

# How to introduce new technologies to reduce nutrient losses: a case of Danish agricultural constructed wetlands

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## Abstract

The Water Framework Directive (WFD) focuses on reduction of nutrients in individual water bodies. Innovative drainage filter technologies currently being tested in Denmark could facilitate nutrient reductions at the sub-river basins and catchment levels. The implementation strategy for these technologies, however, remains a challenge. Using both primary and secondary data, this paper presents an in-depth analysis of the role of these technologies in implementation of the WFD in Denmark. Concepts of impact assessment are used to identify the most suitable approach for incorporating these technologies into environmental measures based on a three-faceted policy instrument typology. A voluntary approach supported by investment subsidies, or incentives that could replace existing requirements, is deemed more appropriate.

*Keywords:* Filter technologies; Policy instruments; River basin management plans; Water quality

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## 1. Introduction

In a bid to achieve the objective of ‘good ecological status (GES)’ stipulated in the Water Framework Directive (WFD) (2000/60/EC), great effort has been directed towards planning, administration, characterization of river basins (RB), monitoring, and assessment of water quality by the EU member states. However, attainment of this ambitious objective by 2015 is no longer feasible (European Commission, 2012). This has prompted the Commission to raise issues regarding the legal framework and governance, funding of the Program of measures (PoM)<sup>1</sup>, integration of quantitative and qualitative aspects in water management, and integration of river basin management plans (RBMP) with other policies (European Commission, 2012). Although a large variety of measures (technical, non-technical or

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<sup>1</sup> A tool for responding to the identified water quality pressures within the river basin.

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economic instruments) exist, some key elements such as the scope, timing and financing of these measures are missing in the RBMP from many member states (European Commission, 2012). These aspects render the RBMP to fall short of clear actions for addressing agricultural pressures. An additional concern is that the farmers do not fully understand the requirements of the WFD.

To address the Commission's concerns, member states have been urged to find long-term solutions that balance environmental protection and sustainable economic development. They have further been sanctioned to explicitly include costs of measures, responsible authorities, and cost bearers in the RBMP and PoM. Additionally, improved collaboration with the farming community in the preparation of the PoM has been called for (European Commission, 2012)<sup>2</sup>. Other recommendations to the member states include the need for balancing voluntary actions and mandatory measures in agriculture to provide a solid baseline for rural development programs and cross-compliance water-related requirements.

Development of the Green Growth Agreement (GGA 2009–2015) in Denmark is a key example of how the Commission's recommendations have been taken up by member states. One initiative under this agreement covered investment in green technologies. This involved the creation of an annual grant for new environment and climate-friendly technologies in the primary industry (Danish Ministry of Environment, 2009). Filter technologies for retention of nutrients from agricultural fields, such as constructed wetlands (CW) and drainage well filters (DWF), are examples of these technologies.

Innovative filter technologies have been proposed as targeted measures in mitigating site-specific nutrient losses by disconnecting agricultural drainage pathways, thereby trapping nutrients in the discharge before reaching recipient surface waters (SupremeTech, 2012). These technologies have recently been included in the official catalog of environmental measures in Denmark (Eriksen *et al.*, 2014). However, some pertinent questions still arise despite this progressive step taken in incorporating the technologies into environmental measures: do farmers see the need for improving water quality, and what are the barriers towards implementing the new technologies through policy measures?

Against this backdrop, this paper presents an in-depth analysis of the filter technologies (mainly CW), and their role in propelling the country towards achievement of the water quality goals. Overall, the paper aims to identify the most appropriate policy instrument for implementing filter technology measures. Specifically, the role of these technologies in balancing stringent water quality requirements and competitive agricultural production is first established, and their quantitative and qualitative aspects that could be incorporated in the Danish RBMP work outlined. Secondly, funding and cost implications of the technologies and how these could be managed to ensure cost-effectiveness are discussed. Finally, strategies for incorporating the technologies into policy measures are analyzed. Whereas the first two specific objectives are achieved through description of the current status of filter technologies in Denmark, the last objective is achieved by discussing how these technologies could fit into an adapted policy framework typology.

The adopted analytical framework and the data used in the study are described in Section 2. Section 3 discusses farmers' knowledge of water quality issues. Section 4 describes the drainage filter technologies, focusing on their application and effectiveness in nutrient reduction, and current status with reference to costs, funding, and sustainability. Assessment and discussion of implementation strategies for the technologies are presented in Section 5, followed by the conclusions.

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<sup>2</sup> Measures could be described as the 'behavioral aim', for example lower application of nitrogen; while instrument is the 'how to achieve this', for example through command and control (CAC). Basic measures are outlined in Article 11 (4) and supplementary measures are given in Annex VI (B) DIRECTIVE 2000/60/EC. However, the term 'measure' in this paper refers to 'technical intervention'.

## 2. Analytical framework and data

To identify the appropriate instrument for incorporating filter technologies into policy measures, the study adopts an impact assessment approach. With regard to policy instruments, impact assessment can be described as an information-based analytical tool that assesses anticipated costs, outcomes, and side effects of planned policy instruments. The tool can be used at each of the three main phases of a policy cycle, namely policy development, instrument development, and policy evaluation, and its results should be considered in making political decisions (OECD, 2001). Although the analysis does not focus on development of policy instruments per se, it touches on the main features being addressed by impact assessment in this phase of the policy cycle. These include four key aspects on compliance, implementability, advantages, and/or disadvantages of specific policy instruments for certain groups in society. Under these aspects a suitable policy instrument ought to (1) minimize possibilities of compliance avoidance by the target group, (2) be easily implementable and flexible to accommodate all possible cases, and (3) ensure achievement of the intended objectives in an efficient and equitable way (OECD, 2001; Hepburn, 2006; Goulder & Parry, 2008). To assess the suitability of different policy instruments with regard to these four aspects, the discussion is based on a three-fold policy instrument typology developed by Dalgaard *et al.* (2014) (see Figure 1). The appropriateness of each instrument in the typology in incorporating filter technologies to environmental measures is distinctively assessed.

