The Common Agricultural Policy aggravates eutrophication in the Baltic Sea

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Paper prepared for presentation at the 172nd EAAE Seminar *'Agricultural policy for the environment or environmental policy for agriculture?'*

May 28-29, 2019.
Brussels.

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Abstract

We study how changes to the common agricultural policy (CAP) affect eutrophication of the Baltic Sea. Our results indicate that if the entire first pillar of the CAP, containing the direct payments, greening and accompanying measures, were to be abolished, production and agricultural land use would be reduced while yields and fertilizer use per hectare would go up. Our computations indicate that the net effect of those opposite forces would be that nitrogen and phosphorus loadings from agriculture decrease, marginally improving indicators of good ecological status for eutrophication in the Baltic Sea, and thus that the first pillar contributes to aggravating eutrophication of the Baltic Sea.

Acknowledgements

This research was funded by BONUS GO4BALTIC (BONUS, Art 185), funded jointly by the EU and national funding institutions in Denmark (the Innovation Fund), Estonia (Estonian Research Council ETAG), Finland (Academy of Finland), Poland (NCBR) and Sweden (FORMAS). The research has also received funding from Stockholm University Baltic Sea Centre – project Baltic Eye.

1. Introduction

The Baltic Sea is not healthy. One problem is eutrophication – the accumulation of nutrients and subsequent impacts on various forms of life in the water. The HELCOM assessment report of 2018 (HELCOM, 2018a) found that 96% of all waters are below good status as regards eutrophication. Despite decreasing trends in nutrient concentrations in many parts of the Baltic, indicators for eutrophication keep deteriorating. Comparing the assessment period 2011-2016 to 2007-2011, nitrate concentration (DIN) deteriorated in 5 out of 17 basins and improved in one.

Agriculture contributes strongly to eutrophication. More than half of the anthropogenic input of nitrogen to the Baltic Sea comes from agriculture. For phosphorous, natural background sources make up around one third of the total loads. Among the anthropogenic sources, diffuse sources (mainly from agriculture) make up 36% of total riverine phosphorus loading to the Baltic Sea (HELCOM, 2018b).

Albeit measurements show decreasing trends in nutrient loads, target levels have not yet been reached (HELCOM, 2018a). Furthermore, climate change is expected to lead to increased precipitation in northern catchments and to increasing water temperatures (IPCC, 2014). More precipitation means more runoff, and higher water temperatures aggravate the effects of eutrophication. Therefore, further reductions of nutrient loads are needed for reaching a healthy Baltic Sea.

The Common Agricultural Policy (CAP) has significant impacts on agriculture. The objectives of the CAP have shifted from supply, productivity and income (Treaty of Rome, 1957) towards sustainable production. “Environment and climate change” is now identified as one of three challenges for the CAP (European Commission 2017). Part of the shift in focus took the form of a move of funds from “Pillar 1” to “Pillar 2”, but still Pillar 1 has the largest budget share of the two (70%) and makes up nearly 30% of the entire EU budget (Buckwell, et al., 2017). Environmental considerations have also entered within Pillar 1 itself: 30% of the farm payment envelope is conditional on the farmer or region satisfying environmental “greening” requirements.

As environmental impact is one of the key challenges of the CAP, it is interesting to investigate how pillar 1 affects the Baltic Sea. Much work has been done on cost-effectiveness of nutrient abatement measures for the Baltic Sea (Gren et al., 2013, Elofsson, 2010). Less has been done on the environmental performance of the CAP. Buckwell et al. (2017) analyse the *direct payments* and find that they do not promote efficient resource use and are inefficient in reaching environmental targets. Others have suggested reorienting the direct payments towards support for the provision of environmental public goods (Matthews 2016, OECD 2011, Tangermann 2011, and WWF 2010).

Gocht et al. (2017) use the European agricultural sector model CAPRI model to evaluate the impacts of the greening on selected indicators and find that in general, the environmental impacts are small. They find some beneficial impacts per hectare of land used but argue that the increased land use resulting from Greening may reverse the sign of the overall impact.

Brady et al. (2017) evaluated Pillar 1, also using CAPRI. Among other environmental and economic indicators, they studied the effect on nitrogen (N) surplus from agriculture. Their results show that removing Pillar 1 might affect N surplus in two opposite ways: On the one hand, total agricultural land use and production were reduced, implying reduced application of N. On the other hand, the remaining agricultural production intensified, implying higher N surplus per hectare of land remaining in production. The net impact implied a small decrease in N surplus, but the agricultural sector model alone was insufficient to determine the environmental implications.

Our study is extensive in terms of policies analysed, covering all of Pillar 1. We expand on previous work by Gocht et al. (2017) and Brady et al. (2017) by including both nitrogen and phosphorous and extending the analysis to retention at catchment level and eutrophication indicators in the Baltic Sea. First, we simulate the removal of the first pillar with the CAPRI model, computing the impacts on production, markets, economic indicators, and agricultural nitrogen balances. Results from the nitrogen balance are used as inputs in a nutrient transportation model, computing riverine loads of nitrogen to the Baltic Sea including retention at the catchment level. For phosphorus, losses from land to sea are determined rather by overall land use than by actual phosphorus surpluses. In the final step, these loads are fed into the BALTSEM model of the Baltic Sea, computing the impacts on selected eutrophication indicators.

