Cost-benefit analysis of abatement measures for nutrient emission from agriculture

Wustenberghs H.[1], Broekx S.[2], Van Hoof K.[3], Claeys D.[1], D'Heygere T.[3], D'Hooghe J.[1], Dessers R.[1], Huysmans T.[3], Lauwers L.[1], Meynaerts E.[2], Vercaemst P.[2]

[1] Institute for Agricultural and Fisheries Research (ILVO), Social Sciences Unit, Van Gansberghelaan 109, B 9820 Merelbeke, Belgium
[2] Flemish Institute for Technological Research (VITO), Boeretang 200, B 2400 Mol, Belgium
[3] Flemish Environmental Agency (VMM), A. Van De Maelestraat 96, B 9320 Erembodegem, Belgium

Abstract— **In intensive animal husbandry areas surface water N and P concentrations often remain too high. The Water Framework Directive calls for additional nutrient emission abatement measures. Therefore, costs and benefits for possible agricultural measures in Flanders were first analysed in terms of soil balance surplus. Finally, abatement measures for agriculture, households and industry were set off against each other and ranked according to their cost-efficiency by the Environmental Costing Model. Increased dairy cattle efficiency, winter cover crops and increased pig feed efficiency turn out very cost efficient. Other agricultural measures are less cost efficient than for instance collective treatment for households and industry.**

Keywords— **nitrogen and phosphorus abatement, surface water, cost efficiency**

I. BACKGROUND AND OBJECTIVES

Nutrient emission from agriculture remains an important environmental issue. In spite of efforts made by farmers and important reductions of soil balance surpluses already achieved, surface water nitrogen and phosphorus concentrations in intensive animal husbanddry areas still exceed standards for good water quality. The European Water Framework Directive (WFD, Directive 2000/60/EC) stipulates that by the end of 2015 "good ecological status" needs to be achieved. This calls for additional nutrient emission abatement measures. However, measures need to be cost-effective and excessive costs may provide an argument to (temporarily) loosen goals for a certain area. Within this context the environmental benefits and sector costs of a set of abatement measures for nutrient emission from agriculture in Flanders were analysed. The final goal is to select cost-effective abatement measures to reduce surface water pollution.

II. MATERIALS AND METHODS

The selection problem is tackled by a three stage approach, involving three research groups and linking results from three different models:

1. determine nutrient emission abatement potential of measures and the costs incurred upon their implementation (ILVO);
2. calculate run-off and leaching reductions (VMM);
3. compile results into the Environmental Costing Model (ECM) that selects least-cost combinations of abatement measures to reach environmental goals (VITO).

The effect of following nutrient emission abatement measures for agriculture were compared to that of the region's prevailing nutrient legislation (including EU Nitrate Directive derogation): livestock reduction, increased dairy cattle efficiency, increased feed efficiency, exclusion of nitrates derogation, lowered fertilisation limits below the EU Nitrate Directive's standard (to 140 kg N-org/ha), tuned fertilisation (only up to crop requirements), manure treatment by anaerobic digestion, buffer strips along watercourses, reduced tillage, winter cover crops (measures abating non-point source emissions) and recycling or processing drain water from greenhouse and container cultures (measures abating point source emission).

A. The Environmental Costing Model (ECM) by VITO

The final selection of cost-effective abatement measures is carried out by using the Environmental Costing Model. By means of mixed integer programming the ECM identifies the least-cost combination of abatement measures to satisfy given multi-pollutant reduction targets. The ECM was initially developed for industrial air pollution sources [1,2]. Recently, it was adapted for water pollution sources [3]. Pollutants targeted in the case of surface water are phosphorus, nitrogen and chemical oxygen demand (COD). Besides agriculture, industry and households are incorporated as emission sources. This enables comparing agricultural measures with measures like individual treatment or connection to sewerage and collective treatment for households or improved end-of-pipe treatment for industrial waste water. In order to rank measures, marginal abatement cost curves are set up.

