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Solution scenarios and the effect of top-down versus bottom-up N mitigation measures – experiences from The Danish Nitrogen Assessment

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Abstract
This paper presents methods and preliminary results developed within The Danish Nitrogen Research Alliance (www.dNmark.org). This include solution scenarios to meet the N loss reduction goals set by the EU Water Framework Directive, The National Emissions Ceilings Directive, and the paradigm shifting, new 2016 Danish N action plan. Compared to the previous series of action plans 1985-2016, the new action plan shifts from input to output based regulation. It introduces geographically targeted measures on top of the existing general regulation, with more room for green growth via an intensified use of N and increased economic benefits from production as long as the defined environmental targets are met. We argue that this opens up for new bottom-up methods to be developed for locally adapted solutions to the N pollution reduction challenge, in addition to top-down measures to further increase N use efficiency.

Key Words
Solution Scenarios, Mitigation Measures, Nitrogen Assessment, Top-down, Bottom-up, The Danish Nitrogen Research Alliance (DNMARK).

Introduction
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 1, left) and terrestrial environment (Figure 1, right) are evident.

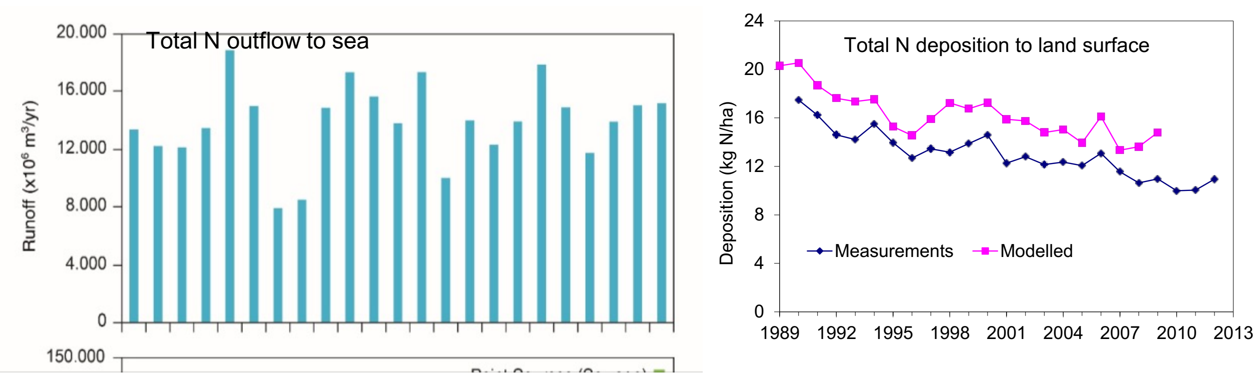

Figure 1. Annual flow-weighted total N concentration in Danish surface water outflow to the sea (Left, based on Wiberg-Larsen *et al.* 2013), and atmospheric N depositions to land surfaces (right, modified after Dalgaard *et al.* 2014, Ellermann *et al.* 2010).

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 (Table 1), and with a time trend in implementation from the former to the latter type of measures. However, most 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).

Table 1. Selected examples of N policy measures, implemented over the past 30 years with the Danish N action plans (after Dalgaard et al. 2014). Geographically targeted types are marked as localized (in brackets).