A number of environmental policy instrument typologies have been presented over the years. One of the earliest was proposed by Majone (1976) based on institutional framework. This typology categorized pollution-control policy tools into (1) regulation, direct public action and subsidies, (2) effluent charges, (3) contract and redefinition of property rights, and (4) organization. Others include: the

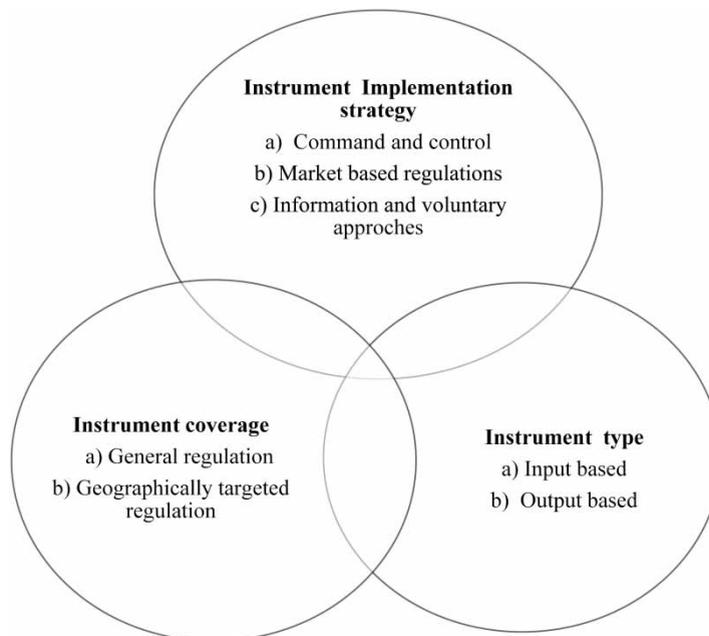


Fig. 1. Typology for nitrogen management policies (Dalgaard *et al.*, 2014).

Bemelmans-Videc *et al.* (1998) three-fold typology comprising regulations (sticks), economic means (carrots), and information (sermons). The Gunningham *et al.* (1998) typology consists of CAC, self-regulation, voluntarism, information strategies, and economic instruments. Golub (1998) advocates for new instruments as opposed to traditional instruments, and classifies these into green taxes and subsidies, voluntary agreements, eco-labels, and eco-audits. Jordan *et al.* (2005) discuss new environmental policy instruments, categorized into market-based, eco-labels, environmental management systems, and voluntary agreements. Bähr (2010) classifies policy instruments into governance and legal instruments. While the former represents the relationship between authorities and those being addressed with the policy suggestions, the latter is the legal form in which governance instruments are adopted. Governance instruments encompass CAC, economic, and suasive instruments whereas the legal instruments comprise soft and hard laws. Halpern (2010) classifies environmental policy instruments in the EU into legislative and regulatory, economic and fiscal, agreement and incentive-based, information and communication based, and best practices. Finally, Wurzel *et al.* (2013) use a three-fold policy instrument typology to establish the extent to which environmental policies have evolved in the last few decades in four European countries and in the EU. This typology includes suasive (information measures and voluntary agreements), market-based (eco-taxes and emission trading), and regulatory (CAC and innovative regulations) instruments.

Despite this wide range of policy typologies, the Dalgaard *et al.* (2014) typology is adopted in the discussion. This typology is based on historical application of policy instruments in Denmark. Furthermore, it incorporates geographical targeting scope into the three key policy instruments (regulation, economic, and information) featured prominently in other typologies. As shown, most of these typologies put more emphasis on instrument implementation strategy while geographical coverage or stages of the nutrient cycle where the regulation can be performed are overlooked. A key challenge to taxation on nitrogen losses has been the uncertainty related to calculation of the nitrogen losses, and the legal foundation for taxation of a roughly estimated loss as discussed prior to Denmark's Aquatic Plan III in 2003 (Source: The Tax group in APAE III). The typology by Dalgaard *et al.* (2014) distinguishes between three distinct yet interconnected facets of nitrogen management policies observed in Denmark for the last 30 years. These include: (1) implementation method, whether through regulation, incentives, or voluntary actions; (2) geographical coverage; and (3) type of nutrient (nitrogen or phosphorus) and the point at which it's targeted (input or output). Given its coverage, the Dalgaard *et al.* (2014) typology is deemed more applicable in the current study. It may, however, be noted that this typology does not outrightly incorporate process-based aspects of a policy instrument.

The process approach deals with measures affecting daily decisions at the farm, such as timing of ploughing, spreading of manure, etc. Although these could be said to be indirectly related to inputs since the aim is higher input utilization, they are not clearly linked to input as is the case with restrictions on nitrogen use (N-norm). So far, most Danish regulation has focused on the CAC, which has had clear effects; however, it has not managed to involve farmers in finding solutions. The process approach further allows for continuous updating of the policy so as to ensure its responsiveness to and reflection of the feedback from the stakeholders (Lam & Hills, 2013). This aspect would be important in the implementation of the filter technologies' measures since feedback on the improvements in technologies' efficiency as well as the achievement of water quality goals is necessary. Process-based aspects may be achieved through participatory approaches. However, care should be taken so as to minimize resource use, thereby increasing policy efficiency.

