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Scenario analysis for nutrient emission reduction in the European inland waters

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Abstract
Despite a large body of legislation, high nutrient loads are still emitted in European inland waters. In the present study we evaluate a set of alternative scenarios aiming at reducing nitrogen and phosphorus emissions from anthropogenic activities to all European Seas. In particular, we tested the full implementation of the European Urban Waste Water Directive, which controls emissions from point source. In addition, we associated the full implementation of this Directive with a ban of phosphorus-based laundry detergents. Then we tested two human diet scenarios and their impacts on nutrient emissions. We also developed a scenario based on an optimal use of organic manure. The impacts of all our scenarios were evaluated using a statistical model of nitrogen and phosphorus fate (GREEN) linked to an agro-economic model (CAPRI). We show that the ban of phosphorus-based laundry detergents coupled with the full implementation of the Urban Waste Water Directive is the most effective approach for reducing phosphorus emissions from human based activities. Concerning nitrogen, the highest reductions are obtained with the optimized use of organic manure.

S Online supplementary data available from stacks.iop.org/ERL/9/125007/mmedia

Keywords: nitrogen emissions, phosphorus emissions, scenarios, Europe's waters, models, GREEN

1. Introduction

In the European Union, despite a large and strict body of legislation, many surface and ground water bodies are still threatened by high concentrations of nitrogen and phosphorus (Bouraoui and Grizzetti 2011, Sutton *et al* 2011, Grizzetti *et al* 2012). The Water Framework Directive (WFD, Directive 2000/60/EC 2000) requires Member States (MSs) to ensure that all surface and groundwater bodies are in good ecological and chemical status by 2015. However, a large number of water bodies will not reach the required objectives (EC 2012). Agriculture remains a major source of pressure on water bodies, and diffuse nutrient pollution is still an important threat to surface water, groundwater, lakes and transitional water quality. According to EEA (2012) diffuse pollution from agriculture is a significant pressure for, at least, 40% and 30% of rivers and lakes, respectively. It has also been reported that at least 30% of groundwater bodies are at risk of not achieving the required quality objectives by 2015 (Hérivaux *et al* 2013).

Nitrogen losses from agriculture are mainly controlled by the Nitrates Directive (Directive 91/676/EEC 1991). After more than 20 years of implementation, the Directive was successful in reducing nitrogen surplus in many countries with large specialized farming activities such as The Netherlands, Belgium, France, etc (Bouraoui and Grizzetti 2011). Despite this large decrease in nutrient inputs, many rivers are still exhibiting high nitrate concentrations, due to the inertia of the environment (combination of storage, lag time) to respond to these changes, and many water bodies (lakes and coastal areas) are still affected by eutrophication associated with excessive nutrients. Evaluating the implementation of the Nitrates Directive for the period 2004–2007, the European Commission (EC 2010) indicated that 14% of the surface water monitoring stations exhibited increasing concentrations while 55% showed decreasing trends. In its latest report concerning the 2008–2011 reporting period the European Commission (EC 2013) indicates that 27% and 19% of the freshwater monitoring stations of surface waters and groundwater, respectively, are showing increasing nitrate concentration trends from the previous reporting period (2007–2011).

Point sources are a significant source of pressure for less than 22% of rivers and groundwater bodies, however affecting about 40% of transitional water bodies (EEA 2012). The Urban Waste Water Directive (Directive 91/271/EEC 1991) was shown to have been very successful in reducing phosphorus losses to water bodies, and to a lower extent also nitrogen losses (Bouraoui and Grizzetti 2011). Additional efforts are still required by some MSs to fulfil their legal obligations with respect to the Urban Waste Water Directive.

