligt baserade informationskampanjer om effekterna av förändrade konsumtionsmönster, mot minskade kväveemissioner och utsläpp av växthusgaser, med fokus på de miljöfördelar detta bidrar till.
- Vi tror att kvävebalanser, och fördelningen av kväveöverskottet till olika typer av förluster, kan utgöra en bättre grund som politiskt styrmedel på en stor skala (landskap och regionalt) snarare än på en liten (fält) skala.

Vi har identifierat några viktiga politiska utmaningar:

- En stor politisk utmaning när det gäller miljöåtgärder inom jordbruket är att minska negativa effekter, samtidigt som man bibehåller eller ökar livsmedelsproduktionen.
- Vid bedömningen av tekniska åtgärder för att minska kväveförluster från jordbruket, är det viktigt med en helhetssyn, inte bara med tanke på den direkta minskningseffekten och kostnaden utan även för att beakta andra fördelar och effekter av själva åtgärden.

- Förutom tekniska åtgärder, kan systemförändringar, t.ex. en minskning av matavfallet, en ökad effektiviteten i livsmedelskedjan, eller främjande av konsumtionsmönster med lägre kvävepåverkan, bidra till att ytterligare minska de totala kväveutsläppen.
- En viktig politisk utmaning är att ta hänsyn till effekten av kväveutsläpp i andra länder på grund av ökad import. Åtgärder för att minska växtnäringsförluster från jordbruket är ineffektiva globalt sett om produktionen sker i andra länder med lika stor eller större miljöpåverkan.
- Ett viktigt dilemma som måste diskuteras politiskt är frågan om kolbindning och det faktum att rötning av gödsel för att producera biogas kan få negativa konsekvenser och leda till lägre C-halt i marken om rötresten inte återförs till jordarna som gödningsmedel. En helhetssyn behövs för användningen av biobaserade energikällor för att minska användningen av fossila bränslen och minska utsläppen av växthusgaser.
- Vi måste producera mer med mindre resurser i framtiden. Ett effektivt jordbruk med modern teknik bör betonas. På detta sätt kan vi erhålla högre avkastning med lägre kväveförluster och nettoutsläpp av växthusgaser osv.

Vi har identifierat några viktiga kunskapsluckor där det behövs ytterligare forskning:

- Ur ett politiskt perspektiv, för att ytterligare motivera minskningen av kväveförlusterna från jordbruket, är det viktigt att identifiera kunskapsluckor samt eventuella överlappningar och luckor i befintliga styrmedel gällande reaktivt kväve.
- Den komplexa växelverkan, synergier och avvägningen mellan olika föroreningar och miljöeffekter kräver relevanta bedömningsverktyg och mer forskning för att hitta den rätta balansen mellan potentiella motstridiga intressen, inklusive t.ex. utsläppsbesparingar, andra miljöeffekter, kostnader och etiska värderingar.
- Det finns ett behov av att förbättra förståelsen av effektiviteten av frivilliga insatser och rådgivande verksamhet.
- Nordiska forskargrupper befinner sig i en stark position att ta sig an forskning om nya metoder för att minska utsläpp av ammoniak, lustgas och nitrat från jordbruksmark, och samtidigt utveckla en betydande och mer hållbar bioekonomi.
- En utvärdering av balansen mellan riktade åtgärder och transaktionskostnader saknas.
- Det finns en kunskapslucka för att definiera, utvärdera och jämföra effekter på t.ex. biologisk mångfald kontra vattenskydd, klimatåtgärder kontra miljömål avseende vattenskydd, etc.
- Det finns stora potentialer för utvecklingen av den nordiska jordbruksbaserade bioekonomin inklusive samordning av miljöåtgärder och ett bättre utnyttjande av kväve i hela produktionskedjan.

- Stödet från det vetenskapliga samfundet inom området för kväveforskning utgör ett viktigt bidrag till den framträdande positionen som de nordiska länderna besitter i olika politiska organ inom EU samt inom konventionen om långväga gränsöverskridande luftföroreningar (CLRTAP). Därför är det viktigt att fortsätta utbyta information och erfarenheter mellan de nordiska länderna angående åtgärder och politiska styrmedel för att minska kväveförlusterna från jordbruket.