Each step in the modelling chain is described in section 2 and the scenario set-up in section 3. In section 4, we present results from the modelling exercise. The final section puts the results in perspective and discusses implications for policy makers.

2. Models and data

2.1. A chain of specialized models

In order to study the impact of the CAP on eutrophication indicators of the Baltic, we combine three different simulation models. Each model is specialized in some aspect of the causal chain from policy to biophysical indicators.

- The CAPRI model captures the impact of CAP on agricultural production on a regional level for the European Union.
- The agro-hydrological nutrient transport model uses the changes in production and fertilization provided by CAPRI to compute nutrient loads to the Baltic
- The BALTSEM model takes the nutrient loads provided by the nutrient transportation model to compute the impact on selected eutrophication indicators in the Baltic Sea.

Each model has been applied to various studies and is documented elsewhere. Therefore, this paper focusses more on how the link works, whereas the description of the models themselves is briefer.

2.2 The agricultural sector model CAPRI

CAPRI (Britz and Witzke, 2014) is a partial equilibrium model for the agricultural sector of the European Union and global trade in food and agricultural commodities. The model consists of a supply model and a global market model linked by an iterative process: the market model feeds prices to the supply model, which in turn determines production. Equilibrium ensures cleared markets for agricultural products, young animals, and feed.

The supply model consists of 276 regional farm models: one farm model for each NUTS2[1] region in the EU, Norway, Western Balkans and Turkey. The model covers 51 tradable commodities. These are produced by about 50 crop and animal activities in each of the regions, using 9 general inputs, 3 crop-specific inputs, 6 intermediate crop outputs, 12 intermediate animal outputs (including manure), 3 types of mineral fertiliser (N, P, K) and 10 tradable and non-tradable feed inputs. Each regional farm model optimises regional agricultural income at given prices and subsidies and is constrained by land availability, policy variables and feed and plant nutrient requirements in each region. The objective function also contains non-linear cost components that allow to fit the model to observed behaviour. Parameters of the cost function per crop activity per region are derived from econometric estimates using the CAPRI database and model structure (Jansson and Heckelei 2011).

The supply model contains regional nutrient balances at the level of NUTS2 for each group of crops and each of the three nutrients N, P and K. Nutrients are supplied by mineral fertilizer, manure, nitrogen fixation, atmospheric deposition, and crop residues. The supply of nutrients must cover the crop need, calculated based on yield levels, estimated over-fertilization rates, and losses in manure handling. The nutrient contents of manure are based on animal growth and feeding. Manure can be traded among NUTS2-regions of the same country to allow for regions with intensive animal husbandry to export excess manure to neighbouring areas that are relatively richer in crop land.

The results of a simulation on NUTS2 level can be downscaled to a finer spatial resolution. This is taken care of by an optional econometric routine after the complete solution of the model. The disaggregation was developed in Kempen (2013). The method is based on minimizing deviations from an *a-priori* distribution of crops and animals across *homogeneous spatial mapping units* (HSMU), while maintaining consistency with the aggregate model results for each NUTS2 region. An HSMU is a cluster of 1km grid cells that are similar in terms of soil type, climate, slope, elevation and NUTS3 (administrative regions) affiliation. HSMU are generally discontinuous, and of different sizes depending on the diversity of the underlying area in terms of the defining characteristics. In EU28, there are about 175 000 HSMU. The *a-priori* distribution of crops is obtained from estimates based primarily on the CORINE land cover data base (satellite images) and NUTS3 production data. The downscaled model results include estimates of nutrient balances of each HSMU, which we use as inputs in the agro-hydrological nutrient transport model.

CAPRI contains a rich set of policy instruments, making it suitable for analysing the impact of agricultural policy on environmental indicators. Figure 1 shows a break-down of the Pillar 1 payments analysed in this study. The bulk of the payments in Pillar 1 consists of the Basic Payment Scheme (BPS). The BPS has a weak impact on production: The payments are paid on a per-hectare basis, subject to the possession of a sufficient number of "entitlements". Since both land and entitlements are scarce in supply, the payments tend to increase the values of land and of entitlements (capitalization). If the payments are removed, part of the shock is absorbed by a devaluation of the entitlements, which are no longer needed. Land that is not profitable to crop without the payments is likely to be abandoned.

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[1] Nomenclature of territorial units for statistics, see https://ec.europa.eu/eurostat/web/nuts/background

