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ORIGINAL ARTICLE

Baltic Sea eutrophication status is not improved by the first pillar of the European Union Common Agricultural Policy

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Abstract

Agriculture is an important source of nitrogen and phosphorous loads to the Baltic Sea. We study how the European Union's (EU) Common Agricultural Policy (CAP), and in particular how its first pillar, containing most of the budget and the decoupled farm payments, affects eutrophication. To aid our study, we use three simulation models, covering the agricultural sector in the EU, a hydrological nutrient flow model and a model of eutrophication in the Baltic Sea. We compute changes in key eutrophication indicators in a business-as-usual baseline and in a hypothetical situation where the first pillar of the CAP, containing the direct payments, greening and accompanying measures, is not present. Comparing the outcomes, we find that in the scenario without the first pillar, production and agricultural land use is lower, while yields and fertiliser use per hectare are higher, causing less nitrogen and phosphorous loads (0.5 to 4% depending on the basin) and less eutrophication in the Baltic Sea as net effect. We therefore conclude that the policies of the first pillar of the CAP contribute to increased eutrophication in the Baltic Sea.

Keywords Common agricultural policy · Eutrophication · Nutrient surplus · Baltic Sea

Introduction

The Baltic Sea is in a poor condition. One problem is eutrophication—the accumulation of nutrients and their subsequent impact on various forms of life in the water. In 2018, 96% of all waters were below 'good' status as regards eutrophication (HELCOM 2018a). Despite decreasing trends in nutrient concentrations in many parts of the Baltic, indicators for eutrophication generally continue to deteriorate. Comparing the assessment period 2011–2016 to 2007–2011, dissolved inorganic nitrogen concentrations (DIN) deteriorated in five out of 17 basins and improved in none.

Agriculture contributes significantly to eutrophication. More than half of the anthropogenic input of nitrogen to the

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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).

Observations show decreasing trends in nutrient loads, primarily due to reduced point loads (such as wastewater treatment plants) and reduced atmospheric deposition. However, targets for maximum allowable nutrient inputs, agreed upon in the Baltic Sea Action Plan, have not yet been reached (HELCOM 2018a). Furthermore, climate change is expected to lead to increased average precipitation and precipitation variability in northern catchments, and to higher water temperatures (The BACC Author Team 2015, ch. 11, ch. 13.). Higher precipitation means more run-off, and higher water temperatures aggravate the effects of eutrophication. Therefore, further reductions of nutrient loads are needed to improve the state of the Baltic Sea.

The EU Common Agricultural Policy (CAP) has significant impact 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 the part called ‘Pillar 1’, historically dealing with farm subsidies and market regulation, to ‘Pillar 2’, which contains a wider variety of opt-in schemes mainly targeting rural development, farm investments and environmental measures. 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 into Pillar 1 itself: 30% of the farm payment envelope is conditional on the farmer or region satisfying three environmental ‘greening’ requirements: to maintain a minimum ratio of grassland to arable land, to set aside a share of all arable land as ‘ecological focus area’, and to maintain a minimum level of crop diversity. Gocht et al. (2017) use a European agricultural sector model, Common Agricultural Policy Regionalised Impact (CAPRI), to evaluate the impacts of greening on selected indicators and find that, in general, the environmental impact is small. They find some beneficial impact per unit area of land used but argue that the increased land use resulting from greening may reverse the overall impact.

Brady et al. (2017) also use CAPRI to evaluate Pillar 1. 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 would decline, implying reduced application of N; on the other hand, the remaining agricultural production would intensify, 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.

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 the cost-effectiveness of nutrient abatement measures for the Baltic Sea (Elofsson 2010; Gren et al. 2013; Hasler et al. 2014). 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 a reorienting of the direct payments towards support for the provision of environmental public goods (Matthews 2016; OECD 2011; Tangermann 2011 and WWF 2010). Himics et al. (2019) analyse impacts of re-orienting the decoupled payments towards climate actions. As part of the EU Commission’s proposal on CAP post-2020, more flexible implementation of the CAP might be introduced, and a new instrument, ‘Eco-schemes’, is proposed for Pillar 1 (European Commission 2018). This scheme will be mandatory for member states and voluntary for farmers, and member states will be given the opportunity to tailor the implementation to the particular features of their country; the farming sector, rural environment and climate.