Reducing and controlling the presence of nutrients in European freshwater calls for management actions both on point and diffuse sources. Research has focused mostly on the development and evaluation of measures at the local scale to reduce nutrient losses to water bodies. However, with the globalization of food trade, a larger scale of analysis is required (Lassaletta *et al* 2014). Only few studies have focused on modelling the impact of alternative management approaches on reducing nutrient loadings to water bodies at the large scale (Setizinger *et al* 2002, Billen *et al* 2013, Reder *et al* 2013). Reder *et al* (2013) evaluated scenarios based on the assumption of the 'economy first' describing a globalization and liberalization of the economy for the horizon 2050. Their storyline was derived through stakeholders' participation. The impact on the emissions from point sources was estimated based on expert judgment while the change in land use was simulated using a land use model. The authors concluded that total nitrogen loadings will remain similar for Northern Europe and will decrease for the rest of Europe. They also predicted an increase of total phosphorus loading due to larger contributions from the domestic and industrial sectors. Billen *et al* (2013), based on a simplified representation of the nitrogen cascade, evaluated the impact of a scenario mimicking the shift to an organic production and a second scenario based on a demitarian diet. They showed that through a reorganization of the agro-food system and reconnecting local food production and food consumption it is possible to provide sufficient food for the whole world while reducing losses of reactive nitrogen in the environment. Seitzinger *et al* (2002) evaluated the impacts of fertilizer reduction due to a change of human diets in two rich industrialized regions (Europe and North America) on dissolved nitrogen exports for the horizon 2050 using the GlobalNews model. The reduction of meat intake resulted in a decrease of dissolved inorganic nitrogen exported in these two regions. This hypothesis has been evaluated several times since and many studies have pointed out the large detrimental impact of animal breeding activities, and hence human diet on the environment (The European Nitrogen Assessment, Sutton *et al* 2011).

Our study aims at investigating the impact of several management options and EU environmental policies to reduce nutrients exported to the European Seas. The study focuses on the short term evaluation of the management alternatives considering the time horizon 2020, which is relevant for the general Europe 2020 strategy. First we will analyse the effects of the full implementation of the Urban Waste Water Directive to provide an insight on the potential reduction achievable. We will then evaluate the impact of banning phosphorus-based detergents while fully implementing the Urban Waste Water Directive. We then investigate two sets of additional scenarios dealing with the impact of a reduction of meat consumption in Europe based of the recommendations by the World Health Organization (WHO 2003) and the World Cancer Research Foundation (WCRF 2007). A final scenario evaluates the impact of an optimized use of manure as a fertilizer.

All our analyses are based on a spatially explicit conceptual model of nutrient fate (GREEN, Grizzetti *et al* 2012) taking into account both diffuse and point sources of nutrients. We also make use of the Common Agricultural Policy Regionalised Impact (CAPRI) agro-economic model in order to define boundary conditions for nutrient use based on likely scenarios of land use, development of the Common Agricultural Policy and trade options (Britz and Witzke 2008). We focus on short term predictions in order to limit the uncertainties of long term predictions in particular those involving changes in land use and production system. The first part of the paper presents all the evaluated scenarios and their associated assumptions. We also detail the agro-economic and the conceptual nutrient models. Then the results of the efficiency of all scenarios are presented followed by a discussion on the way forward.

2. Methods and data

2.1. Overview

Scenarios are descriptions of possible futures reflecting different perspectives on the past, the present, and the future (van Notten *et al* 2003). In the present study, scenarios are used as a coherent, consistent and plausible description of a future state of the system under investigation built to avoid unsustainable developments. Our scenarios can be described as forecasting as we use the present situation as the starting point, and they are quantitative, not descriptive, focusing on the regional scale.

The development of a consistent set of scenarios raises the issue of the scale of the analysis. Worldwide dynamics controlling economic and demographic trends call for global scale assessments, although they are not able to represent regional processes and are not detailed enough to support national or European policies. On the contrary, local scale analyses are generally more reliable, but are unable to take into account regional dynamics and could not be transposed to a broader regional context. We build our analysis on an existing uniform modelling approach for the whole Europe that has proven accurate enough to analyse the effects of EU