B. The SENTWA model by VMM

Environmental benefits of abatement measures, needed for the abatement cost curves, are partly taken from the SENTWA model (System for the Evaluation of Nutrient Transport to Water). [4,5,6] This model calculates nutrient losses to surface water, using data on livestock numbers, nutrient excretions, manure transports and nutrient inputs on cultivated land; hydrologic, geomorphic and meteorological conditions; soil use and agricultural techniques and practices. The model takes different types of nutrient losses into account: direct ones (e.g. of mineral fertilisers during application or of animal manure during pasturing), subsurface run-off and surface run-off (direct or linked with erosion). Monthly losses are calculated taking precipitation, crop development stage and spread of agricultural activities into account for relatively small areas, such as river sub-basins.

C. Estimations and modelling by ILVO

Environmental benefits for the ECM are also partly taken from direct estimations of percentage nutrient loss reductions.

For the case of nutrient and COD emission by agriculture, environmental benefits were evaluated through their effect on the parameters used as input for SENTWA or through their percentage reduction in run-off, leaching and drain water discharge (parameters directly fed into the ECM).

As a point of reference, abatement measures were evaluated for their effect on soil balance surplus, whenever possible. The soil balance was drawn up using MIRANDA, a straightforward modular calculation model that uses farm-specific data on livestock and crops, manure production, manuring possibilities and compulsory manure processing to determine manure surplus and manure transport (exchange between surplus production and remaining manuring possibilities) [7,8]. The soil surplus was then calculated using these manuring data, mineral and other organic fertilisation, seed input, biological N fixation, atmospheric N deposition, crop outputs and ammonia losses to the air.

Abatement measure costs were estimated by taking investment and operational cost into account. Data were derived from market transactions whenever possible. These were found in farm accountancies, investment files, public authorities' expenditures, sales figures from supply sectors, etc. When no workable market transaction costs were found, subsidy amounts were used, conform the CAP principle that second pillar subsidies cover the costs incurred when implementing agri-environmental schemes. In this case, however, it needs to be borne in mind that subsidies might not internalise externalities to the economic optimum and that transaction costs might be underestimated. In the ECM marginal costs are ranked irrespective of the agent bearing the cost, i.e. no difference is made between private and social costs.

III. RESULTS AND DISCUSSION

A. Results in terms of cost versus soil balance surplus

Two nutrient abatement measures show negative *costs*, i.e. economic benefits. The first is manure processing by anaerobic digestion and converting the biogas into electricity with a combined heat and power (CHP) engine. Investment is recovered by electricity sales, savings on heating and "green power" and CHP support. However, costs are only negative if support schemes continue to exist and if digestate could be applied to cropland without further treatment, which currently is prohibited. The second, more robust, negative cost is for increasing dairy cattle's efficiency: even though it is hard to estimate breeding costs, it is clear that decreased costs for producing a given amount of milk with smaller herds outweigh increased cost of higher concentrate requirements. Moreover, decreased excretion per given amount of milk by smaller herds outweigh increased excretion per cow [9]. Costs for dairy efficiency are lowest if redundant grassland can be converted to arable land. However, the substituting arable crops will need to be fertilised and certainly in the case of maize this will reduce environmental benefits (Table 1).

The largest soil balance surplus reductions are gained by decreasing nutrient input, either by a flat rate restriction of fertilisation limits to a maximum of 140 kg N from manure or by only fertilising up to crop requirements (tuned fertilisation). Both measures reduce N and P surpluses by about one third (Table 1). Costs for tuned fertilisation, however, are estimated at only one third of those caused by a flat rate decrease, (0,48 €/kg and 1,45 €/kg N surplus reduction). When expressed in this way, an overall restriction of fertilisation even seems the most expensive abatement measure (Figure 1).

The second largest soil balance surplus reduction was gained by further increasing feed efficiency, i.e. decreasing N and P content in concentrates, thus reducing excretion per animal. Especially in fattening pigs large improvements still seem possible (Table 1). Costs for increasing feed efficiency for pigs, in proportion to soil balance surplus reduction, are estimated at 0,10 €/kg N, i.e. the lowest of all positive cost/benefits. Cost for further increasing feed efficiency in poultry are higher, as poultry feeding already is quite close to efficiency limits.

Livestock reduction is one of the more expensive measures , due to income loss. On average over all livestock types it is estimated at 0,81 €/kg N.