Our study is extensive in terms of policies analysed, covering all of Pillar 1, and focuses on the environmental effects. We report agricultural income effects but do not go into detail with wider budget impacts. Shifting support from decoupled payments to more environmental support might compensate for some of the income effects, but the options for that and its effects are beyond the scope of this study. The modelling in the present study does not address the new CAP proposal or the eco-schemes, but we expand the analysis done in previous work by Gocht et al. (2017) and Brady et al. (2017) with a more detailed modelling of how the current CAP affects the nutrient loads to the Baltic Sea and the eutrophication of the sea. This application includes both nitrogen and phosphorous loads and the retention at catchment level, as well as eutrophication indicators in the Baltic Sea. Decision makers can draw from the results from this integrated analysis for evaluating how removal of the CAP Pillar 1 subsidies will affect the sea, but further research would be needed to provide results on how a shift to more environmental subsidies will alter these results.

In the present study, we first simulate the removal of the first pillar with the CAPRI model, computing the impacts on production, markets, economic indicators and agricultural nitrogen balances. We use the results from the nitrogen balances as inputs into 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 by overall land use rather than by actual phosphorus surpluses. In the final step, we combine the diffuse loads computed by the nutrient transportation model with other non-diffuse loads and use the resulting total loads in simulations with the physical-biogeochemical Baltic Sea Long-Term Large-Scale Eutrophication (BALTSEM) model of the Baltic Sea, computing the impacts on selected eutrophication indicators.

Each step in the (unidirectional) modelling chain is described in the 'Models and data' section, and the scenario is set-up in the 'Scenarios' section. In the 'Results and discussion' section, we present results from the modelling exercise. The final section summarises the results and discusses implications for policy makers.

Models and data

A chain of specialised 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 specialised 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 fertilisation 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, the limited space in this paper is focused on how the link was implemented, whereas the description of the models themselves is kept somewhat brief.

The agricultural sector Common Agricultural Policy Regionalised Impact model

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 nine general inputs, three crop-specific inputs, six intermediate crop outputs, 12 intermediate animal outputs (including manure), three 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. Model behaviour is also influenced by econometrically estimated non-linear cost components (Jansson and Heckelei 2011).

The supply of arable and grassland depends on land rents and on regulations, such as the greening requirement to maintain some minimum ratio of grassland to arable land. The aggregate supply of agricultural land is governed by marginal cost functions estimated (but not well described) by Renwick et al. (2013). Those estimates were based on (i) aggregate land supply elasticities of the LEITAP model similar to those described by Tabeau et al. (2006), (ii) land transformation elasticities for agro-ecological zones in Table 7 of Golub et al. (2006) and (iii) simulation experiments on 1-km2 grid level carried out with the model Dyna-CLUE (Verburg and Overmars 2009).

The supply model contains nutrient (N, P, K) balances at the NUTS2 level for groups of crops. Nutrient sources are mineral fertiliser, manure, nitrogen fixation, atmospheric deposition and crop residues. The supply of nutrients must cover the crop need, calculated based on yield levels, estimated over-fertilisation 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. Manure trade across national borders is not allowed in this model version, likely leading to too high application rates in some countries, most notably the Netherlands. As the catchments of the Netherlands do not load into the Baltic Sea, this shortcoming is not considered a severe limitation of our study.

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 minimising 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

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

HSMU is a cluster of 1-km 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 2000[2] land cover database (processed 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 breakdown 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 weakly positive 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 (capitalisation). If the payments are removed in CAPRI, 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.

Thirty percent of Pillar 1 payments consist of the 'greening' top-up, which is paid as a top-up to 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 and 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 make up a small share of the total CAP budget, they have strong production effects.

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 Fig. 1 suggests that they may be important in Lithuania, Poland and (parts of) Germany.

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 on request.

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 is computationally effective. The model was developed from a dataset of more than 4000 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 dataset. From the dataset 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 fertiliser, 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 their 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. The resulting N loading from each catchment to the Baltic Sea can be calculated by combining N losses at the HSMU scale with catchment-wide N retention estimates.