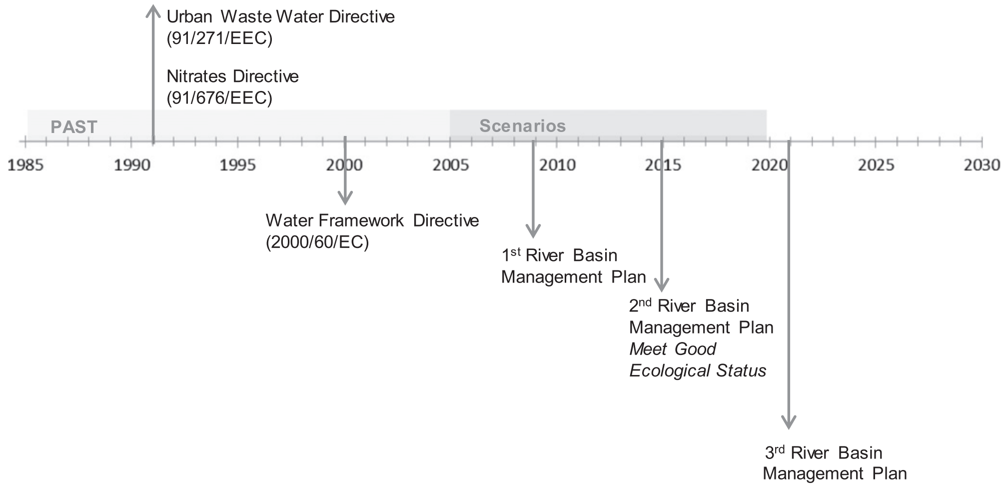


Figure 1. Time table of the environmental directives (and associated deadlines) and temporal coverage addressed by this study (in grey).

environmental legislation considering the specificities of each MS and associated administrative regions and allowing implementation at watershed and sub-watershed level (Grizzetti *et al* 2012). We used this modelling approach to analyse the impacts of different scenarios of management on the nitrogen and phosphorus export in European surface waters. The scenarios are applied to all river basins draining in the European Seas including the Atlantic Ocean, the Mediterranean Sea, the North Sea, the Baltic Sea, and part of the Black Sea (Danube river basin). We considered 2020 as time horizon, which is relevant for the general Europe 2020 strategy, and the second cycle of implementation of River Basin Management Plans under the WFD (2021). The study period extends from 1895 to 2020 covering thus the implementation of the Nitrates Directive, the Urban Waste Water Directive, the Water Framework Directive and almost two full rounds of implementation of River Basin Management Plans (figure 1).

The evaluation of scenario effectiveness needs to be drawn in parallel with the analysis of past trajectories and the current situation (baseline). In the study we evaluated trends of nitrogen and phosphorus emissions for the period 1985–2004 and this is referred to as PAST. The current status is referring to the years centred on 2005 and it is called REF scenario. This specific year was selected because it included the most complete input data at the sub-national level. More information was available for the years after 2005, but the spatial details were not enough to support the implementation of our modelling framework, and the basic information on land cover and point sources were centred on year 2005 (see also table S1 in supplementary material).

Next, we developed a business as usual (BAU scenario, table 1) scenario that aims at propagating the current trend of anthropogenic pressures while considering the status-quo in the mitigation of land based nutrient emissions. It includes changes in population (Goldewijk 2011) at regional level, prospects for food production and consumption and associated change in land use distribution. This reference is used to assess (i) how future nutrient pressure will evolve if no action is taken and (ii) the efficiency of various nutrient mitigation measures at the horizon 2020.

It has been demonstrated that the mitigation of point sources is an efficient way to reduce the amount of nutrients transferred to the aquatic system, especially for phosphorus (Bouraoui and Grizzetti 2011). However many countries still do no fully comply with European Union requirements. Consequently, two scenarios are considered with respect to the Urban Waste Water Directive.

The Urban Waste Water Directive scenario (UWD scenario, table 1) mimics the full implementation of the 91/271/EEC Directive concerning urban wastewater treatment. This requires all MSs to implement efficient wastewater treatment infrastructures. It defines a set of conditions and contingencies, including the size of municipalities and the sensitivity of receiving area and requires waste water discharged to undergo appropriate treatments.

The phosphate free detergent scenario (UWD-PFREE scenario, table 1) is based on the Commission proposal COM (2010) 597 amending Regulation 648/2004/EEC concerning the use of phosphates and other phosphorus compounds in household laundry detergents. It has been concluded that a European ban of phosphates and others phosphorus compounds in household laundry detergent will reduce both the contribution of phosphates to eutrophication in EU waters and the cost of phosphorus removal in waste water treatment plants.

In order to prevent diseases as diabetes or obesity, it is now scientifically accepted that meat products, in particular beef and pork, have to be consumed in adequate quantity, which is often below current intake levels. The World Health Organization clearly states the importance of having fruits, vegetables and carbohydrates in human daily diet (WHO 2003). To meet these diet recommendations, the European Union's population should decrease the consumption of meat and in general of animal proteins. This has been advocated also as a measure to reduce the environmental effects of nitrogen pollution (Sutton *et al* 2013, Westhoek *et al* 2014). Transcribing such a change in the population's

Table 1. Summary of the scenarios of management developed in the study.