Table 1 Estimated soil nutrient balance surplus for Flanders (kg N or P /ha) and percentage reduction compared to the reference situation

	N		P	
Abatement measure	Surpus	Δ	Surpus	Δ
Basic measures	105.6		9.6	
Livestock reduction	101.1	- 4.3 %	7.8	- 18.8 %
Dairy cattle efficiency				
excl. grassland ↓	97.2	- 7.9 %	9.3	- 2.5 %
incl. grassland ↓	102.9	- 2.5 %	9.4	- 1.5 %
Feed efficiency (total)	85.4	- 19.2 %	6.8	- 29.0 %
fattening pigs	91.9	- 13.0 %	6.9	- 27.9 %
poultry	99.1	- 6.2 %	9.5	- 1.1 %
Derogation exclusion	96.1	- 9.0 %	9.6	- 0.0 %
Lower fertilisation limit	68.1	- 35.5 %	7.2	- 24.8 %
Tuned fertilisation	67.6	- 36.0 %	6.3	- 34.5 %

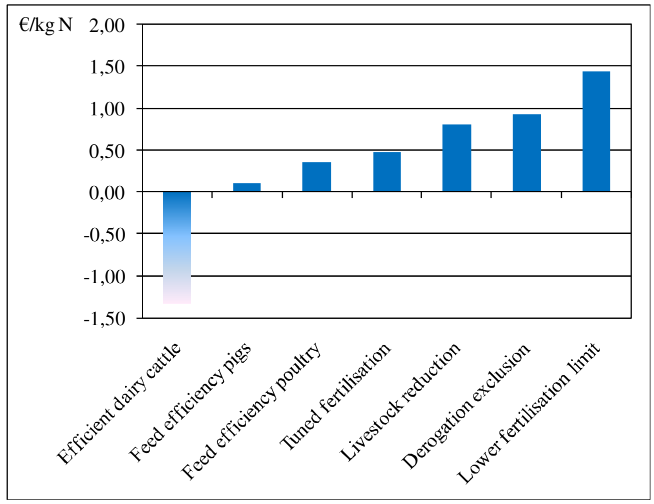

Fig. 1 Average abatement cost of N reduction in Flanders

B. Results in terms of cost efficiency in reducing nutrient losses to surface water

The SENTWA model was then used to estimate the impact of measures on nutrient losses to surface water. This enables to compare the effectiveness of agricultural measures with measures aimed at reducing losses from point sources, i.e. from households and industry.

Figure 2 shows results from the Environmental Costing Model: a marginal abatement cost curve for reducing N-losses for the whole Flemish Region. As required by the WFD, a distinction is made between basic and supplementary measures. Basic measures can be described as the minimum requirements to implement other Community or Regional legislation. Basic measures will be implemented irrespective of the WFD requirements and are not the subject of the cost effectiveness analysis. The supplementary costs of these measures are set to zero. Basic measures included in the analysis are:

- execution of the investment programs in sewage and wastewater treatment as required in the Urban Wastewater Directive;
- improvement of individual treatment for industry to reach the emission targets as required by the IPPC directive and existing legal standards;
- prevailing nutrient legislation, including Nitrate Directive derogation.