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[2] Available from https://land.copernicus.eu/pan-european/corine-land-cover/clc-2000/view

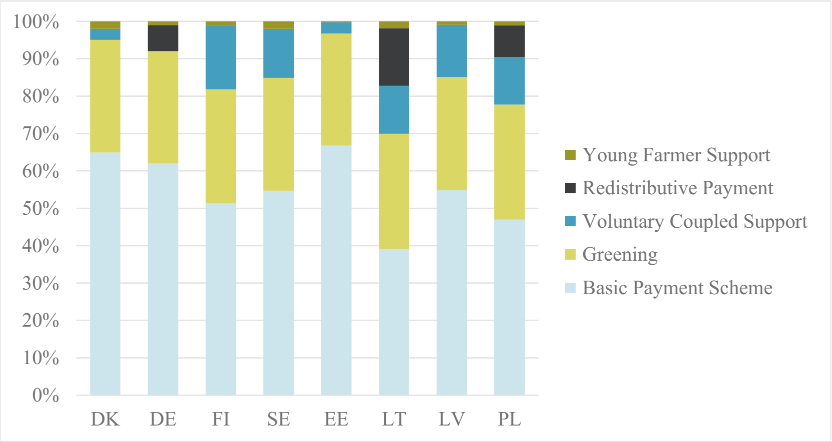

Fig. 1 Share of payments within the first pillar belonging to various support schemes. Numbers from the CAPRI baseline for 2030

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. reducing the area grown with arable crops leads to a proportional reduction in the P loading from diffuse sources.

The Baltic Sea Long-Term Large-Scale Eutrophication 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, 2013b).

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 timescales. 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 its 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.

Scenarios

For analysing the effect of the Pillar 1 payments, we create a scenario where Pillar 1 is not present and compare it 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 nitrogen balances are used as input in the agro-hydrological nutrient transportation model, which subsequently feeds into BALTSEM. Both scenarios are implemented for the entire European Union, albeit the focus of our analysis is on countries around the Baltic Sea.

The *reference* scenario assumes that the current agricultural policy continues up to 2030. The reference scenario also contains trend estimates based on market projections from OECD, FAPRI, FAO and DG-AGRI (Britz and Witzke 2014).

The *No Pillar 1* scenario is identical to the reference scenario, with the exception that there is no first pillar of the CAP present. This means that there is no basic payment scheme, no greening support, no support to young farmers and no voluntary coupled support. Furthermore, there are no good agricultural and environmental conditions, payment entitlements or greening requirements.

Results and discussion

Impacts on agricultural production and fertilisation

In the simulation without Pillar 1, agricultural production and land use decline compared to the reference scenario. Production of oilseeds, grassland and cereals are generally much affected, as is the 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 in 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 in the simulation without Pillar 1 compared to the reference scenario. For the EU as a whole, the reduction is 6.5%, consisting of a larger reduction in fodder areas (− 7.7 million ha) and a more moderate reduction in arable areas (− 4.1 million ha). Grasslands generally decline more than arable land due to the removal 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 of arable land is dominated by the abandonment of 2.1 million ha of set-aside land that is maintained in the reference scenarios thanks to its eligibility for decoupled payments, but also reflects a significantly smaller cereals area (− 1.1 million ha). The land use reductions are broadly consistent with, albeit somewhat smaller than, those reported by Renwick et al. (2013), analysing a scenario without Pillar 1 for the previous (2006–2013) CAP for the target year 2020, also using CAPRI. In the animal sectors, there is a reduction in the number of animals in general and of ruminants in particular (− 2.3% for the EU). In the reference scenario, ruminants for meat production are subject to coupled support in many countries and they are also indirectly subsidised by decoupled payments to grassland and other feed.

Of the countries around the Baltic Sea, 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 twofold. Part of the explanation is that direct payments constitute a high share of revenues per hectare in those countries. More importantly, though, the land supply elasticities governing the responsiveness of agricultural land supply to changes in land rents via a marginal cost term for land supply are the greatest in those countries (0.6 for Finland and 0.5 for Sweden, compared to values below 0.2 for all other EU 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.