Scenario	Description	Diffuse sources input	Point sources input	Climate
PAST	Past trajectory (1985–2004)	Land use 1985–2004	Population 1985–2004	1985–2004
REF	Baseline (2005)	Land use 2005	Population 2005	1985–2005
BAU	Scenario business as usual	Land use/management 2020;	Population 2020; connexion rate and treatment level as in 2005	1985–2005
UWD	Scenario full implementation of the Urban Waste Water Directive	Landuse/management as in BAU	Population 2020; connexion rate and treatment level as required by the UWWT Directive	1985–2005
UWD-PFREE	Scenario full implementation of the Urban Waste Water Directive + phosphorus free detergents	Landuse/management as in BAU	As in UWD and in addition use of phosphorus-free detergents	1985–2005
WHO	Scenario change in human diet according to WHO's recommendations	Landuse/management 2020 considering changes in animal breeding activities	As in BAU	1985–2005
WCRF	Scenario change in human diet according to WCRF's recommendations	Landuse/management 2020 considering changes in animal breeding activities	As in BAU	1985–2005
MANU	Scenario of optimization in the reuse of manure as fertilizer	As in BAU with optimal distribution of the manure	As in BAU	1985–2005

lifestyle raises the issue of the adaption of agricultural production and the respective change in land use. We thus test two scenarios transcribing diet recommendations, one based on the World Health Organization (WHO 2003; WHO scenario, table 1) and the other on the World Cancer Research Foundation (WCRF 2007; WCRF scenario, table 1).

As indicated in the introduction, large surpluses of nitrogen and phosphorus are found for most European countries, with excess nitrogen beyond 200 kg N ha^{-1} in The Netherland and Belgium (Leip *et al* 2011). A key reason is the imbalance between the manure nutrient supply and the crop nutrient demand. Specifically, the phosphorous/nitrogen ratio in animal manure in combination with application losses of nitrogen might result in a systematic over fertilisation with phosphorous if applications attempt to cover the demand for nitrogen (Eghball and Power 1999). Despite the fact that the Nitrates Directive has been in place for more than 20 years, high nitrogen losses are observed, in particular in large breeding areas (Bouraoui and Grizzetti 2011). Thus, we developed a scenario based on an optimal reuse of organic manure and adjustment of mineral inputs (MANU scenario, table 1). This scenario intends to assess the impact of improved organic nutrients supply. It emphasizes the possibility of redistributing the manure locally produced, according to the demand for both nitrogen and phosphorus in surrounding areas.

To include the inter-annual variability related to climate (wet versus dry years), all scenario were run considering the precipitation of the period 1985–2005 (Thieu *et al* 2012). The scenarios evaluated in the study are summarized in table 1.

2.2. Land-use and livestock model

The land-use simulated for the different scenarios, including the baseline scenario, the business as usual scenario, and the WHO and WCRC healthy diet scenarios, is based on the application of the CAPRI modelling system (Britz and Witzke 2008). CAPRI is an economic simulation tool for analysis of the European agricultural sector (Britz and Witzke 2008). CAPRI combines a regional supply model for EU's agriculture with a global market model which iterate to a convergent solution. The supply side, solved at given prices for any particular iteration, simulates land use for arable cropping, grassland, and animal production in the EU MSs. Global markets are captured in a spatial multi-commodity model for raw agricultural products and some first stage processing products such as dairy and vegetable cakes and oil. CAPRI considers about 50 primary crop and animal production activities and 50 inputs and outputs. It provides for each land-use related scenario at NUTS 2 administrative level the crop extent and crop share, and the synthetic and organic nitrogen and phosphorus fertilizer application per crop. These values are disaggregated at a 1 km grid based on a land cover map and then aggregated at the sub-basin level (see Grizzetti *et al* 2012, for further details). CAPRI is since recently part of so-called AGMIP (Agricultural Model Intercomparison Project, von Lampe *et al* 2014) and has proven to provide similar results as different other global economic models with a focus on agricultural and food markets.