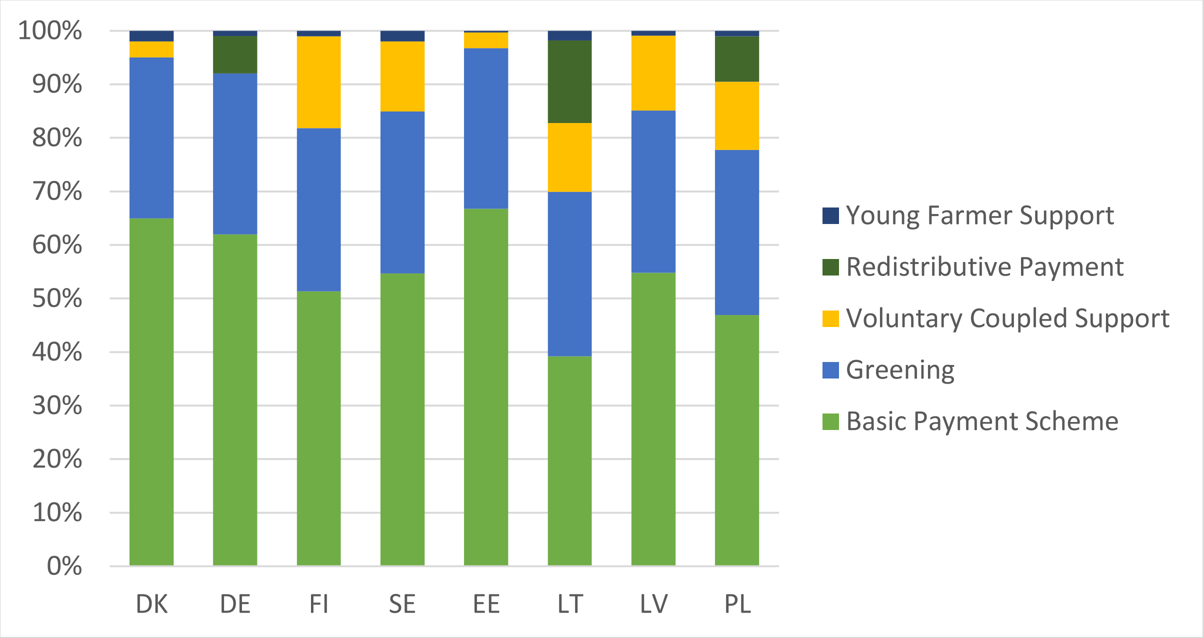

Fig 1 Share of payments within the first pillar belonging to various support schemes. Numbers from the CAPRI baseline for 2030

30% of Pillar 1 payments consists of the "greening" top-up, which is paid as top-up on the BPS, with similar impacts on production. The greening package also contains three compulsory restrictions: (i) to maintain the grassland/arable land ratio versus a reference situation, (ii) to comply with a minimum set-aside rate (up to 5% "ecological focus area"), and (iii) to comply with a certain lower bound on the number of crops grown.

Pillar 1 also contains Voluntary Coupled Support (VCS), which are optional payments directly coupled to production that are defined by each member state within certain bounds given by the EU regulation. For instance, Germany does not use any VCS at all, whereas Finland uses coupled payments extensively. Removing VCS payments in simulations therefore affects member states differently. The VCS payments in CAPRI were based on notifications by the commission (European Commission, 2015). Even though VCS makes up a smaller share of the total CAP budget, it has a strong production link.

There are special payments for young farmers and small farms (redistributive payments). In this CAPRI version, where each region contains a single representative farm but farm structure is not modelled, those payments are implemented based on shares of farms in each region satisfying the criteria. Therefore they have small effects on the results. The decomposition in Figure 1 suggests that they may be important in Lithuania, Poland and (parts of) Germany.

CAPRI is continuously developed. Our study was based on CAPRI Star 1.3, available from www.capri-model.org, with some updates: Nutrient availability factors for manure in Baltic countries were re-estimated based on survey data on manure handling technologies (see http://projects.au.dk/go4baltic/farm-survey/). Also, the areas of silage fodder in Denmark and the shares of legumes in silage mixtures in Denmark and Lithuania, affecting N-fixation, were updated with expert data from the Stockholm Baltic Eye institute and Aarhus University. The model and associated database are available from the authors upon request.

2.3 The agro-hydrological nutrient transport model

Agricultural management practices are among the major drivers of agricultural nutrient losses. Consequently, an appropriate scale to simulate nutrient loss from a scientific perspective should be at the farm scale. In a previous study (Andersen et al. 2016), an agro-hydrological N transport model for the Baltic Sea drainage basin was developed which, at the same time, is running at a high spatial resolution and yet computationally effective. The model was developed from a dataset of more than 4.000 agricultural fields with combinations of climate, soils and agricultural management which overall describe the variations found in the Baltic Sea drainage basin. The soil-vegetation-atmosphere model Daisy (Hansen et al., 1991) was used to simulate N loss from the root-zone of all agricultural fields in the data set. From the data set of Daisy simulations, the most important drivers for N loss were identified by multiple regression statistics and formed into a statistical N loss model. In the present study, the statistical model is applied at the HSMU scale driven by the following inputs provided partly by CAPRI: crop type, farm type, total N input to the crop including fertilizer, manure, N-fixation, atmospheric N deposition, and N in the seed, and additionally information on clay content and soil carbon content in the topsoil. N leaching from non-agricultural land uses is set according to Andersen et al. (2016).

Nitrogen leached from the root-zone of agricultural fields and from other areas is subject to denitrification, often referred to as N retention, during transport to the sea through groundwater and surface waters (streams, lakes and wetlands). Andersen et al. (2016) combined own work with the work of Stålnacke et al. (2015) into estimates of respectively groundwater and surface water N retention in the entire Baltic Sea drainage basin sub-divided into 117 individual catchments. For each catchment the resulting N loading to the Baltic Sea can be calculated by combining N losses at the HSMU scale with catchment-wide N retention estimates.