The smaller agricultural area without Pillar 1 comes with a higher intensity in terms of yields and inputs compared to the reference. The higher intensity is the result of on the one hand less production in less productive areas and on the other hand higher yields in all regions. 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. The higher prices follow from a combination of less production at the EU level and higher feed demand for cereals to compensate for lower availability of grasslands. Figure 2 illustrates the impacts on land use and intensity. The green bars show the reduction in area and the blue bars show the increase in fertilisation per hectare. In countries with larger reductions in area, such as Finland, Sweden and Germany, there are also larger increases in fertiliser use per hectare. The average increase in use of N fertiliser per hectare is about 4%, with some variation across countries. The increased

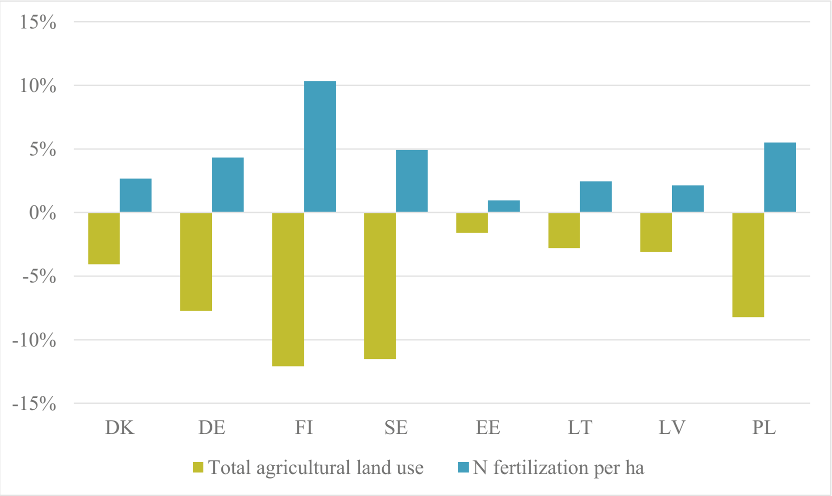

Fig. 2 Impacts (percent difference to reference scenario) on total agricultural land use and nitrogen fertilisation per hectare in the scenario without Pillar 1. Agricultural land use is the sum of grass and arable land. N fertilisation is the sum of mineral N application, manure N application and N added from crop residues divided by the total agricultural area in use

Table 1 Simulated impacts on nitrogen balances in countries around the Baltic Sea in the scenario without pillar 1. All values except the final row are in 1000 t nitrogen annually, *italicised* numbers indicate differences to reference scenario. The final row shows the impact on total surplus expressed as percent of the reference scenario value

Nutrient balance item	DK	DE	FI	SE	PL	EE	LT	LV
+ Application of mineral fertilisers	160.8	1625.8	136.6	157.6	1271.2	50.5	220.8	93.7
Diff to reference	*− 5.4*	*− 66.9*	*− 4.6*	*− 17.9*	*− 29.0*	*− 0.1*	*− 1.0*	*− 0.6*
+ Application of manure	305.6	1340.4	87.2	139.8	633.2	27.1	79.3	43.0
Diff to reference	*− 1.2*	*− 12.3*	*− 2.3*	*− 4.6*	*− 7.8*	*− 0.2*	*− 1.7*	*− 1.1*
+ Nutrients in crop residues[a]	149.7	1388.3	103.7	213.3	682.1	58.3	195.2	156.1
Diff to reference	*− 2.8*	*− 89.6*	*− 3.2*	*− 16.8*	*− 48.0*	*− 0.6*	*0.7*	*− 1.3*
+ Nitrogen fixation[b]	36.8	164.1	6.2	34.3	70.9	12.1	43.3	22.5
Diff to reference	*0.1*	*− 17.5*	*− 0.3*	*− 1.6*	*− 6.8*	*0.0*	*− 2.0*	*0.9*
+ Atmospheric deposition[c]	46.7	167.4	11.4	30.9	152.6	9.1	28.7	19.7
Diff to reference	*− 2.0*	*− 13.5*	*− 1.7*	*− 3.9*	*− 13.7*	*− 0.2*	*− 0.9*	*− 0.7*
− Uptake by plants	421.2	3256.4	233.2	381.7	1658.8	93.9	373.4	241.0
Diff to reference	*− 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
Diff to reference	*− 2.7*	*− 31.5*	*− 3.5*	*− 11*	*− 42.5*	*− 0.5*	*− 1.3*	*− 1.0*
Relative diff in surplus (% of reference)	− 1.0	− 2.2	− 3.0	− 5.4	− 3.6	− 0.8	− 0.7	− 1.1

a. Nutrients in crop residues are part of the uptake by plants, re-allocated among crops depending on crop rotation.b. Nitrogen fixation depends on cropping of pulses and of the use of clover in ley mixtures.c. Atmospheric deposition is constant per hectare. The reductions in simulation reflect changes in area use per country and region.Source: Own computations with CAPRI

intensity is important since higher surplus per hectare tends to increase the leaching more than proportionally (Delin and Stenberg 2012).