Year	**N measures imposed:**	Command and Control	Market-Based Regulation or Governmental Expenditure	Information and Voluntary Action
1985	Max. stock density.	X		
	Mandatory slurry tank floating barriers.	X		
	No runoff from silage clamps and manure heaps.			
	Min. slurry capacity and ban on winter spreading	X		
	of slurry for spring crops (including subsidies to	X		
	invest in slurry tanks etc.).		X	
1987	Mandatory fertilizer 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 utilization.	X		
	Max. N applied to crops equaling econ. optimum.		X	
	Subsidies to low-N grasslands in environmentally		X	
	sensitive areas.		(localized)	X
1998	Max. N applied 10% below economic optimum.	X		
	6% mandatory catch crops.	X		
	Subsidies to more organic farming, new		X	
	wetlands, extensification and afforestation.		(localized)	
2001	Promotion of low excretion livestock feeding.			X
2004	More catch crops, and tightened ammonia	X		
	restriction (e.g. broadcasting banned), and special	X		
	restrictions near sensitive nature areas.	(localized)		
	Subsidies to promote better manure handling and			
	animal housing (BAT).	X	X	X
2009	Buffer zones around streams, lakes and NH_4	localized		
	sensitive habitats.			
	More catch crops ($\approx$14%) mitigating less set	X	X	
	aside.	X		
	Tax on mineral P in feed.			X
	Max. N applied $\approx$15% under economic optimum.			
	Optimized feed practice promotion.			
2011	Ban on autumn soil tillage before spring crops	X		

With the implementation of the National Emissions Ceilings (NEC), and in particular the EU Water Framework Directive (WFD), and the different targets for reduced N pollution in different areas of the country, the current policy is seriously challenged. Goals for N reduction have been over fulfilledin some parts of the country, whereas large deficits still appear in other parts of the country. Consequently, in 2016 a new and radically different action plan has been passed in parliament, with a coming shift to more locally defined reduction targets, and a paradigm shift from regulation of mainly N input to a regulation mainly tied to N outputs (i.e. "end of pipe" nutrient status in the environment), and with different reduction targets for the various watersheds of Denmark.
The present paper presents some of the methods and solutions developed to assess and implement this new policy, drawing on experiences from the interdisciplinary Danish Research Alliance (www.dNmark.org), and the ongoing Danish Nitrogen Assessment to be finalized in 2017.

Methods

Within the Danish Nitrogen Alliance methods to assess the whole Nitrogen budget for Denmark have been developed (Hutchings *et al.* 2014), including figures for the agricultural sectors' N inputs and N outputs , and official values for N leaching, derived via the empirical N-LES model.

In line with OECD (2000), the main indicators for the overall effect of N mitigation measures used in the present paper comprise N surplus and N Use Efficiency (NUE, or just N-efficiency). The system boundary comprises the entire primary production of the Danish agricultural sector, including cropland, livestock and grazing lands, and the related N surplus and N-efficiency. The agricultural N surplus is defined as N input minus N output in agricultural products from the agricultural sector (equation 1); while N efficiency (NUE) is defined as N output in agricultural products per unit N input (equation 2).

(1) N surplus = N output –N input ≅ N leaching + NH_3 emission + denitrification – soil N change
(2) N-efficiency= (N output) / (N input)

In the Danish Research Alliance we work with the concept of solution scenarios, including the geographically targeted measures to be implemented with the new Danish 2016 action plan. In the implementation of these solution scenarios and measures to mitigate N pollution we distinguish between i) Top-down measures, i.e. the traditional measures, implemented equally over the whole country (the majority of measures listed in Table 2), and ii) Bottom-up measures (i.e. more locally defined actions to meet N reduction demands, for example the voluntary action type listed in the right column of Table 2). Moreover, in the alliance we work with both local stakeholders (in different watersheds representing different geographical settings) and national stakeholders (for the implementation of national solution scenarios).

Results and discussion

Developments in N inputs and N outputs since 1950 document the generally improved N use efficiency (Figure 2), related to the different types of N losses and soil N pooling (equation 1).