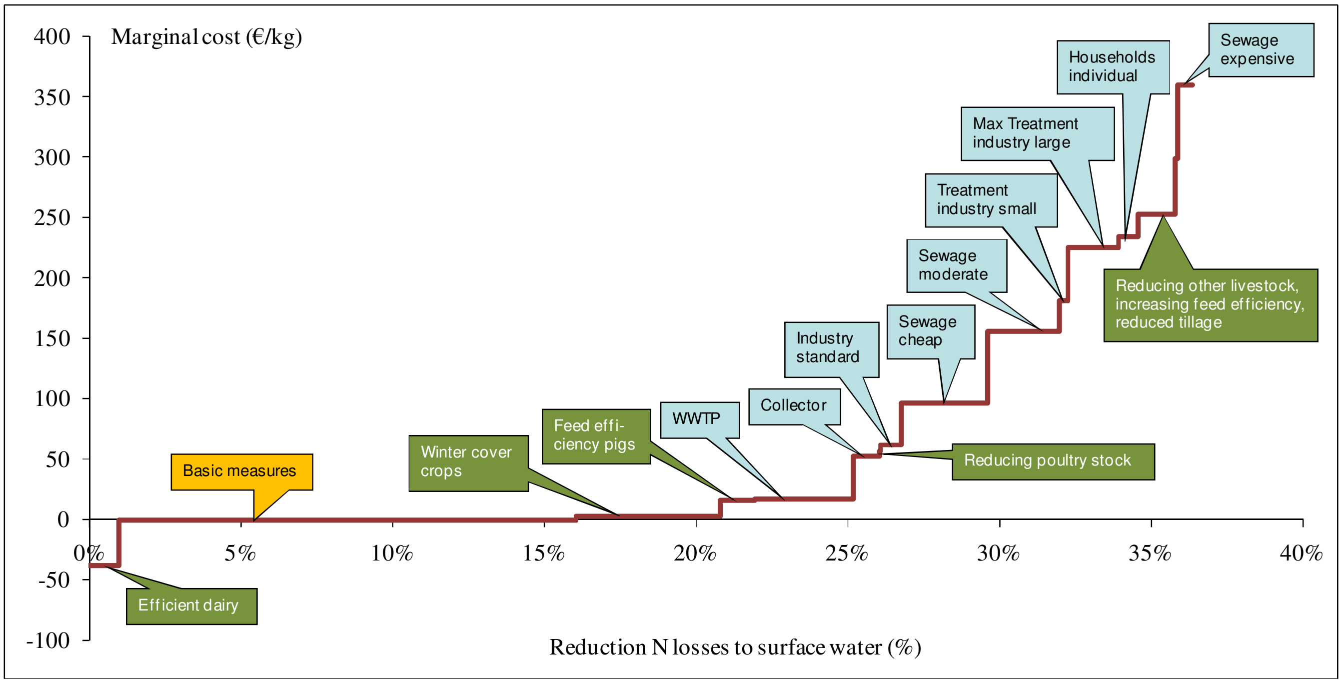

Fig. 2 Marginal abatement cost curve of reduction of N-losses in Flanders for households, industry and agriculture

Supplementary measures for households and industry are:

- improving efficiency of collective treatment and constructing small scale treatment stations (WWTP)
- connecting existing sewage to collective treatment collectors (collectors);
- extending the sewage system for households, grouped according to cost compared with small scale individual treatment households: cost sewage < cost individual treatment (sewage cheap), cost sewage < 2 x cost individual treatment (sewage moderate), cost sewage > 2 x cost individual treatment (sewage expensive);
- small scale individual treatment for remote houses (households individual);
- further improvement individual treatment in large industrial plants with difference between intermediate concentration targets based on targets set for the Urban Wastewater Directive (industry urban standards) and a maximum technically feasible scenario (max treatment industry large);
- further improvement individual treatment in small industrial plants (treatment industry small).

It is important to notice that these cost figures are based on averages for the whole Flemish region. Measures which in general are not very cost efficient for N losses can be more efficient for other parameters or for specific catchment areas.

Compared with measures aiming at reducing N emissions from household or industrial point sources, agricultural measures, such as efficient dairy cattle, winter cover crops and feed efficiency for pigs are considered very cost efficient. Other measures, such as reducing livestock, tuned fertilisation and reduced tillage are less cost efficient than for instance measures concerning collective treatment for households and industry.

The ECM results, showing agricultural measures less cost efficient than generally expected are also caused by the SENTWA results. Though nutrient use decreased significantly, nutrient losses decreased much less. More recent research on the revision of the SENTWA model show a more significant linkage between nutrient usage and nutrient losses, which would increase the efficiency of agricultural measures [11]. However, the relative inelastic response of nutrient losses towards nutrient usage on a short term is also confirmed within this study.

Figure 2 shows that implementing the relatively cheap agricultural measures and WWTP in Flanders would only lead to 25 % reduction of N losses to surface water. Implementing all measures explored in this study, would lead to about 36 % reduction. In 2006, N targets for good water quality as defined by the Flemish Environment Agency were on average exceeded by 41 %. Achieving the N targets on a short term (e.g. 2015) thus seems very unlikely.

IV. CONCLUSIONS

Preliminary calculations of average cost per kg soil balance surplus reduction show that there is still "good value for money" in applying abatement measures that are good agricultural practice, rather than environmental measures in the strict sense. ECM results for marginal cost per kg N loss to surface water confirm these results. Increased dairy cattle efficiency, sowing winter cover crops and increased pig feed efficiency turn out to be very cost efficient. Other agricultural measures are less cost efficient than for instance collective treatment for households and industry. In Flanders, however, achieving N targets on a short term seems very unlikely, even when implementing all currently available abatement measures.