The production changes reduce the total N surplus from agriculture. Table 1 shows the surplus computation in CAPRI decomposed into fertilisation sources and removal by harvest. Without the first pillar, total N surplus (the bottom line) decreases by 0.5 to 5.4%, on country level, and total N surplus decreases by 2.6% (94,000 t). The primary driving factor is the lower overall use of fertilisers. On sub-national level, the net effect may be either a reduction or increase in overall nitrogen surplus, depending on the local production mix and subsidies of the reference scenario.

Impacts on nutrient leaching and loading to the Baltic Sea

Nitrogen leaching from the root-zone 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 is shown in Fig. 3, for the reference scenario (Panel A) and as difference to the reference scenario in the simulation without the first pillar (Panel B). 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).

Nitrogen loading to the Baltic Sea was calculated by combining root-zone 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 was calculated for 117 sub-basins and served as inputs to the BALTSEM model.[3] In total, the riverine loading is reduced by 11,700 t 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 declined by 943 t.

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 Fig. S3 in the supplementary material). Table 2 shows differences in percent relative to the reference scenario for the simulation without Pillar 1 for a number of eutrophication indicators. Surface winter nutrient concentrations, chlorophyll-a

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

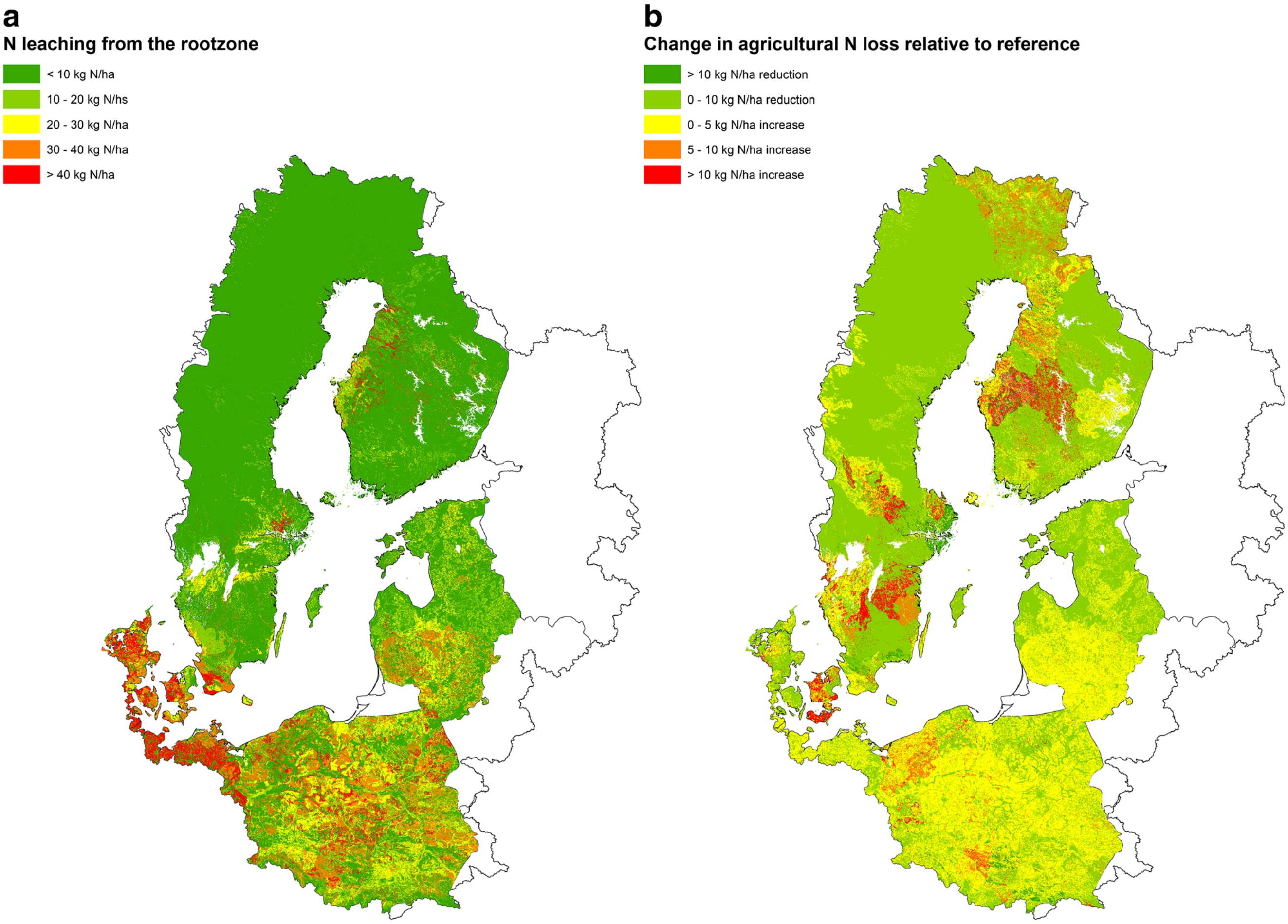

Fig. 3 Nitrogen leaching from the root zone for each HSMU, all land uses combined, Panel A shows the situation in the reference scenario, panel B shows absolute differences to the reference scenario in the simulation without Pillar 1. The coloured areas of the map show drainage basins that were simulated in CAPRI. Loads from the non-coloured areas were assumed to be constant

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 changes in primary production and nitrogen fixation. Nitrogen fixation indicates the impact on the occurrence of cyanobacteria blooms that is a severe problem during summertime, primarily in the Baltic proper and Gulf of Finland.

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 of only 0.2%, despite a 1.7% N load reduction[4] 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.

The response of 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 in 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.

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

Table 2 Relative difference (%) in selected eutrophication indicators in the simulation without Pillar 1 relative to the reference scenario, as an average of the impacts in the time-period 2040–2050, for each of seven basins of the Baltic Sea

Indicator	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[a]	− 0.2	− 0.3	− 0.2	− 1.4	− 0.5	− 0.9	− 0.4