2.3. Nitrogen phosphorus fate model

GREEN is a spatially explicit statistical model developed to estimate nutrient fluxes to surface water in large river basins (Grizzetti *et al* 2012). GREEN contains a simplified representation of the processes of nutrient transport and retention in river basins and a spatial representation of the various nutrient sources and physical characteristics that influence the nutrient transformations and losses. To apply the model, the area of interest is divided into a number of sub-basins that are connected according to the river network structure. In GREEN, Europe is discretised in nearly 2200 river basins and about 33 000 sub-basins (Grizzetti *et al* 2012). The modelling framework and components are illustrated in figure 2.

GREEN considers inputs from diffuse sources that include mineral fertilizers, manure applications, atmospheric deposition (only for nitrogen), crop fixation (only for nitrogen), and scattered dwellings, and point sources that consist of discharges of industrial and waste water treatment plants. For each sub-basin the model considers the input of nutrient diffuse sources, point sources and loads coming from upstream and estimates the nutrient fraction of diffuse sources retained during the transport from land to surface water (basin retention) and the nutrient fraction retained in the river segment (river retention). The model has been calibrated against annual nitrogen and phosphorus loads at several hundreds of monitoring points spread throughout Europe (Grizzetti *et al* 2012). The nutrient retention, including retention in lakes is computed on annual basis and includes permanent and temporal nitrogen and phosphorus removal. The model allows the apportionment of nutrient loads according to the difference sources. The model has been thoroughly evaluated and successfully applied for Europe with predicted loads within 10% and 13% of the measured nitrogen and phosphorus loads, respectively. The major data requirements are listed in table S1 (supplementary material).

2.4. Scenarios parameterization

2.4.1. Point source calculations. Two point sources scenarios were developed: one to evaluate the impact of the full implementation of the Urban Waste Water Directive (UWD) and the second evaluating the full implementation of the urban directive associated with the ban of phosphorus-based detergents (UWD PFREE). Point source emissions are estimated starting from the collection of household and industrial effluents. The calculation is performed at the river basin scale and integrates for all agglomerations a detailed and spatially explicit census of wastewater collection, connexion to sewers and treatment as reported by most of the EU-27 MSs. This value is calculated by basin according to the identification of wastewater treatment for all releases and the corresponding nitrogen (N) and phosphorus (P) removal fraction defined according to the work of Van Drecht *et al* (2009). The per capita emission of nutrient is calculated at the

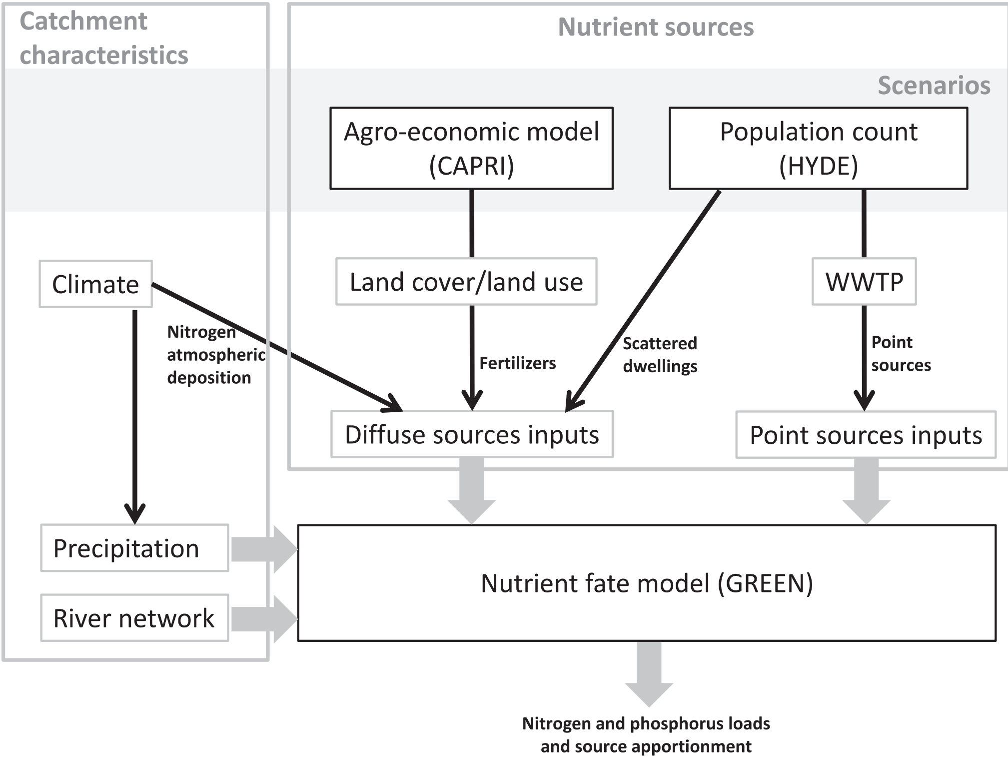


Figure 2. Flow chart of the major components of the modelling framework.