Phosphorus may be transported from agricultural soils to surface waters by both sub-surface and surface pathways. Sub-surface transport. i.e. leaching, is determined by the long-term (decades) phosphate accumulation in relation to the phosphate sorption capacity of soils (Schoumans and Chardon, 2015). Phosphorus loss by surface processes, mainly in the form of bulk transport of soil particles with associated P, is determined mainly by land use/crop cover in combination with prevalent climate. Thus, P loss by neither transport pathway is to any large degree governed by current agricultural practices but rather by overall land use. Therefore, pragmatically, in this study we model changes in the loading of P from diffuse sources exclusively as a function of the fraction of arable land. i.e. a decrease in the area grown with arable crops leads to a proportional decrease in the P loading from diffuse sources.

2.4 The BALTSEM model

The Baltic Sea is a huge estuary with significant horizontal and vertical salinity gradients. The coupled physical-biogeochemical model BALTSEM is developed to simulate the spatiotemporal effects of nutrient inputs and physical drivers on the status of the marine environment. The model features mechanistic process descriptions for water circulation and mixing, and biogeochemical cycling of the major nutrients (N, P and Si) in water column and sediments. Details of the model construction are available in Gustafsson et al. (2012), Savchuk et al. (2012) and Gustafsson et al. (2017). The model has been used for management purposes in determining Maximum Allowable Inputs used by HELCOM (HELCOM, 2013a,b).

The Baltic Sea is a dynamic system that changes slowly, residence times are about 9 and 50 years for nitrogen and phosphorus, respectively (Gustafsson et al., 2017). Thus, most previous model scenarios have focused on long-term projections (e.g. Meier et al., 2018, Murray et al., 2019). Given that CAP typically is defined for the next decade this study needs to focus on intermediate time-scales. To link the models, the changes in annual loads computed with the agro-hydrological nutrient transport model were assumed to become perpetuated, as a shift in the baseline scenario, and the impacts were computed for the average of the years 2040-2050. The results are compared with a reference simulation without changes in present loads. In reality, differences would be masked by natural variability due to weather and hydrographic conditions, but since the two simulations are run with exactly the same external forcing (except for nutrient loads) changes are detected.

3. Scenarios

For analysing the effect of the Pillar 1 payments, we create a policy scenario to be compared to a reference scenario where there is no change of the present policies. Both scenarios are developed and simulated in the CAPRI model and the downscaled results on nitrogen balance and surplus at NUTS2 regional level are used as input in the Agro-Hydrological nutrient transportation model.

As *reference* scenario, we use the standard CAPRI baseline for 2030, demonstrating the most probable future development for the European agriculture under the current policies. The reference scenario in that way simulates the current policy, CAP and other likely agricultural policy developments continued up to 2030. The baseline is generated based on market projections from OECD, FAPRI, FAO and DG-AGRI, trend projections and expert knowledge on future policy developments (Britz and Witzke, 2014).

In the *No Pillar 1* scenario, we remove the first pillar of the CAP. This takes away all the direct payments, implying that there is no greening support, no support to young farmers and no voluntary coupled support. Further, there are no Good Agricultural and Environmental Conditions or greening requirements in the policy scenario. The Statutory Management Requirements are part of other legislation and not only valid under the first pillar. Therefore, they are not removed.

4. Results

4.1. Impacts on agricultural production and fertilization

Removing pillar 1 results in a decline of agricultural production and land use compared to the baseline scenario. Production of oilseeds, grassland and cereals are generally much affected, as is production of pulses in regions where there is coupled support for such crops in the reference scenario. Milk and meat production decline less than crops and grasslands. Figure S1 of the supplementary materials shows impacts various sectors. For all products, inelastic consumer demand causes prices to rise in response to reduced supply, and this effect somewhat dampens the contraction of supply.

Agricultural areas generally decline. Sweden and Finland experience the largest relative change in agricultural land use with reductions of about 12%. The explanation for Sweden and Finland reacting more strongly than other regions is found in the model parameters: the responsiveness of agricultural land supply to changes in land rents is greater in those countries, based on estimates done with spatial land allocation model (see Renwick et al., 2013). That outcome is in turn explained by the relatively large land buffers that is created by forestry in those countries. In Germany and Poland agricultural areas decline by about 8%, predominantly in pastures. In Germany, the reductions happen in areas outside of the Baltic drainage basin and thus do not directly affect the nutrient loads. Grass lands generally decline more than arable land, due to the abolition of the greening requirement: that the ratio of grass/arable areas must not be reduced. Without this requirement, grasslands are abandoned where unprofitable to maintain.

The reduction in area is coupled with an intensification in terms of yields and inputs. This is illustrated in Figure 2, where the blue bars show the reduction in area and the orange bars show the increase in fertilizer use per hectare. In countries with larger reductions in area, such as Finland, Sweden, Germany and Finland, there are also larger increases in fertilizer use per ha. The average increase in use of N fertilizer per hectare is about 4%, with some variation across countries. The increased intensity is important, since higher surplus per hectare tend to increase the leaching more than proportionally (Delin and Stenberg, 2012). Less productive land is abandoned as agriculture there is often more dependent on subsidies, and higher prices make higher input use more profitable on the remaining land. Furthermore, expansion in some higher yield areas was previously discouraged by a lack of payment entitlements.