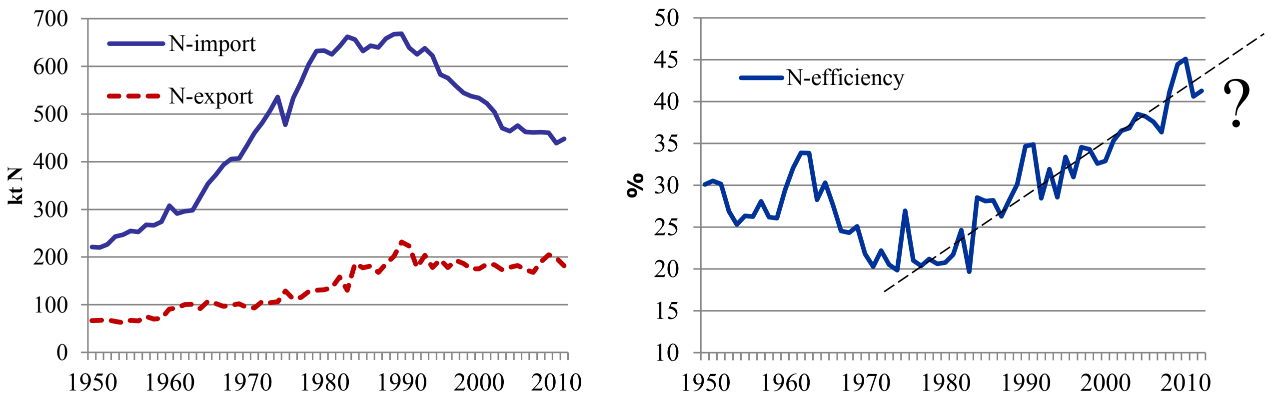

Figure 2. Total sum of N importss to- and sum of N exports in products from Danish agriculture, and overall N use efficiency for Danish agriculture over the period 1950-2012. How different solution scenarios may further increase the N use efficiency and reduce N losses is the question mark addressed.

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; Table 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).

The question addressed in this paper is how this new policy, as a baseline for the developments towards 2030, will affect both the N-surplus and the different types of losses in equation 1, as well as the overall N-efficiency (equation 2). In the DNMARK project, this is done in relation to the following three main types of solution scenarios: 1) New production chains with more efficient nitrogen utilization and recirculation (for example extensive implementation of biogas production, both from manures and green biomass, and in combination with bio-refinery systems and the recycling of waste streams). 2) Geographically targeted measures based on locally adapted management and planning (geographically differentiated land use), and 3) New consumption patterns leading to land use changes and changes in nitrogen cycles (for example more organic food consumption).

For the present paper presentation, the overall national NUE of selected solution scenarios is accounted using the techniques defined above, and compared to the 2030 baseline mentioned. For comparison, each solution scenario is defined in order to meet the Danish WFD goals, and it is assessed how this equal effect on nitrate leaching for each scenario will interfere with other types of reactive N losses simulated. These results on side effects in the form of pollution swapping will be relevant to any country in the process of revising agri-environmental policies to meet multiple targets for reduced pollution of the aquatic environment as well as other N pollutants. These effects may be combined with development of a viable agricultural business sector (for example via the implementation of new cropping systems with simultaneous higher N harvest and lower N losses, as with more grass or beets grown for protein, starch and sugar production via bio-refineries (Parajuli et al. 2015). Given local differences present, the implementation of N measures will vary between watersheds, and methods to facilitate locally targetted actions and documentation of N effects are needed. In the www.dNmark.org alliance we therefore develop both a local landscape GIS-model used for dialogue with stakeholders in six pilot landscapes, and a national model for the assessment of general NUE and N-surplus effects. We argue that this opens up for new bottom-up solutions be developed for locally adapted, effective N pollution reductions, on top of the general top-down measures and solutions to further increase N use efficiency. Examples to illustrate this point will be presented.

Conclusions

N loss reduction goals set by international commitments are addressed by the paradigm shifting 2016 Danish action plan. Compared to the previous series of action plans 1985-2016, the new action plan shifts from input to output based regulation, and introduces geographically targeted measures on top of the existing general regulation. We argue that this opens up for new bottom-up methods to be developed for locally adapted solutions to the N pollution reduction challenge, in addition to top-down measures to further increase N use efficiency and mitigate unsustainable pollution swapping effects.

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