Appendix 1. Workshop, Gothenburg 12–13 January, 2017

A project workshop (Nitrogen and Agriculture in the Nordic countries – causes and effects, measures and recommendations) was carried out in Gothenburg 12–13 January, 2017. The workshop gathered 11 participants for two days of presentations (see Appendix 2) and discussions on the topic of nitrogen losses from agriculture in the Nordic countries. The workshop only included participants from Sweden, Denmark, Norway and Finland. The main focus of the workshop was nitrogen from the agricultural sector, i.e. flows of reactive nitrogen in agriculture, hence reactive nitrogen from other sources were only discussed briefly.

The aim of the workshop was to exchange information and experience between the Nordic countries on measures and policy strategies to reduce nitrogen losses from agriculture.

Additional objectives of the workshop were to provide recommendations on:

- Issues, strategies and policy instruments to achieve cost effective abatement of reactive nitrogen from agriculture in the Nordic countries.
- The need for further work to understand the nitrogen reduction effects of integrated, cost effective control strategies for reactive nitrogen in the Nordic countries.

The workshop was divided into three sessions, and within each session a number of questions were addressed and discussed:

- Impact assessment and the nitrogen budget
- Successful policy examples
- Measures, synergies and trade-offs

The conclusions and recommendations from the workshop are presented in this report within gray boxes. These discussions are based on the knowledge and views of the 11 people who participated in the workshop. Another 8 people were invited, but could not attend the workshop. Hence in order to improve the quality of the report even further, some of the people who were unable to attend the workshop were invited as co-authors to this report.

Appendix 2. Abstracts from the Workshop

Paths to a sustainable agricultural system

Kajsa Pira, AirClim, Sweden

The project "Pathways to a Nordic food system that contributes to reduced emissions of greenhouse gases and air pollutants" covers Denmark, Finland, Norway and Sweden and focus on methane, nitrous oxide, ammonia and to some degree carbon dioxide emissions. In a first report "Nordic agriculture air and climate" (Antman *et al.*, 2016; Pira *et al.*, 2016) some of the findings were:

- Although the Nordic region, to a large extent, is culturally, social and economically homogenous, agricultural structures, topographic and climate conditions, land use and production figures differ significantly between the countries.
- The agricultural sector and mainly livestock manure accounts for as much as 96% of the total emissions of ammonia in Denmark and approximately 90% on average in the Nordic countries. These levels are unlikely to drop significantly unless the right measures and policies are being put into place.
- There are several conflicts of interests counterproductive of the objective to reduce emissions from agriculture that need to be addressed. These include animal welfare, biodiversity and cultural landscape, farmers' income and land use.
- There is a need for a paradigm shift in how we perceive agricultural production, food systems and consumption, the import/export balance, consumption patterns, and how we perceive efficiency in the farming sector and take into account environmental and climate impact factors.

The project has now with help from researchers at the Swedish University of Agricultural Sciences developed scenarios for future diets in the four countries, based on organic farming practices and principles of limiting livestock to available resources that do not compete with food production. Three scenarios were modelled with different number of livestock. In each scenario land was allocated to grow all food in the diets for the projected populations in 2030. Preliminary results show that the scenarios will lead to 35–70% reductions of ammonia emissions in Sweden. The full report will be published later in 2017.

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Developments in Danish N mitigation measures, effects, and impacts on the overall N budget

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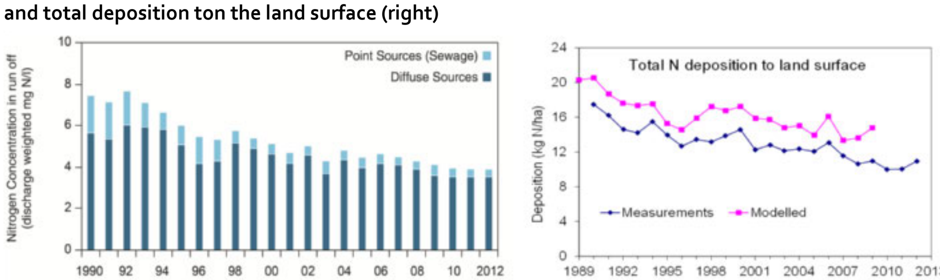
In 1985, the first Danish action plan to reduce losses of nitrogen (N), phosphorus and organic material to the aquatic environment set the target to half total N-leaching from the root zone of Danish agricultural soils, and at the same time reduce other types of losses significantly. Today, this goal has been met (Dalgaard *et al.*, 2014), and the effects on N losses to both groundwater (Hansen *et al.* 2011), the aquatic- (Figure 15, left) and terrestrial environment (Figure 15, right) are evident.