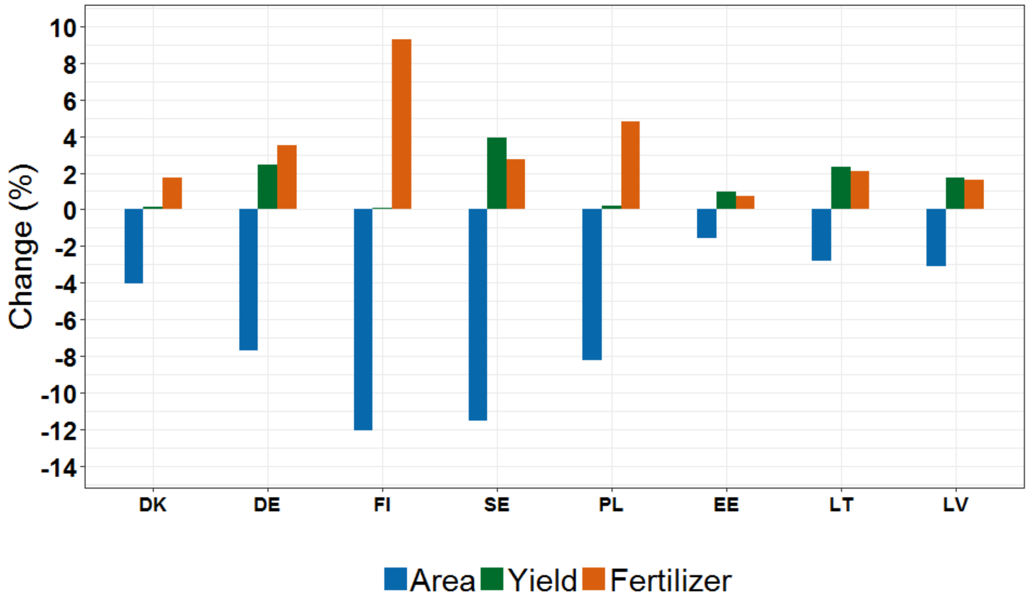

Fig 2 Changes in agricultural area, yield and fertilizer use (manure, mineral and crop residues). Fertilizer use is shown in percentage change per ha and yield is an aggregate of the total field crops over total utilized area

The production changes reduce the total N surplus from agriculture. Table 1 shows the surplus computation in CAPRI decomposed into fertilization sources and removal by harvest. Without the first pillar, total N surplus (the bottom line) decreases by 0.5 -5.4%, on country level, and total N surplus decreases by 2.6% (94 000 ton Nitrogen). The primary driving factor is the lower overall use of fertilizers. On sub-national level, the net effect may be either a reduction or increase in overall nitrogen surplus, as visible in Figure 3[2], and those spatially disaggregated results were used to compute loads to the Baltic Sea per drainage basin.

Table 1 Nitrogen balance in the No Pillar 1 Scenario, aggregated to country-scale. All values are in 1000 tons N, *italicized* numbers are absolute difference to reference scenario and numbers in brackets are percent difference to reference

Country -->	**DK**	**DE**	**FI**	**SE**	**PL**	**EE**	**LT**	**LV**
Mineral fertilizers	160.8	1625.8	136.6	157.6	1271.2	50.5	220.8	93.7
	-5.4	*-66.9*	*-4.6*	*-17.9*	*-29.0*	*-0.1*	*-1.0*	*-0.6*
Manure	305.6	1340.4	87.2	139.8	633.2	27.1	79.3	43.0
	-1.2	*-12.3*	*-2.3*	*-4.6*	*-7.8*	*-0.2*	*-1.7*	*-1.1*
Crop residuals	149.7	1388.3	103.7	213.3	682.1	58.3	195.2	156.1
	-2.8	*-89.6*	*-3.2*	*-16.8*	*-48.0*	*-0.6*	*0.7*	*-1.3*
N-fixation	36.8	164.1	6.2	34.3	70.9	12.1	43.3	22.5
	0.1	*-17.5*	*-0.3*	*-1.6*	*-6.8*	*0.0*	*-2.0*	*0.9*
Deposition	46.7	167.4	11.4	30.9	152.6	9.1	28.7	19.7
	-2.0	*-13.5*	*-1.7*	*-3.9*	*-13.7*	*-0.2*	*-0.9*	*-0.7*
Export by harvest	421.2	3256.4	233.2	381.7	1658.8	93.9	373.4	241.0
	-8.6	*-168.3*	*-8.6*	*-33.8*	*-62.8*	*-0.6*	*-3.6*	*-1.6*
Total Surplus	278.4	1429.6	111.9	194.2	1151.2	63.2	193.9	94.0
	-2.7 *(-1.0)*	*-31.5* *(-2.2)*	*-3.5* *(-3.0)*	*-11* *(-5.4)*	*-42.5* *(-3.6)*	*-0.5* *(-0.8)*	*-1.3* *(-0.7)*	*-1.0* *(-1.1)*

Source: Own computations with CAPRI

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[2] Figure S2 in the supplementary material shows the change in loads per drainage basin.

4.2. Impacts on nutrient leaching and loading to the Baltic Sea

Nitrogen leaching from the rootzone from both agricultural areas and from other land uses was calculated with the agro-hydrological nutrient transport model for both the baseline scenario and for the scenario without Pillar 1. Nitrogen leaching at the HSMU level in the baseline scenario is shown in Figure 3. Nitrogen losses are high in large parts of Denmark, Germany, the southernmost part of Sweden, and to some extent in Poland. Nitrogen losses are lower in the Baltic states, mid- and northern Sweden, and Finland. The northern part of the drainage basin is in a near-pristine state (Humborg et al., 2003).