MS level based on total food and vegetable proteins intakes ($g\,yr^{-1}\cdot$ person) retrieved from FAO database (2009), using emission coefficients from Jönsson and Vinnerås (2004). Other emissions including per capita emission from P-based detergents used for laundry and dishwasher, respectively, and industrial emissions are added (Bouraoui and Grizzetti 2011).

For non-EU27, a census of all agglomerations larger the 2000 inhabitants (Geoname database) has been used, assuming an additional mean contribution of industrial releases. Information related to the raw per capita emissions of nutrients is calculated at the country level, and then downscaled to the basin scale. The fraction of household's emission collected through a septic tank or other individual collecting systems not connected to the sewage network is considered as scattered dwelling sources and calculated similarly, assuming no industrial emission and a 50% average of retention (before reaching surface water).

With respect to the Commission proposal COM (2010) 597 on the use of phosphates and other phosphorus compounds in household laundry detergents the phosphorus content is set to zero in the scenario PFREE. Other types of detergents such as dishwasher detergents were not considered as technically and economically viable alternatives have not yet been found. The contribution of phosphorus from laundry detergents for all European countries has been estimated by Bouraoui and Grizzetti (2011). Figure 3 reports the P emissions from different activities.

2.4.2. Healthy diet scenarios. The two diet scenarios include prospective changes in human food consumption following the recommendations made for a healthier diet by the World Health Organization (WHO 2003; WHO scenario) and by the World Cancer Research Fund (WCRF 2007; WCRF scenario). WHO recommends eating less than 300 g $week^{-1}$ of red meat and at least 200 g d^{-1} of fruit and 200 g d^{-1} of vegetable; WCRF recommends even lower meat consumption. Both diet scenarios consider related adaptation of agricultural land use to support a human diet with slightly less meat, more fruit and vegetables (see Wolf *et al* 2011).

The impact of these two scenarios on land use, livestock and farming practices are simulated by the CAPRI agro-economic model in order to ensure the economic sustainability of the scenarios. Overall the WHO scenario leads to a decrease of the beef demand by 5.5% and pig demand by 4.8%. The WRCF scenario leads to more drastic changes with decreases of beef and pig demand by 34.3% and 34.5%, respectively.

2.4.3. Manure management scenario. In the MANU scenario, an optimization of the amount of animal manure locally produced is considered. In this optimization procedure, the available amount of manure calculated in the baseline scenario is first applied on grassland area, and the remaining part is then used as crop fertilizer. In both cases, supplies of phosphorus manure (P_{org}) and nitrogen manure (N_{org}) cannot exceed the net demand of the plant (either grass or crop).

This net demand is calculated according to the crop requirement minus the inputs corresponding to nitrogen deposition, fixation and nitrogen crop residues. The net demand has to be covered by a suitable application of organic