### 2.1. Data

The study utilizes both primary and secondary data with the latter comprising past research findings and reports on performance and cost-effectiveness of drainage filter technologies (Jacobsen & Gachango, 2013; Kjaergaard & Hoffmann, 2013; Kjaergaard & Iversen, 2014; Gachango *et al.*, 2015c), report on the implementation the EU WFD in Denmark (European Commission, 2012), and various studies on policy instruments in the implementation of the WFD (Gouldson *et al.*, 2008; Jacobsen, 2012a; Taylor *et al.*, 2012; Van Grinsven *et al.*, 2012; Dalgaard *et al.*, 2014). These data are supplemented with primary data extracted from a survey of 267 Danish farmers on their willingness to adopt CW. A detailed description of the survey that was conducted between March and June 2013 is provided in Gachango *et al.* (2015a) and Gachango *et al.* (2015b). This is further linked to previous findings regarding experiences with the implementation of traditional wetlands in Denmark<sup>3</sup>. It should, however, be noted that a major distinction exists between constructed and traditional wetlands. The latter involve more farmers, and are often established on low-lying fields with large areas of between 10–50 ha being taken out, while the former take up relatively small areas (for example, 1 ha) and involve an individual farmer. However, the knowledge regarding incentives in traditional wetlands' implementation would be useful in the case of CW. Furthermore, the implementation of measures along streams as discussed in the water councils (Nature Agency, 2014) provides information on regulation set-up which would encourage smaller CW.

### 3. Farmers' knowledge of water quality issues

As a starting point in incorporating filter technologies as environmental measures, it is necessary to establish both the level of acknowledgment, by farmers, of the existence of water quality problems, and their understanding of WFD requirements. Consequently, their attitude towards existing approaches of implementing nutrient reduction measures should be assessed. Based on the primary data extracts, the subjective farmers' perception of water quality in the recipient water bodies (fjords and coastal waters) draining from their farms is assessed. A four-point scale with 'low', 'moderate', 'good', and 'very good' categories is used. A tabulation of these perceptions alongside the current average ecological status in the corresponding fjords and coastal waters in the RB is presented in Table 1.

Major discrepancies between the actual water quality status and farmers' perception are observed in all the 15 RB represented in the data. These differences could either indicate farmers' unawareness of the extent of water quality problems or their unwillingness to acknowledge that the problem actually exists. They could also imply that when the quality is above a given level people may perceive it as good although it is far from the requirements linked to high water quality. Such differences could be addressed through information sharing and sensitization of farmers to the current water quality and the ecological status requirement for each body of water. Wright & Jacobsen (2011) show how the Agricultural and Water Plan (AGWAPLAN) project tried to engage in active involvement so as to accomplish farmers' acceptance of the environmental objectives, which led to acceptance of the fact that something needs to be done. Such interventions would facilitate the implementation of more targeted pollution-reduction measures at farm level.

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<sup>3</sup> Approximately 6,000–8,000 ha of traditional wetlands had been established in 2012 although the aim in the RBMP from 2011 was the establishment of an additional 10,000 ha of lakes and fresh meadows, and 1,500 ha of pasture wetlands (Hansen *et al.*, 2011; Jacobsen, 2012b).

Table 1. Comparison of farmers' perception with actual quality in the fjords and coastal waters ( $N = 267$ ).

RB	Respondents	Current average ecological status <sup>a</sup>	Water quality perception frequency (%)			
			Low	Moderate	Good	Very good
Kattegat	35	Poor	8.6	28.6	25.7	37.1
Limfjorden	179	Poor	9.5	28.5	35.2	26.8
Mariager fjord	20	Poor	5.0	35.0	40.0	20.0
Randers fjord	5	Poor	20.0	0.0	80.0	0.0
Ringkøbing fjord	2	Poor	0.0	0.0	0.0	100.0
Horsens fjord	1	Poor	0.0	0.0	100.0	0.0
Wadden sea	1	Poor	0.0	100.0	0.0	0.0
Lillebelt-Fyn	2	Poor	0.0	0.0	100.0	0.0
Odense fjord	3	Poor	0.0	33.3	0.0	66.7
Storebelt-Fyn	3	Poor	0.0	33.3	66.7	0.0
Sydfynske ø- hav	3	Moderate	33.3	0.0	33.3	33.3
Kalundborg	1	Poor	0.0	0.0	100.0	0.0
Isefjord	1	Moderate	0.0	100.0	0.0	0.0
Køgebugt	2	Moderate	0.0	0.0	50.0	50.0
Smålandsfarvandet	9	Poor	22.2	11.11	55.6	11.1

Source: Own data,  $N = 267$ .

<sup>a</sup>The current average ecological status comprising a four-point scale (poor, moderate, good, and high) has been identified by Jensen *et al.* (2013) based on water quality weighted by the size of the individual water bodies ( $\text{km}^2$ ).

Farmers' awareness and understanding of the WFD requirements and the concept of GES are assessed by calculating the frequency of ('No', 'Partly', and 'Yes') responses to two questions: (1) Do you know the meaning of GES of all water bodies? and (2) Do you know the meaning and requirements of the Water Framework Directive (WFD)? The results presented in Table 2 show that approximately 34% of the farmers do not know the requirements of the WFD and almost 51% do not understand the GES concept. A relatively small number of farmers (80) indicated having received some information or communication about GES, with municipalities being cited as the main source at 69% (Table 3). From these results it is clear that the first requirement towards new interventions, namely, 'accepting that the current status is not good enough', is lacking.

#### 4. Innovative filter technologies

Although a range of farm-level measures can be implemented to mitigate nutrient pollution in water bodies (Eriksen *et al.*, 2014), we focus on CW and DWF. Key issues with regard to effects, costs, and implementation consequences are discussed.

Table 2. Farmers' awareness and understanding of WFD and GES ( $N = 267$ ).