The agricultural area decreases in all countries due to removal of pillar 1, most notably in Finland (13.5%) (See table S1 of the supplementary materials for details). Overall, agricultural land is reduced by 6.2% in the EU part of the Baltic Sea drainage basin. The agricultural production is, however, intensified on the remaining agricultural land resulting in increases in specific agricultural nitrogen losses.

Nitrogen loading to the Baltic Sea was calculated by combining rootzone N losses with catchment based estimates of N retention (i.e. removal of nitrate due to denitrification) during transport in groundwater and surface waters. Nitrogen loading is calculated for 117 sub-basins and serves as inputs to the BALTSEM model. In total, the riverine loading was reduced by 11,700 tons N or 2.2%.

The diffuse phosphorus loading to the Baltic Sea is reduced according to the reduction in agricultural area for each of the 117 sub-basins. Overall, the phosphorus loading is reduced by 943 tonnes.

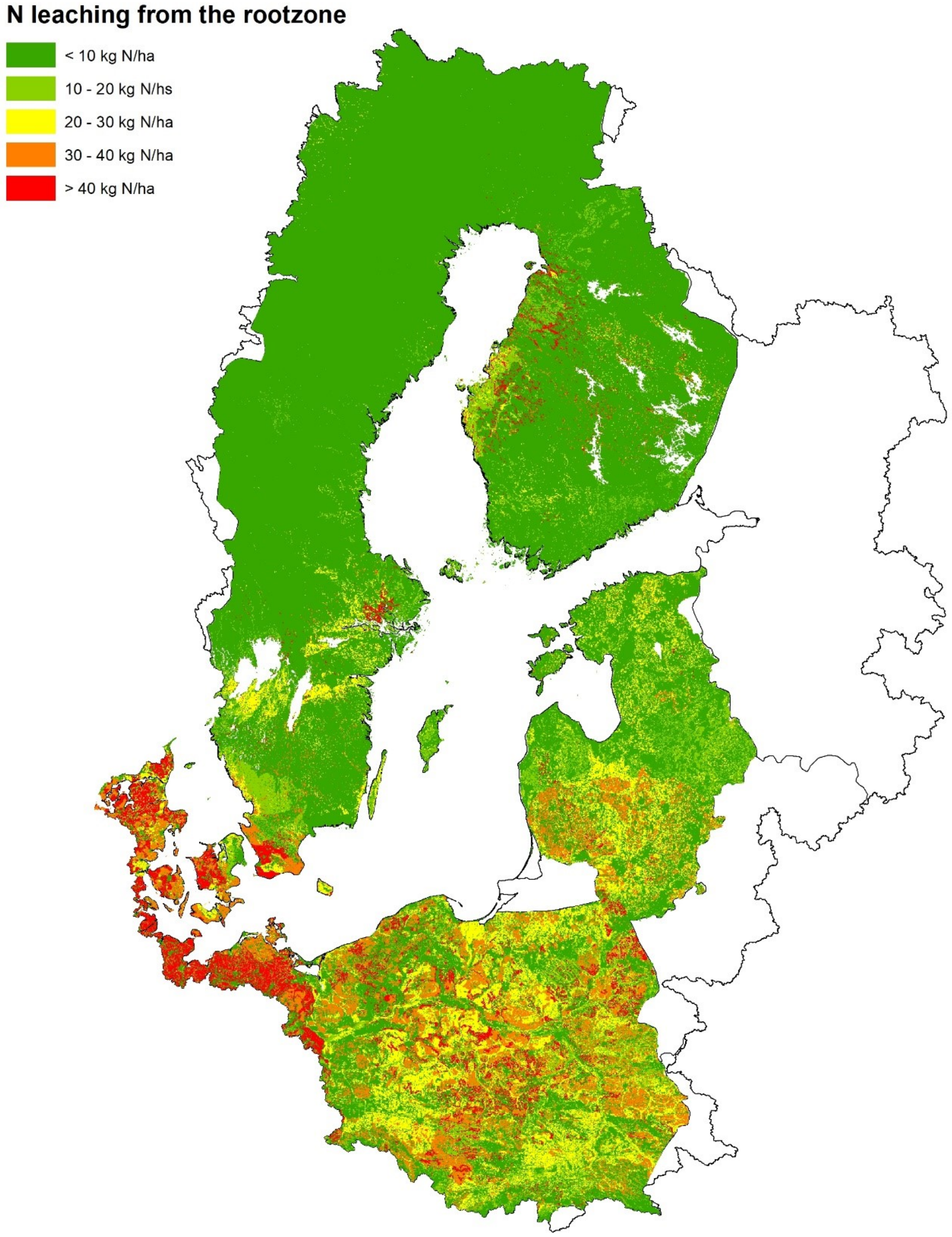

Fig 3 Nitrogen leaching from the rootzone for each HSMU, all land uses combined, baseline scenario. The map also shows the non-EU countries in the Baltic Sea drainage basin

4.3. Impacts on eutrophication in the Baltic Sea

The BALTSEM model computes impacts of reduced loads of N and P on indicators of eutrophication in seven basins of the Baltic Sea. Assessments show that all basins are affected by eutrophication, although less so in the northern Bothnian Bay, and in recent years, the Kattegat (HELCOM, 2018a). Our results show improvements in most indicators in most basins (a map of the basins is printed in figure S3 in the supplementary material). Table 2 shows changes in percent relative to the reference scenario when Pillar 1 is removed for a number of eutrophication indicators. Surface winter nutrient concentrations, Chlorophyll-a concentration and Secchi depth are all established indicators used in eutrophication status assessments (e.g. HELCOM, 2018a) and in addition to those we also show change in primary production and nitrogen fixation. Nitrogen fixation indicate the impact on the occurrence of cyanobacteria blooms that is a severe problem during summertime primarily in Baltic proper and Gulf of Finland.