Surface winter DIP[b]	− 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[c]	+ 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

a. DIN = Dissolved inorganic nitrogen. b. DIP = Dissolved inorganic phosphorousc. Secchi depth measures transparency of water. A higher value is better.n.a.: There is no N-fixation in the Bothnian Bay

Economic impacts

We evaluated the economic impacts on producers, consumers and taxpayers. The removal of Pillar 1 implies a shift of economic benefits from producers back to taxpayers. In Table 3, summarizing the economic impacts, this shift is visible as a gain (reduction in costs) for taxpayers of a 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 million Euro in Germany. Agricultural income, defined as revenues minus variable costs plus subsidies, is lower without the subsidies, despite somewhat higher commodity prices.

There is also a shift in welfare from consumers to producers caused by increased prices. Impacts on consumers are measured as *money metric.*[5] 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 oilseeds by 1.4% and for protein crops by 24% caused by the stronger reduction in supply in that sector. Table S2 of the supplementary material shows price impacts for selected products.

The bottom line of Table 3 shows that Pillar 1 implies a net loss of one billion euro annually for the EU as a whole.[6] The signs of the net impact vary across countries. Due to trade flows across national borders, the higher prices paid by, for example, German consumers benefit producers in other countries, and thus the sum of impacts on consumers, producers and taxpayers in Germany becomes negative. Our computation of impacts on taxpayers 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 Denmark and Sweden, for which the savings to taxpayers 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.

Summary and conclusions

We analysed how the first pillar of the CAP impacts eutrophication in the Baltic Sea. Using three simulation models, we computed and compared two scenarios: a reference scenario representing business as usual up to 2030 and a contrasting scenario where the first pillar of the CAP is not present but where all other parameters were unchanged. Our results indicate that eutrophication of the Baltic may improve without CAP Pillar 1 compared with the reference. Previous studies of similar scenarios (Brady et al. 2017) were inconclusive in this respect because it was not clear which effect was dominating: the reduction of leaching due to reduced agricultural land use or the increase in leaching due to increased intensity of production. The present study also evaluates the final spatial distribution of the effects in the sea. The core outcome of our analyses is that the benefits of reduced total nutrient loads dominate the negative impacts of increased intensity of production in some areas. Therefore, we conclude, the first pillar of the CAP aggravates eutrophication of the Baltic Sea caused by agriculture.