Awareness/understanding level	Percentage frequency – WFD	Percentage frequency – GES
No	33.7	50.9
Partly	43.4	36.3
Yes	22.9	12.7
Total	100.0	100.0

Table 3. Source of 'GES' information.

Information source	Respondents (N)	Percentage frequency (N = 80)
Agricultural advisors	35	43.8
Municipality	55	68.8
Farmers	14	17.5
Agency	31	38.8
Media	37	45.3
Input suppliers	0	0.0
Other sources <sup>a</sup>	9	11.3

<sup>a</sup>Other sources of information included local water board, fishermen's union and individual studies.

#### 4.1. Efficiency and application of innovative filter technologies

Although a potential for 15,000 ha of CW exists (Balticdeal, 2011), only 21 CW sites (16 surface flow CW and five sub-surface flow CW) and one DWF had been established by the end of 2015, almost 10 years after the commencement of a pilot project in 2006<sup>4</sup>. Preliminary monitoring data indicate potentially high levels of nutrient removal efficiencies by fully established technologies (Orbicon, 2012; Heckrath *et al.*, 2013; Kjaergaard & Iversen, 2014). Consequently, analysis of the cost-effectiveness of both surface and sub-surface flow CW has resulted in relatively low cost per unit of nitrogen and phosphorus removed (Jacobsen & Gachango, 2013; Gachango *et al.*, 2015b).

Further comparisons of CW performance with other nutrient reduction measures show CW as being a better measure with reference to area utilization. Kjaergaard & Iversen (2014) conclude that approximately 1.6–2.0 ha of CW at a nitrogen removal rate of 25%–30% have the same nitrogen removal efficiency with 78 ha of catch crop<sup>5</sup> or 63 ha of uncultivated area such as buffer zones. The surface flow CW are also seen as more cost-effective measures compared to measures related to cultivation (Knudsen & Lemming, 2012; Gachango *et al.*, 2015c). However, cost-effectiveness is highly related to location of the wetlands and the costs involved. CW in lowland areas are expected to be less cost-effective owing to higher water-pumping costs. Furthermore, high nitrogen levels are necessary for the nitrogen effect per ha to be high. Eriksen *et al.* (2014) show that there can be large variations in the effect per ha of drainage area per year depending on the nitrogen losses per ha. The nitrogen losses range between 12 kg and 70 kg nitrogen/ha/year. Assuming that the wetland is 1 ha and the drained area is 100 ha, with an effect of 25%, three main groups have been established: low effect (392 kg nitrogen/ha wetland/year), medium (938 kg nitrogen/ha wetland/year), and high (1,563 kg nitrogen/ha wetland/year). This is equivalent to 4 kg, 9 kg, and 16 kg nitrogen/ha of drained area. The costs in the analysis are based on previous findings in Kjaergaard & Iversen (2014) and Gachango *et al.* (2015c). Two cost levels are estimated, where the low cost level is associated with high ground without a pump. The annual cost is approximately €4,030 based on 15-year depreciation at 4%. The high cost level is based on low-lying fields where pumping is required. The annual cost here is estimated at €9,260

<sup>4</sup> A new 'food and agricultural package', agreed by the Danish government and supporting political parties on 22 December 2015, proposed the establishment of approximately 1,000 constructed wetlands.

<sup>5</sup> A crop grown when the main crop has been harvested to ensure that the soils are not left bare or to take up excess nutrient remaining in the field after the main crop.

per year. The analysis shows that the high cost option together with low nitrogen losses from the fields gives high costs per kg nitrogen in reduced loss (€30.74/kg nitrogen), whereas the low cost option on sites with high effect is cost-efficient (€3.49/kg nitrogen). It has been discussed in relation to the analysis that the cost estimates used by advisors in applications for project funding might be a little high, which increases the costs' estimates in the calculation. Consequently, investment costs might be reduced when the technology is widely adopted.

In the Food and Agricultural Package from December 2015 a target of 1,000 CW by 2021 has been included (MFVM, 2015). The average effect is assumed to be 9 kg nitrogen/ha in the catchment related to the CW and the investment associated with CW is €73,800 per CW, which is somewhat higher than levels used in Eriksen *et al.* (2014). The total sum that has been allocated to CW is €74 million and so the farmers will be fully compensated for the investment. Based on 20 years and 4%, the annual cost is €4,966 per year or €5.5 per kg nitrogen (Jacobsen, 2016). As seen from the above, not all locations are suitable for effective CW and so, with an aim of 1,000 projects in a country with 11,000–12,000 full-time farms, this will be a challenge.

Compared to traditional wetlands with a cost of around €5.50–€5.91/kg nitrogen, the most efficient CW is a more cost-efficient option, whereas CW located in areas with low efficiency will have higher cost per kg nitrogen removed. Moreover, phosphorus removal by the CW will help to improve the overall efficiency as discussed in Jacobsen & Gachango (2013) and Gachango *et al.* (2015c). The Food and Agricultural Package from 2015 also includes the construction of 4,300 ha traditional wetlands on top of the already expected 8,700 ha that should be established from 2016–2021. This implementation level is high compared to the level of implementation achieved in 2010–2012 of around 600 ha traditional wetlands per year (MFVM, 2015). A high level of more traditional wetlands, combined with relative many new CW, requires that many farmers are using these options on their farm. The Food and Agricultural Package also includes a targeted set of measures that will be focused on other measures such as catch crops, early sowing, lower nitrogen application. These measures are required to counteract the negative effect of higher nitrogen norms, which is also a part of the Food and Agricultural Package.