Figure 15: Annual flow-weighted total N concentration in Danish surface water outflow to the sea (left) and total deposition ton the land surface (right)



Note: Left, based on Wiberg-Larsen *et al.* 2013), and atmospheric N depositions to land surfaces. Right, modified after Dalgaard *et al.* 2014, Ellermann *et al.* 2010.

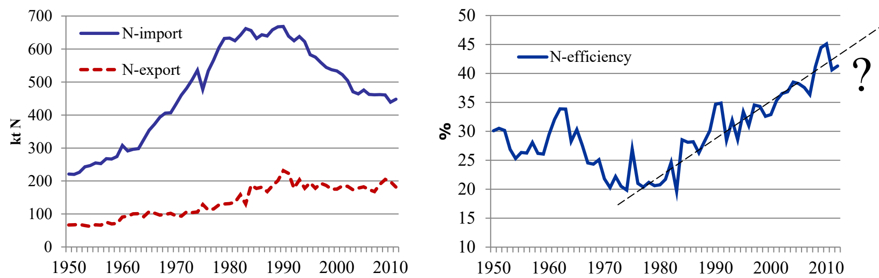
The reductions in N losses from agriculture have been accomplished by policy measures, ranging from Command and Control instruments, over Market Based Regulation and Governmental Expenditure to more Voluntary Action, and with a time trend in implementation from the former to the latter type of measures. However, most

[3] The present paper is abstracted from Dalgaard T, Brock S, Børgesen CD, Graversgaard M, Hansen B, Hasler B, Hertel O, Hutchings NJ, Jacobsen B, Jensen LS, Kjeldsen C, Olesen JE, Schjørring JK, Sigsgaard T, Andersen PS, Termansen M, Vejre H, Odgaard MV, de Vries W and Wiborg I (2016). Solution scenarios and the effect of top down versus bottom up N mitigation measures – Experiences from the Danish Nitrogen Assessment. Feature Presentation for the International Nitrogen Initiative Conference INI2016. Melbourne Australia, 5th–8th December 2016.

of the measures have, mainly for political reasons, been implemented uniformly for the whole country, with the same type of standards for all farmers across the country (general regulation).

Developments in N inputs and N outputs since 1950 document the generally improved N Use Efficiency, NUE (Figure 16):

Figure 16: Total sum of N imports to- and sum of N exports in products from Danish agriculture, and overall N use efficiency for Danish agriculture over the period 1950–2012. How different, new measures may further increase the N use efficiency and reduce N losses is the question mark addressed



A main cause for the doubled N-efficiency during the latest four decades (going from about 20% in 1980 to about 40% in 2010; Figure 2) is the ongoing better utilization of livestock manures, and a higher efficiency in the livestock production. Until the mid-1980s increased crop yields per N input, with extensive conversion from spring cereals to higher yielding winter cereals, added significantly to the higher NUE. However, especially with the implementation of the series of action plans for the aquatic environment, including statutory maximum N fertilizer norms for each crop, the obligatory substitution rate between livestock manure and synthetic fertilizers was tightened, and efficient techniques to increase the NUE of manures was so successful that the fertilizer import dropped significantly. From more than 400 kt N imported in the form of synthetic fertilizers in the beginning of the 1980s to below 200 kt N today.

Over the years, the national N action plans especially focused on measures to reduce the nitrate leaching to the aquatic environment; both groundwater and surface waters (for instance via extensive use of catch crops, more winter green fields, and a more effective utilization of fertilizers; Figure 1). This has affected the N balance significantly, and has more than halved the total nitrate leaching out of the root zone. The total N-surplus also has been reduced significantly too (by 43% over the same period), but relatively less than the nitrate leaching. With the new 2016 Danish N action plan the focus on targeted reduction in N leaching, in order to meet requirements of the EU Water Framework Directive (WFD) has further increased, whereas the general regulation with fertilizer norms has been loosened (from a level 15–20% below the economic optimal crop fertilizer norms, back to the production economical optimum).

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Pathways leading to emissions of N_2, N_2O, NO and HONO

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The emissions of N_2O from cultivated soils are primarily driven by two microbial processes: nitrification and denitrification (Butterbach-Bahl *et al.* 2013). Nitrifying organisms produce N_2O as a by-product in their oxidation of ammonia to nitrite, while N_2O is a free intermediate in the stepwise reduction of NO_3^- to N_2 by denitrifying organism; $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$ catalyzed by NAR, NIR, NOR and N_2OR, respectively. Thus, the NO/N_2O/N_2 product stoichiometry of denitrification depends on the relative activity of NIR, NOR and N2OR, and can vary grossly depending on the conditions (Bakken *et al.* 2012). Denitrifying organisms can be net sinks for N_2O under certain conditions (Qu et al, 2016). Nitrification is a net source of N_2O under any circumstance because the organisms lack the enzyme N_2O reductase (N_2OR), but their N_2O/NO_3^- product stoichiometry is modulated to some extent by oxygen availability and the composition of the nitrifying community (Hink et al 2016).