Table 2 The table shows change (%) in selected eutrophication indicators when removing Pillar 1 compared to the Reference scenario, as an average of the impacts in the time-period 2040-50

	Kattegat	**Danish Straits**	**Baltic proper**	**Bothnian Sea**	**Bothnian Bay**	**Gulf of Riga**	**Gulf of Finland**
Nitrogen loads	-0.9	-0.6	-1.7	-1.7	-0.7	-1.2	-0.5
Phosphorus loads	-2.7	-2.2	-2.6	-4.0	-3.2	-1.5	-1.3
Surface winter DIN	-0.2	-0.3	-0.2	-1.4	-0.5	-0.9	-0.4
Surface winter DIP	-0.4	-0.7	-1.3	-1.6	-2.0	-0.8	-1.2
Chlorophyll-a	-1.3	-1.6	-2.5	-2.2	-3.0	-0.4	-2.0
Secchi depth	0.3	0.5	0.5	0.2	0.0	0.0	0.5
Primary production	-1.5	-2.1	-3.1	-2.0	-2.8	-1.3	-2.6
Nitrogen fixation	-1.1	-1.4	-2.1	-3.6	n.a.	0.4	-2.8

n.a.: There is no N-fixation in the Bothnian Bay

Both P and N concentrations (Surface winter DIP/DIN) are reduced in all basins. The response of nutrient concentrations to the load reduction is highly variable due to internal biogeochemical processes and inter-basin exchange (see Savchuk, 2018). For example, is the change in surface DIN only 0.2% despite a 1.7% N load reduction[3] and concurrent decrease in nitrogen fixation suggesting an increase in denitrification. In contrast, there is a relatively large decrease in both DIN concentration and nitrogen fixation in the Bothnian Sea. Also, the response on winter DIP to P load change is complex. The Baltic proper and Gulf of Finland are the basins with most eutrophication problems, such as extensive hypoxia and cyanobacteria blooms, and in these the reductions of both algal biomass indicated by Chlorophyll-a concentration (2.5% and 2%, respectively) and primary production (3.1% and 2.6%, respectively) are among the highest of all basins. Reduction is also evident on the nitrogen fixation in these basins (2.1% and 2.8%, respectively) indicating a reduction in the occurrence of cyanobacteria blooms. Decrease in nitrogen fixation in the other basins is of less significance since the change is relative to minor level of nitrogen fixation due to much lower abundance of cyanobacteria and Bothnian Bay they are completely absent. Lower algal concentrations lead to a slight improvement in the transparency of the water (Secchi depth) in all basins except for Bothnian Bay and Gulf of Riga. The transparency in the latter basins is strongly dominated by terrestrial organic matter supply rather than algae concentration.

4.4. Economic impacts

We evaluated the economic impacts of the reform on producers, consumers and tax payers. To a large extent, the reform implies a shift of economic benefits from producers back to tax payers when subsidies are withdrawn. In Table 3, summarizing the economic impacts, this shift causes a gain (reduction in costs) for taxpayers of similar size as the loss for producers. Tax money spent decreases by the amount of the sum of the premiums in pillar 1, corresponding to between 144 million Euro in Estonia and 4791

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[3] Note that the load reduction in Baltsem refers to total N load including atmospheric deposition and point sources, and thus are smaller than the load reductions from agriculture alone.

million in Germany. Agricultural incomes, defined as revenues minus variable costs plus premiums, are reduced in all countries, and reduction is strongly linked to the reduction in subsidies.

Table 3 Welfare impacts in 2030 (current prices, million euro annually) without Pillar 1. Italics show absolute change to the reference scenario. Negative numbers imply a loss when it relates to consumers and producers and a gain when it comes to tax payers' costs

	Consumer surplus	**Agricultural income**	**Tax money spent on CAP**	**Total impact**[1]
Denmark	398 703	1 228	64	399 867
	-61	*-748*	*-818*	*9*
Germany	4 277 930	16 764	819	4 293 875
	-459	*-4449*	*-4 788*	*-120*
Finland	291 261	1 430	1 218	291 473
	-42	*-380*	*-517*	*95*
Sweden	742 719	512	383	742 848
	-104	*-593*	*-704*	*7*
Estonia	21 807	179	63	21 923
	-9	*-136*	*-144*	*-1*
Lithuania	42 364	578	155	42 787
	-12	*-452*	*-504*	*40*
Latvia	30654	186	95	30745
	-8	*-253*	*-277*	*16*
Poland	724195	8751	891	732055
	-176	*-2622*	*-2989*	*191*

[1] *Total impact = Consumer surplus + Agricultural income – Tax money spent. Some impacts that are computed in CAPRI are ignored. Those are impacts on holders of Tariff Rate Quotas, profits of processing industries, and impacts on competing land use sectors.*

There is also a shift in welfare from consumers to producers, caused by increased prices. Impacts on consumers are measured as *money metric*[4]. Higher prices dampen the negative impact on agricultural income. To consumers, the most strongly felt price increase is for beef at around 2-3%. Producers benefit from larger price increases than consumers, in relative terms. For beef, producer prices go up by about 5%, for cereals and oil seeds by 1.4%, and for protein crops by 24% caused by the stronger reduction in supply in that sector. Price impacts for selected products are shown in table S2 of the supplementary material.