In addition to nitrogen removal and phosphorus retention, CW provide other functions. On one hand, they provide positive services such as biomass production, biodiversity and nature development, hydraulic retention, and climate change mitigation through carbon sequestering (de Klein & van der Werf, 2014). On the other hand, they could pose a risk for emitting greenhouse gases such as nitrous oxide and methane (Kayranli *et al.*, 2010). The CW development project in Denmark, however, strives to achieve the primary functions of nutrient reduction together with other positive functions as well as ensuring reduced negative side effects from the wetland ecosystems (Orbicon, 2012).

Implementation of targeted nutrient reduction technologies is highly relevant in Denmark given that approximately 50% of agricultural land is drained through tiles and ditches (Olesen, 2009). Moreover, nitrogen loss through agricultural drainage accounts for 45%–60% of the total nitrogen loss, translating to approximately 22,000 tons annually. Phosphorus loss through the same drainage pathway is estimated at 33% of total phosphorus loss (Blicher-Mathiesen *et al.*, 2012).

#### 4.2. Subsidies and cost implications of the innovative filter technologies

Nutrient filter technologies have in the past been supported by rural development fund, EU-LIFE project, municipalities, private companies, the state, and private partners (Gertz, 2011). Approximately

€19 million has previously been set aside annually for ‘new green technologies’, which include CW. The bulk of the funding has been provided through rural development funds for non-productive investment in agriculture (NPIA) (Danish Ministry of Environment, 2009). Funds’ application procedure, eligibility of expenses, and overall support criteria in establishment of CW are outlined in Ministry of Food, Agriculture and Fisheries (2012).

Prior to the passing of the new ‘agricultural package’ (MFVM, 2015), investment in CW was only eligible for full support if it exceeds the mandatory investments required by law, and it does not replace any other obligatory requirements. Additional conditions stated that farm area on which a farmer constructs the wetland does not qualify for support under the agri-environmental payments. Consequently, the state could not purchase such an area supported under non-productive investment, although the area could still qualify for the EU single payment. Some of these conditions could potentially slow down the adoption and diffusion of the filter technologies since farmers would be required to have the willingness and capacity to absorb the opportunity cost of setting aside productive land for wetland construction. With initial investment costs of a surface flow CW estimated to range between €20,000 and €53,000 per hectare depending on the site (Orbicon, 2012; Gachango *et al.*, 2015c) and opportunity cost estimated to range between €456 and €1,688/ha/year (Jacobsen & Gachango, 2013; Gachango *et al.*, 2015c), some farmers have in the past viewed such an investment as being burdensome, as reported by one farmer. (Also, the ‘what do I get out of it?’ has been unclear to the farmers.)

*‘I will not construct a wetland before I am sure it can replace the buffer zones or catch crops.’*

Farmers are very reluctant to apply for funding to create CW. Gachango *et al.* (2015b) reported that although 64% of farmers in the survey were aware of the CW fund’s existence, the application rate was 6.7%. Non-application to the fund in the said study was attributed to insufficient information regarding the application process, perceived lengthy and bureaucratic paperwork, and economic factors. It could be deduced that either farmers have previously not had a full understanding of the application guidelines, or that these guidelines have not offered the right incentives for fund application by farmers. This situation calls for more or better packaged information and/or incentives. This could be informed from the incentives in traditional wetlands where reallocation of the area has acted as the greatest incentive for farmers’ participation in the projects.

With the new Food and Agricultural packages described above, it is clear that some of these challenges need to be overcome in order to ensure that the target of 1,000 CW can be achieved. It is not clear whether the relative high investment allocated per CW is due to the inclusion of supporting measures (paying advisors, etc.) in order to facilitate a high degree of implementation among farmers.

## 5. Strategy for implementing innovative drainage filter technologies

In this section each of the policy dimensions in the typology outlined by Dalgaard *et al.* (2014) is briefly discussed. Additionally, assessment of burdens and advantages that these policy instruments would have is made using farmers and the state as the reference groups. This choice is driven by the fact that on one hand, farmers have been faced with other stringent regulations and, on the other hand, the state strives to achieve its objectives as stipulated in the GGA. This assessment is made in light of implementing the filter technologies’ measures using the specified policy instruments.

### 5.1. Instrument implementation strategy

**5.1.1. CAC.** The CAC approach is a traditional type of regulation whereby authorities use direct control over polluters. The polluters are either prohibited from carrying out certain practices that lead to pollution, or are required to perform other practices aimed at reducing pollution, with failure to comply being punishable by law (Perman, 2003). CAC policies are classified into specification-based, performance-based, and process-based standards. The first category dictates that emitters adopt certain technologies or measures that will ideally meet the emission standards. These standards have a direct effect on the dischargers' production process. The second category also stipulates that emitters should meet certain emission conditions, however, they have the flexibility of choosing their most preferred method among those available to them. The last category basically outlines management decision-making processes aimed at improving environmental outcomes (Gunningham & Sinclair, 2005; Goulder & Parry, 2008). Both specification and performance standards have major drawbacks such as high monitoring and information requirements, leading to high administration, monitoring, and enforcement costs (Ribauda *et al.*, 1999). In addition, the standards are characterized with uncertainties regarding price and quantity of emissions (Goulder & Parry, 2008). The main shortcoming of the process-based standards is that they require well-established farm-management practices, and adequately funded, trained and empowered regulators to ensure effectiveness of the policy instrument (Gunningham & Sinclair, 2005).