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The campaign Focus on Nutrients (Greppa Näringen)

Stina Olofsson, The Swedish Board of Agriculture

Actions for abatement of reactive nitrogen from agriculture have been conducted for a long period of time in Sweden. The first plan of action for reduced plant nutrient losses was started at the end of the 1980s. Today, the work is based on EU directives, international commitments and national environmental objectives. Measures to reduce plant nutrient losses are carried out via: legislation, financial instruments as Agri-Environmental payments and extension services and information as Focus on Nutrients. The most far-reaching measures are taken in areas appointed as vulnerable to nitrate pollution, which is about 75% of arable land.

Information and extension services are significant parts of the Rural Development Program. The strategy is to get measures done on a voluntary basis and the work is seen as a cost effective policy instrument. Focus on Nutrients offers advice, free of charge for farmers, and is a joint venture between the Swedish Board of Agriculture, Federation of Swedish Farmers and the County Administration Boards. Approximately 8,000 farmers take part, who cultivates 1 million hectares and 40% of Sweden's arable land, the most intensive cultivated part. Farmers can choose between about different advisory visits, sorted by themes. At the initial advisory visit, the farmer and the advisor discusses the need of additional counselling and establishes a nutrient balance as a starting position for the farm. The advisory plan is followed up one or several times during future visits.

The issues discussed at the visits include a range of topics such as strategies for fertilizing, manure handling, animal feeding, precision farming and wet land construction. The advisor always has to relate to how measures taken will influence farm economy. Repeated visits and follow up of changes are important to influence changed behavior. Focus on Nutrients emphasises that the advisor should focus the progress on each farm. The webpage www.greppa.nu contains several interactive services where farmers and other interested can use a tool for valuation of manure and calculate the optimal application of nitrogen. Farmers can also calculate a plant nutrient balance for the own farm.

Restrictions on nitrogen use in Danish agriculture

Kristoffer Piil, SEGES – the Danish Farm Advisory services

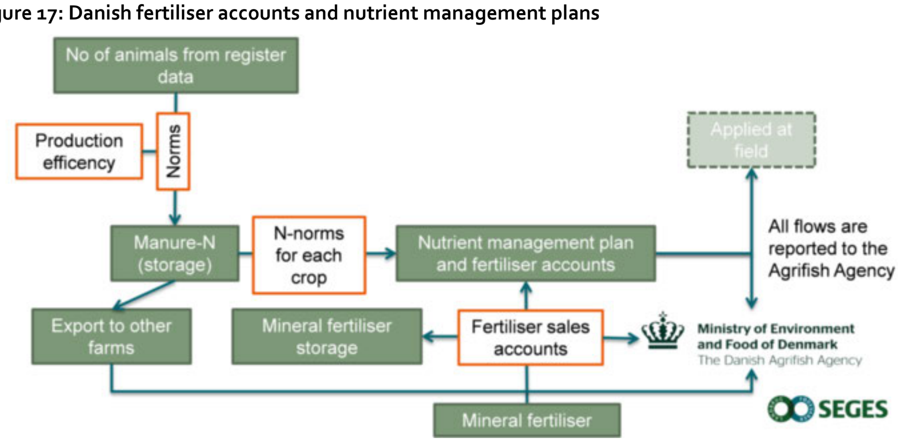
Over the past 30 years Denmark has managed to decrease the nitrogen load to marine waters by 50%, as well as turning an overall trend of increasing nitrogen content in groundwater to a decreasing trend. This has been done mainly by improving the nutrient utilisation efficiency in agriculture as well as setting restrictions on the use of nitrogen fertiliser in agriculture. P loads have also decreased significantly during the past 30 years, mainly due to better wastewater treatment.

The Danish agricultural nitrogen regulation is built on a system of mandatory fertiliser accounts and nutrient management plans combined with detailed regulation on timing and types of farming actions. Detailed regulation covers e.g. requirements of 8–14% catch crop winter cover, earliest tillage dates to avoid early autumn tillage and a set of rules for manure application techniques and a slurry closed period. Broadcasting of slurry prohibited, as is autumn application of manure for all crops other than rape seed.