The present study does not aspire to provide a realistic alternative to the present policies of the first pillar but merely

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[5] 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.

[6] This is a partial analysis, omitting, e.g. third countries with which the EU trades, agents such as processing industries and traders and the rest of the economy.

Table 3 Welfare impacts in 2030 (current prices, million euro annually) without Pillar 1. *Italicised* numbers 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[a]
Denmark	398,703	1228	64	399,867
Diff to reference	*− 61*	*− 748*	*− 818*	*9*
Germany	4,277,930	16,764	819	4,293,875
Diff to reference	*− 459*	*− 4449*	*− 4788*	*− 120*
Finland	291,261	1430	1218	291,473
Diff to reference	*− 42*	*− 380*	*− 517*	*95*
Sweden	742,719	512	383	742,848
Diff to reference	*− 104*	*− 593*	*− 704*	*7*
Estonia	21,807	179	63	21,923
Diff to reference	*− 9*	*− 136*	*− 144*	*− 1*
Lithuania	42,364	578	155	42,787
Diff to reference	*− 12*	*− 452*	*− 504*	*40*
Latvia	30,654	186	95	30,745
Diff to reference	*− 8*	*− 253*	*− 277*	*16*
Poland	724,195	8751	891	732,055
Diff to reference	*− 176*	*− 2622*	*− 2989*	*191*
Baltic Sea EU countries	6,529,632	29,628	3687	6,555,573
Diff to reference	*− 872*	*− 9633*	*− 10,742*	*238*
Other EU countries	14,423,862	142,456	6596	14,559,722
Diff to reference	*− 2824*	*− 26,167*	*− 29,755*	*763*
EU-28 total	20,953,494	172,084	10,283	21,115,295
Diff to reference	*− 3696*	*− 35,800*	*− 40,497*	*1001*

a. Total impact = consumer surplus + agricultural income – tax money spent. There would also be impacts on other economic agents that are not considered here, such as traders and sectors competing for agricultural land and labour

to analyse their impacts in comparison with having no first pillar at all. Nevertheless, the results should be useful in the ongoing process of developing the CAP for the period 2020–2027. In its communication on the new CAP after 2020, the European Commission identified a need to raise environmental and climate ambitions (European Commission 2017) and the legal proposals of 2018 foresee increased freedom for member states to design national implementation plans, including 'eco-schemes' as part of Pillar 1.

Our results suggest that re-orientating support towards reduction of eutrophication might be beneficial in the region of the Baltic Sea based on the result that no policy at all would be better than the present policies in that respect. We find that Pillar 1 policies affect nutrient leaching differently in different regions, catchments and Baltic Sea basins. This is not surprising since the natural conditions and agricultural production intensity and 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.

Economic theory suggests that policy interventions can be beneficial to society if there is public good or bad associated with production that market forces cannot handle. Eutrophication would be a candidate, and environmental concerns are indeed a key challenge for the future CAP to handle. But, if the link between the policy measure and the public good is weak, the efficiency of the measure in delivering public good will be low and other ways of addressing the issues of public good should be considered. As mentioned in the 'Introduction' section, it is an explicit objective of the CAP to address issues of 'Environment and climate change', and our analysis indicates that with respect to eutrophication of the Baltic Sea, the present Pillar 1 policies as a package are not effective.

In this paper, we limited the analysis of impacts of Pillar 1 to the specific 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 it also 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, Nainggolan et al. (2018) find that nutrient loss abatement in the Baltic Sea region might have positive spill-overs on climate change mitigation.

Our results indicate that agricultural income would be much lower without Pillar 1. This is hardly surprising since most of the support is given in the form of decoupled payments with little strings attached. Even though supporting agricultural income is a stated objective of the policy, including the current greening requirements, it is contestable that agricultural income is a public good. We therefore conclude that part of the budget of the current 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.

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