In Denmark, reduction of pollution from agricultural nutrients has mainly been targeted using CAC approaches covering both nutrient-related and area-related policies (Mikkelsen *et al.*, 2010). This has resulted in significant reductions of nutrient emissions although the required GES of the country's water bodies is yet to be reached. This state calls for further reductions in emissions by farmers (Windolf *et al.*, 2012). However, extended use of CAC may not be optimal since these regulations are expected to continue imposing higher costs on farmers, especially those in catchments with high reduction requirements (Jacobsen, 2012b; TCNA, 2013). Furthermore, CAC instruments would increase prospects of financial losses to the farmers due to large amounts of initial investments and maintenance costs of filter technologies, and loss of productivity through setting aside of productive land. CAC would be preferred where the Marginal Abatement Cost Curves (MAC) of the farms being regulated are uniform and the government can easily know each farmer's MAC. The current nitrogen-quota system in Denmark applies differentiation based on soil types, crops and use of irrigation to reduce the difference in MAC. However, farms always have different MAC, thereby making the application of CAC more complicated (Gruber, 2004). Although compliance is often guaranteed in CAC, the instrument may not be an ideal strategy of implementing the filter technologies owing to the mentioned shortcomings. Furthermore, studies have shown that imposition of environmental measures through CAC has not been viewed as a favorable approach by farmers (Macgregor & Warren, 2006; Barnes *et al.*, 2009, 2013; Gachango *et al.*, 2015a). Theoretical and empirical studies have also shown that CAC is a less efficient and effective instrument compared to market-based and voluntary instruments. Consequently, given the global competitiveness of agricultural production, future strategies of achieving environmental goals should cushion producers against inefficient use of resources, and provide them with sufficient opportunities to incorporate innovative production methods with flexibility (TCNA, 2013).

**5.1.2. Market-based instruments/economic instruments.** Market-based instruments are presented as a more cost-effective alternative to CAC for their ability to raise the cost of environmental-protection

avoidance, and implement the ‘polluter pays principle’ (PPP) (Hanley *et al.*, 2007). They broadly include input taxes on nitrogen and phosphorus fertilizers, tradable nutrient quotas or emissions trading, subsidies for external audit or adoption of best practices, financial compensation for setting aside productive agricultural land, and liabilities’ rules (Gunningham & Sinclair, 2005). Although Hanley *et al.* (2007) indicate that these incentives have a theoretical appeal, sufficient practical evidence of their suitability is still lacking. Furthermore, an adequate information base, strong legal structures, competitive markets, and political feasibility requirements must be in place for market-based instruments to effectively improve environmental protection (Xepapadeas, 2011).

Market-based approaches being used in Denmark include taxes on added phosphorus in feedstuff, and nitrogen fertilizers, subsidies, tradable rights, and payments for agri-environmental services. Although Payment for Agri-Environmental Schemes under the Danish Rural Development Programme (2007–2013) covered the establishment and management of wetlands for nitrogen and phosphorus retention, CW have been supported as NPIA (Ministry of Food, Agriculture and Fisheries, 2012). This implies that CW adopters do not qualify for the 5-year annual area payment in compensation for losses associated with changes in farm management. Additionally, the area under CW does not qualify for state acquisition but areas under natural and permanent wetlands do qualify<sup>6</sup>. The requirements under NPIA, however, give farmers the flexibility of restoring wetland area to production land in the future.

Implementing filter technologies at farm level would bring physical changes in the respective farm’s landscape. Such changes with no productivity improvement are likely to be resisted by farmers and may therefore require more incentives. Gunningham & Sinclair (2005) advocate for a substantial level of direct financial subsidy to farmers where water pollution abatement efforts involve changes in farm landscape. Some empirical studies have shown higher compensation requirement among farmers when proposed agri-environmental schemes involve changes in agricultural practices (Espinosa-Goded *et al.*, 2010; Beharry-Borg *et al.*, 2013). Other studies show that making payments that are far beyond the direct costs incurred by farmers when implementing such schemes is a necessary condition in encouraging farmers’ participation (Christensen *et al.*, 2011).

Use of subsidies as a policy instrument is, however, often criticized for violating the PPP by actually ‘paying the polluter’ (PTP). Farmers may also become dependent on subsidies to keep their farms in business. Subsidy levels therefore ought to be checked so as to get rid of beneficial subsidies while PTP approaches should be replaced with those consistent with PPP (Hanley *et al.*, 2002; Shortle *et al.*, 2012).

*5.1.3. Information and voluntary approaches.* Information-based instruments aim at improving environmental performance through provision of better information upon which decisions can be based. They constitute provision of targeted information, naming and shaming/faming by publicizing emission inventories, and registration, labeling, and certification schemes (Taylor *et al.*, 2012). Voluntary approaches (VAs) refer to policies, programs, and initiatives that polluters agree to participate in willingly without being coerced to do so. VAs are broadly categorized into three types: (1) unilateral initiatives that are characterized by self-regulating polluters with no government intervention;

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<sup>6</sup> CW have a lifespan of at most 20 years and are therefore not considered as permanent. Farmers may, however, leave sections of their farms as wetlands permanently without any constructions (these are the permanent wetlands).

(2) negotiated agreements involving regulators' and polluters' negotiations and agreement on the terms of the environmental program; (3) public voluntary programs that are government-sponsored with the regulator setting the eligibility criteria, rewards, and obligations of participation (Segerson, 2013a).