The fertiliser accounts are made at the level of the individual farm, and built on a set of standards for maximum nitrogen application rates and minimum utilisation standards for manure. Maximum nitrogen application rates for each crop are calculated as the financially optimal application rated based on all field trials with increasing N levels over the past 10 years, taking into account the soil type and the previous crop. Both mineral fertilizer and organic fertilizer are included in the fertilizer account, and manure production is calculated from a set of norms based on the farms livestock production. Manure production norms differ between the types of domestic animals and between stable types and can be corrected for production efficiency, if the efficiency can be documented. Calculation of the mineral fertiliser need at farm level is done by subtracting the available nitrogen in organic fertiliser from the total maximum nitrogen quota calculated from the farms crop mixture. The available nitrogen in organic manure is calculated according to mandatory minimal utilisation demands for total N in manure, to ensure that nutrients in organic fertiliser are utilised efficiently. E.g. for cattle slurry 70% of total N is considered readily available and must be utilised. Fertiliser accounts and nutrient management plans are mandatory and must be reported to the Danish Agrifish Agency under the Ministry of Food and Environment.

Prior to 2017 nitrogen quotas for crops have been set at 10–20% below the financially optimal level. This under fertilisation has affected crop yield and quality, and a decline in protein content in Danish grain has been observed over the past 25 years.

Figure 17: Danish fertiliser accounts and nutrient management plans



Nutrient balances and soil organic carbon as key factors for better agronomic and environmental performance

Eila Turtola, Natural Resources Research Institute Finland (Luke)

Ideally, achieving high yields with low nutrient inputs would result in low nutrient field balances and good environmental performance. In fact, nutrient field balances can integrate the environmental and agronomic performances of fields as they consider the yield achieved and not only the inputs of nutrients. However, in environmental subsidy schemes, such as Finnish agri-environmental payment, the achieved yield is not a priority such that it would become an obstacle to get the payment except for a few extreme cases. This can lead farmers to optimize the subsidies and many important factors such as soil structure may get less attention.

If the yield level is of second importance, soil structure may become gradually deteriorated with impacts on soil erosion, plant growth, uptake of water and nutrients and thereby on losses of nutrients to water and air. For instance, soil compaction has been shown to reduce nitrogen (N) uptake of cereals even more than the yield, followed by an increase in N balance of 20 kg/ha (Alakukku & Elonen 1995). Similarly, waterlogging can increase markedly the optimum phosphorus (P) requirement of plants (Ylivainio *et al.* 2017) and decrease the aggregate stability of a soil (Soinne *et al.* 2016) that may lead to vulnerability of surface runoff, soil erosion and P losses.

In Finnish clayey soils under cultivation, the aggregate stability is controlled by soil organic carbon (OC) content, with the critical range around 4% (Soinne et. al 2016). In a follow-up study of a sample of cultivated Finnish soils, a continuous reduction of OC content was detected (Heikkinen *et al.* 2013), and based on the data, a considerable proportion of clayey soils probably fall below 4%. While soil organic matter has a positive impact also on the yield potential of a field, accompanied with a lower N fertilizer optimum and lower N field balances (Valkama *et al.* 2013), it is one of the most important soil properties that should be considered as background factors for the environmental performance of a particular field.

In the Finnish agri-environmental payment scheme, it would be of utmost importance to reliably sample and analyze all cultivated fields for their OC content, to detect the critical fields for both the increased soil erosion risk as well as for better prediction of N fertilizer requirement to reduce the N balances. Moreover, as part of the environmental schemes, nutrient field balances could be used to track fields where the nutrient use efficiency is not optimal due to e.g. problems in soil structure or imbalanced fertilization. When detected, a closer look could be given on these fields followed with targeted road maps on how to orientate towards better agronomic and environmental performance.

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NORDIC NITROGEN AND AGRICULTURE

The Nordic countries have, during the last 20 years, introduced efficient measures to reduce nitrogen losses to the environment. Still, N losses from the agricultural sector are high. In this report we provide recommendations on strategies and policy instruments to achieve cost effective abatement of reactive nitrogen from agriculture in the Nordic countries.

This report is based on a literature review. Additional input was also obtained from discussions at a workshop held in Gothenburg in January 2017. The workshop made it possible for experts from the four Nordic countries Denmark, Finland, Norway and Sweden to come together and discuss and compare policies and mitigation measures regarding nitrogen and agriculture. During the workshop we identified a number of policy challenges, policy actions and also knowledge gaps where further research is needed.

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