REFERENCES

1. Eyckmans J, Meynaerts E, Ochelen S (2005) The Environmental Costing Model: a tool for more efficient environmental policymaking in Flanders. The ICFAI Journal of Environmental Economics, vol. 3 (2): 7-24.
2. Lodewijks P, Meynaerts E (2007) The Environmental Costing Model: a tool to advise policy makers in Flanders on issues of cost efficiency. Proc. 6th Internat. Conference on Urban Air Quality, Cyprus, 2007
3. Broekx S, Meynaerts E, Vercaemst P, Ochelen S, Beckers A (2006) Towards a good surface water state in the Flemish Region of Belgium with the Environmental Costing Model. In: Brebbia C A, Antunes do Carmo J S (eds.) Water Pollution VIII: Modelling, Monitoring and Management. WIT Press, Southampton, UK: 139-146
4. Nolte Ch, Werner W (1991). Stickstoff und Phosphateintrag über diffuse quellen im Flussgebiet des Elbeeinzugsgebietes im Bereich der ehemaligen DDR, Agrarspectrum Schriftenreihe Bd. 19, Dachverband Agrarforchung, DLG-Verlag, Frankfurt (Main)
5. Pauwelyn J, Depuydt S, Sockart P (1997). Studie ter kwantificering van de nutriëntverliezen per stroombekken naar het oppervlaktewater door landbouwactiviteit in Vlaanderen: Een praktijkgericht onderzoek ter ondersteuning van het milieu- en landbouwbeleid. Studie i.o.v. VMM. Ministerie Middenstand en Landbouw, Instituut voor Scheikundig Onderzoek, CODA
6. Verlinden G., Vogels N. (2002). Wetenschappelijk onderzoek en calibratie en validatie van de drainage-, grondwater- en excesverliezen in het SENTWA-model voor de landbouwstreek polders teneinde de kwantificering van de nutriëntverliezen per stroombekken naar het oppervlaktewater afkomstig van de bemesting in Vlaanderen verder te verfijnen: eindrapport. Bodemkundige Dienst van België, Heverlee, Belgium
7. Sanders A, Lenders S, Carlier P J, Lauwers L (2004) MIRANDA: Modulaire simulatie van mestafzetruimte. Studie i.o.v. VMM, Centrum voor Landbouweconomie, Brussels, Belgium, MIRA/2004/01 at http://www.milieurapport.be
8. Claeys D, Lauwers L, Marchand F M, Van Meensel J, Buysse J, Van der Straeten B, Van Huylenbroeck G (2008) Derogation on the EU Nitrates Directive: does it make a difference? Proc. 12th EAAE Congress at http://www.eaae2008.be
9. Wustenberghs H, Fernagut B, Lauwers L, Overloop S (2007) Exploring the variability in dairy cattle N-excretion for monitoring regional N balances. In: Bosch Serra A D, Teira M R, Villar J M (eds.) towards a better efficiency in N use. Proc. 15th Nitrogen Workshop. Editorial Milenio, Lleida, Spain.
10. Claeys D, D'hooghe J, Dessers R, Wustenberghs H, Lauwers L, Van Meensel J, Vander Vennet B (2007) Reductiepotentieel en kosten van beleidsmaatregelen met betrekking tot diffuse en puntbronnen. Maatregelen en instrumenten die verontreinging door de landbouw kunnen voorkomen. Studie i.o.v. VMM, ILVO, Merelbeke at http://www.ilvo.vlaanderen.be
11. Seuntjens P, Joris I, Provoost J, De Neve S, Salomez J, Sleutel S, Wendland F (2008) Estimating the consequences of changes in manure policy on surface water. Study for the Flemish Environment Agency.

Corresponding author:

- Author: Hilde Wustenberghs
- Institute: Institute for Agricultural and Fisheries Research (ILVO)
- Street: Burg. Van Gansberghelaan 115, box 2
- City: 9820 Merelbeke
- Country: Belgium
- Email: hilde.wustenberghs@ilvo.vlaanderen.be