VAs are increasingly being used as environmental instruments. However, de Vries *et al.* (2012) argue that information on regulators' aims and motives in VAs is sketchy, and the existing economic literature does not give clear guidelines to the policymakers about the appropriateness of VA policy instruments. However, de Vries *et al.* (2012) highlight the following key factors for consideration in designing VAs: (1) effectiveness in setting pollution-abatement targets, participation, and abatement targets' realization; and (2) efficiency in terms of costs relative to other policy instruments (static efficiency), and in relation to technology and innovation incentives (dynamic efficiency). Major advantages of VAs include non-imposition of unwanted costs on the parties involved, potential cost saving due to their flexibility, and greater collaboration between the regulator and participating firms or groups (Segerson, 2013b). The effectiveness of VAs is, however, highly dependent on the design of the program and the context being evaluated. For example, the AGWAPLAN project showed a large interest in voluntary participation in reduction of nitrogen losses and farmers could find cheaper solutions locally (Wright & Jacobsen, 2010). However, the findings also suggest that farmers are unlikely to propose measures that are more costly than a given threshold. In the case of the Nordsminde catchment, the suggested measures did not reach the target. Voluntary measures have in some instances been less successful as the compensation given to farmers has to reflect the income lost (Ministry of Food, Agriculture and Fisheries, 2012). The information approach in Denmark has mainly focused on promotion of optimized feed practice and low-excretion livestock feeding, and tightened ammonia restrictions and special restrictions around nature-sensitive areas. VAs include subsidies for the promotion of better manure handling and animal housing, organic farming, low-nitrogen grasslands in sensitive areas, extensification, afforestation, and creation of traditional wetlands (Dalgaard *et al.*, 2014). Most information and voluntary approaches (IVAs) are employed as complements to other types of regulations, making it difficult to measure their specific contribution to emission reduction. However, they play an important role in awareness creation (Gouldson *et al.*, 2008).

Although more Danish farmers have shown a preference for IVAs in implementing nutrient reduction measures, and a high willingness to adopt CW, availability of sufficient information remains a challenge (Gachango *et al.*, 2015a, 2015b). This challenge has also been cited as a key hindrance in adoption of CW among Swedish farmers (Hansson *et al.*, 2012). Information on current status and requirements for reaching the GES of water bodies within the RB therefore needs to be made more accessible to farmers. Additionally, information on the cost efficiency of filter technologies ought to be well packaged for the farmers, and sufficient resources set aside to enhance dissemination. Provision of such information could lead to cost savings, and motivate voluntary adoption of pollution-mitigating technologies (Ribaud, 1998). Provision of incentives for participation in the voluntary establishment of filter technologies may also be necessary. These could be in financial form (subsidy) or a regulatory threat (Segerson, 2013b). Regulatory threat may be preferred since use of subsidies may result in increased budgetary burden (Ribaud *et al.*, 2011).

## 5.2. General versus targeted instruments

General instruments are applied uniformly to all polluters whereas targeted instruments employ some form of environmental differentiation. The former implicitly assumes a direct and additive relationship

between the emission of the pollutant and the degree of welfare loss by the society (Baumol & Oates, 1988). However, this assumption does not hold for non-point pollution due to stochastic processes and heterogeneous production activities resulting in diverse environmental impacts (Shortle & Horan, 2001). In theory, differentiated instruments are found to be more cost-effective (Baumol & Oates, 1988). Empirical studies, however, give divergent results, which could be attributed to the degree of heterogeneity accounted for and its corresponding level of detail, and the targeted population (Lacroix *et al.*, 2007). The studies carried out in Denmark correspond to the theoretical underpinnings by finding spatially targeted policies being more cost-effective (Schou *et al.*, 2000; Konrad *et al.*, 2014). However, these studies do not account for transaction costs, without which highly targeted policy options tend to outperform the uniform options (Horan & Shortle, 2001).

Use of general regulation has been predominant in Denmark. The designation of the whole country as a Nitrate Vulnerable Zone at the onset of the implementation of the EU Nitrate Directive strengthened its use (Smith *et al.*, 2007). Geographically targeted regulations have been introduced in recent years and include subsidy for reduction of nitrogen in grasslands within environmentally sensitive zones and buffer zone establishment around streams, lakes, and ammonia-sensitive habitats (Dalgaard *et al.*, 2014). Extended use of targeted measures is deemed necessary given that the WFD proposes establishment of RBMP as the main avenue of meeting the water quality goals. So far, Denmark has complied with the requirements by developing RBMP for each of its four RB districts (23 sub-RB districts). However, water quality goals in these RB are yet to be reached (European Commission, 2012), thus calling for further actions. The filter technologies could be suitably implemented as targeted measures for catchments with high nutrient and pesticide loads. They facilitate retention of sediments and heavy metals and adsorption of pesticides besides nutrient removal. Furthermore, their effectiveness is highly dependent on the level of nutrient load in discharge and other site-specific factors such as soil types (Heeb, 2012; Kjaergaard & Iversen, 2014). Consequently, the hydraulic conditions required for increased efficiency of the technologies can be met at minimal cost if the technologies are established in catchments with elaborate drainage systems or where such systems can be easily established. Their implementation in low-lying agricultural fields would further lead to secondary benefits of flood control.

### 5.3. *Input based versus output based*

Input-based instruments comprise taxes on damage-increasing inputs, or subsidies on damage-reducing inputs. Output-based instruments encompass charges or subsidies based on individual emissions, or an ambient charge imposed on polluters collectively (Shortle & Horan, 2013). Ambient-based instruments have little information requirements and adequately address the moral hazard problem inherent in input-based instruments. However, they are deemed inefficient for employing a collective fine or subsidy. Their practical application is also limited compared to the input-based regulations (Xepapadeas, 2011).

In Denmark, all nutrient reduction measures, except for regulations imposed on buffer zones around water bodies, and on special ammonia restrictions near sensitive nature areas, have focused on inputs (Dalgaard *et al.*, 2014). Input-based measures have greatly contributed to decreases in nitrogen–soil balance in the north-west European countries. However, not all countries have observed significant decreases in nitrate concentrations in groundwater and surface water resulting from these interventions. Farmers in intensive livestock areas in Belgium, France and the Netherlands still find it difficult to meet the targets (Van Grinsven *et al.*, 2012). A call by the WFD to reduce these concentrations demands a shift from

input- to output-based approaches. The filter technologies qualify as ‘end of pipe’ solutions that would effectively reduce nitrate concentrations in the recipient water bodies. This is further enhanced by the fact that the farm discharge is retained in the filter structures before being released to the recipient water body. This would facilitate the monitoring of pollutants, thereby increasing the efficiency of regulating non-point pollution (Xepapadeas, 2011). Moreover, nutrient reductions under WFD are targeted at sub-RB, thereby making it easier to implement the filter technologies at the most optimal locations.