For most countries, the sum of the impacts on producers, consumers and tax payers is relatively small. Due to trade flows across national borders, the higher prices paid by e.g. German consumers benefit producers in other countries, and thus the sum of impacts on consumers, producers and tax payers in Germany becomes negative. However, our computation of impacts on tax payers per country only reflect the total cost for the CAP in that country but does not account for the rate of budget contribution to the EU. This may be of importance to the large net contributors DE and SE, for which the savings to tax payers thus might be larger than reflected in the table. The converse might be true for agricultural net-exporters which are net-receivers in the budget exchange with the EU, such as Poland. Our paper does not aspire to analyse the budget impacts in greater detail, but we do note that the net impact across the countries and agents listed in table 3 is positive, reflecting improved economic efficiency of the agricultural sector, albeit that conclusion is hampered by the omission of the rest of the EU and third countries with which the EU trades, as well as agents such as processing industries and traders.

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[4] Money metric uses the utility function of the demand system to compute how much the consumer would have had to spend in the reference scenario in order to be as well-off as in the current scenario. A negative change implies that the consumer was better off in the reference scenario – there would have been money left.

5. Policy recommendations / discussion /conclusions

Economic theory suggests that policy interventions can be beneficial to society if there are public goods or bads associated with production that cannot be handled by the market forces. Eutrophication would be a candidate, and environmental concerns are also mentioned as a key challenge to be handled by the CAP. But, if the link between the policy measure and the public good is weak, the efficiency of the measure in delivering public goods will be low, and other ways of addressing the public good issues should be considered.

We evaluated the impacts on eutrophication and economic indicators of removing the entire first pillar of the CAP, which includes the "greening" measures directed towards delivery of environmental goods. Our results indicate that eutrophication of the Baltic may improve marginally from such a reform. Previous studies (Brady et al., 2017) were inconclusive in this respect, because it was not clear which effect was dominating: the reduction of leakage due to reduced agricultural land use, or the increase in leakage due to increased intensity of production. Using the three models, we found that removing the first pillar marginally reduces eutrophication. Thus, on the one hand the first pillar of the CAP seems to contribute aggravate eutrophication of the Baltic Sea caused by agriculture. On the other hand, it does support agricultural income. Even though supporting agricultural income is a stated objective of the policy, it is contestable that agricultural income is a public good.

We also find that different regions, catchments and Baltic Sea basins are differently affected by the Pillar 1 policies. This is not surprising, since the natural conditions, and agricultural production patterns differ. Some of the policies in Pillar 1 are regionally differentiated (such as exceptions from the Greening measure for crop diversity in forestry-dominated areas), but most are applied at a uniform rate across regions, and variations in payment levels relate mostly to historical payments, not to the delivery of public goods.

In this paper, we only analysed impacts of Pillar 1 on the particular problem of eutrophication of the Baltic Sea. However, agriculture interacts with the environment in many ways and can contribute to several policy objectives in synergistic or conflicting ways. Brady et al. (2017) also analyse the impacts on biodiversity and on greenhouse gas emissions. They find that removing Pillar 1 would reduce climate gas emissions from the EU, but also that it could lead to a loss of biodiversity in marginal areas where land may be abandoned as well as in other areas where production intensity may increase. Regarding synergies, e.g. Nainggolan et al. (2018) find that nutrient loss abatement in the Baltic Sea region might have positive spill-overs on climate change mitigation. Not least important, a central objective of Pillar 1 is to support agricultural income, and our results indicate that it has been successful in the sense that removing it would reduce total income of the sector.

Thus, hitting many birds (policy objectives) with a single stone (Pillar 1) seems difficult, even with a very large stone. Taking this argument one step further, part of the budget released by abolition of Pillar 1 might be more effectively spent on measures explicitly targeting selected environmental problem, such as water quality, climate change or biodiversity loss, taking regional characteristics into account and setting sound economic incentives for farmers.

Our study has some limitations. As regards leaching, several large catchments in Russia, Belarus and Ukraine are not modelled in CAPRI. These countries, not subject to the CAP, would only be indirectly affected via trade impacts. Our assumption of "no change" for these countries might, if anything, lead to an overestimation of the impacts in the Baltic. Furthermore, reduced production within the EU could result in "leakage" effects to third countries: If demand within the EU remains fixed, import and production from outside of EU is likely to increase due to higher prices in the EU, and may cause increased environmental pressures there. Some of those effects may take place in Baltic Sea catchments of Russia, Belarus and Ukraine. Other may cause local pollution in other parts of the world. Such local effects should not primarily be a concern for EU policy makers since local problems are best handled with local policies.

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