#### 5.4. Choice of implementation strategy for innovative filter technologies

As shown in Figure 1, Denmark has over the years adopted a general nutrient reduction regulation imposed mainly through the CAC approach with almost all the instruments being input based. This approach has been supported by a few voluntary measures, such as setting aside land and increasing grassland. The almost single-sided approach of implementing policy measures has, however, not performed as expected (Mikkelsen *et al.*, 2010). This shortfall could be attributed to the fact that: (1) pollution externality may result from other types of failures of private governance structures, such as technological spillovers and asymmetric information, in addition to market failure; and (2) the transaction cost of implementing a first-best policy could be too high (Lehmann, 2012). The challenge of transaction costs is evidenced by high heterogeneity of marginal abatement damages and costs in non-point source pollution. Damages caused by a pollution unit vary with the ecological, technical and socioeconomic conditions of the pollution source and recipient body. Consequently, polluters’ direct and opportunity cost of pollution abatement depends on their level of technology and input use, and the output they produce. These conditions render a single policy inefficient (Lehmann, 2012). Howlett & Rayner (2007) advocate for a policy mix to enhance efficiency.

Implementation of filter technologies involves direct and opportunity costs on the part of the farmers. Use of a single policy may lead to inefficient reduction of pollution, thereby rendering employment of a mix of policy instruments more appropriate. Based on our discussion in the preceding sections, IVAs and market-based instrument approaches are seen as the most suitable strategies for implementing the innovative filter technologies. The approaches should, however, be integrated with support-mechanism instruments such as continuous research and knowledge generation, opening up of established sites as demonstration projects for knowledge diffusion, and fostering network-building participation (Gouldson *et al.*, 2008). This will improve relationships among different stakeholders, thereby opening avenues for free flow of information. This would further enhance policy efficiency by responding to the feedback from stakeholders on the changes or improvements in nutrient reduction measures as well as reflecting on the future requirements for water quality. The support mechanism will also ensure flexibility. Flexibility has been observed to some extent in the Danish regulation with respect to catch crops, which has significantly reduced some costs (Jacobsen, 2012a). More flexibility would, however, allow drainage filter technologies to replace reduction in nitrogen norms, which would increase income and at the same time reduce the nitrogen losses from the farms. This trade-off approach requires that the environmental effect is evaluated prior to the investment in filter technologies at a given location. To find the most appropriate instrument for implementing filter technologies, we can borrow a leaf from the traditional wetland measure that has been implemented through a voluntary program over the last 15 years. Although over 12,000 ha have been restored (EU-LIFE, 2014), a huge potential still exists (Knudsen & Lemming, 2012). The low uptake has been attributed to the high economic value of agricultural land and the requirement that the wetlands meet a certain threshold of nutrient reduction before any

compensation is due (OECD, 2008). An incentive that addresses these hindrances would therefore be appropriate for filter technologies.

An incentive of increasing nitrogen norms of 143 kg nitrogen per ha of mini-wetland and 62 kg nitrogen per ha of drained area has been used in two projects looking at farmers' choice of measures at the farm level. The findings from these projects show that farmers are willing to consider mini-wetlands and/or CW as an alternative to other measures (MST, 2015; Jacobsen & Hansen, 2016). Among the ten farmers in the Nordsminde catchment participating in the project, seven have chosen mini-wetlands with the drainage area being 17% of the total agricultural area.

The most appropriate implementation strategy for the new filter technologies would be a geographically focused, voluntary approach where filter technologies replace other more general and expensive measures, leaving the choice to the farmer. Since the measures involve investments, a subsidy could be provided, just as has been the case with traditional wetlands. This should, however, be linked to a minimum required effect.

## 6. Conclusions

This paper carries out an in-depth assessment of innovative filter technologies used in the implementation of the WFD in Denmark. The role of these technologies in addressing the challenge of stringent water quality requirements and competitive agricultural production is established, and their cost implications discussed. An analysis of the strategies for incorporating the technologies into policy measures, in the quest to achieve the requirements of the WFD, is then carried out. Despite being at the lower phases of technology life-cycle, these site-specific technologies have shown great potential for the reduction of nutrients in agricultural discharge. The targeted nature of these technologies further enhances their preference in implementation of the WFD, which requires the use of localized and output-based approaches at RB levels.

The study identifies differences between farmers' perception of water quality and the quality reported in the RBMP. This misfit, coupled with insufficient information on available incentives for adoption of these technologies, is seen as a potential hindrance for further measures and environmental investments at the farm level.

Using some elements of impact assessment, different policy instruments that could be adopted in implementing the innovative filter technologies are explored. Based on a three-faceted policy instrument typology, the compliance, implementability, advantages, and disadvantages of each instrument in implementing the filter technologies are assessed. The study suggests that the output-based filter technologies should have a geographical target. Their implementation should focus on VAs supported by investment subsidies, or replacement of existing nutrient reduction requirements. The latter is likely to have the greater effect. This suggestion is in line with the recently adopted Food and Agricultural Package. These approaches should, however, be linked to an assessment of effect (nitrogen removal/phosphorus retention per unit) as this is expected to vary with location. The expected levels of 1,000 CW before 2021 and more than 1,000 ha per year of traditional wetlands are perceived as a large challenge, which will require a very positive approach by many farmers and a very supportive administrative set-up.

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