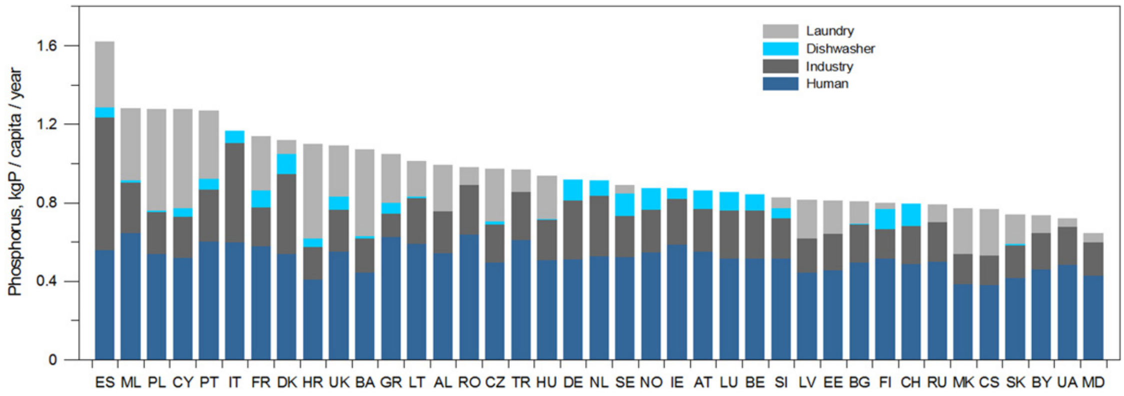


Figure 3. Per capita emission of phosphorus (in kgP/capita/year) for regions included in the study area according to Bouraoui and Grizzetti (2011).

fertilizer (manure application after gaseous losses and with a certain N:P ratio) and with mineral input to fulfil the remaining plant requirements for both nitrogen and/or phosphorus.

If $N{:}P_{manure} < N{:}P_{plant\ demand}$ the manure is considered as N-deficient. In this case, mineral P is supplied until the plant P demand is reached. In case of a shortage of manure, adequate mineral input (P_{min}) is added. Since the nitrogen demand could not be covered by the amount of manure supplied ($N{:}P_{manure} < N{:}P_{plant\ demand}$) a mineral nitrogen supply (N_{min}) is calculated to satisfy the crop and grass needs (calculated in turns). Otherwise, if $N{:}P_{manure} > N{:}P_{plant\ demand}$ then the priority is given to the satisfaction of the N demand first, and a mineral P adjustment is systematically calculated.

The MANU scenario aims at minimizing the nitrogen surplus with a zero surplus being optimal. However, in some cases, not all manure can be applied without exceeding the demand for N or P. The resulting residual, calculated at the level of the about 33 000 sub-basins, is considered as an exportable supply able to support deficient areas. The residual manure distribution is optimized within all EU basins according to the following procedure.

- Residual (not applied) manure is cumulated at the basin scale (with an average quality $N{:}P_{manure}$), and redistributed to sub-basins located in that particular basin according to their residual demand for both nitrogen and phosphorus ($N{:}P_{plant\ demand}$). By doing so, residual manure application prioritizes sub-basins with a need similar to the quality of manure potentially exportable at the basin scale.
- In case all residual manure could not be redistributed in a basin (without exceeding the crop and grass demand for N and/or P), the remaining residual manure is proportionally distributed to all sub-basins according to their size, and weighted with respect to their initial excess of manure.
- Mineral application is finally calculated to cover the residual demand for N and/or P for each individual sub-basin.

The total amount of manure applied at the scale of European river basins is preserved only its distribution at the sub-basin scale is affected.

3. Results

The impacts of the various scenarios on total nitrogen and phosphorus loads to the European Seas are shown in figures 4 and 5 for nitrogen and phosphorus, respectively, presenting the contribution of the major sources: point sources, agriculture and other diffuse sources.

For all European Seas there is an increase of the total nitrogen load in the BAU with respect to the reference scenario (REF) (figure 4). This is mainly due to the increase of population and associated food requirements and emissions. Fully implementing the Urban Waste Water Directive (UWD scenario) lowers the total nitrogen loads for all seas, bringing the emissions to the levels of the BAU scenario with a relative decrease of the load from point sources by 13% in the Mediterranean Sea, 16% in the Atlantic Sea and 32% in the North Sea. On the contrary it results in an increase of the nitrogen load by 4% in the Baltic and 25% in the Black Sea. This is explained by the initial lower connexion rate and/or treatment levels in these two regions, in particular in the new MSs. Through the implementation of the Urban Waste Water Directive there is a shift from scattered dwelling emission to point source emission. It is important to note that these aggregated results hide the national variability that can exist within a specific sea. As expected, the ban of phosphorus in laundry detergent (UWD-PFREE scenario) has no effect on nitrogen loads to the seas. The most efficient scenario for reducing the nitrogen loads is the manure management (MANU scenario), and this holds for all seas. The reductions range from 36% in the Mediterranean Sea to 41% in the Baltic area. Concerning the two diets scenarios, the WCRF scenario is relatively more efficient in reducing the nitrogen load than the WHO scenario, due to the lower beef and pork demand in the WRCF scenario. However for all seas, the reduction of loads is extremely small with reductions ranging from 2% in the Black Sea to 5% in the North Sea.

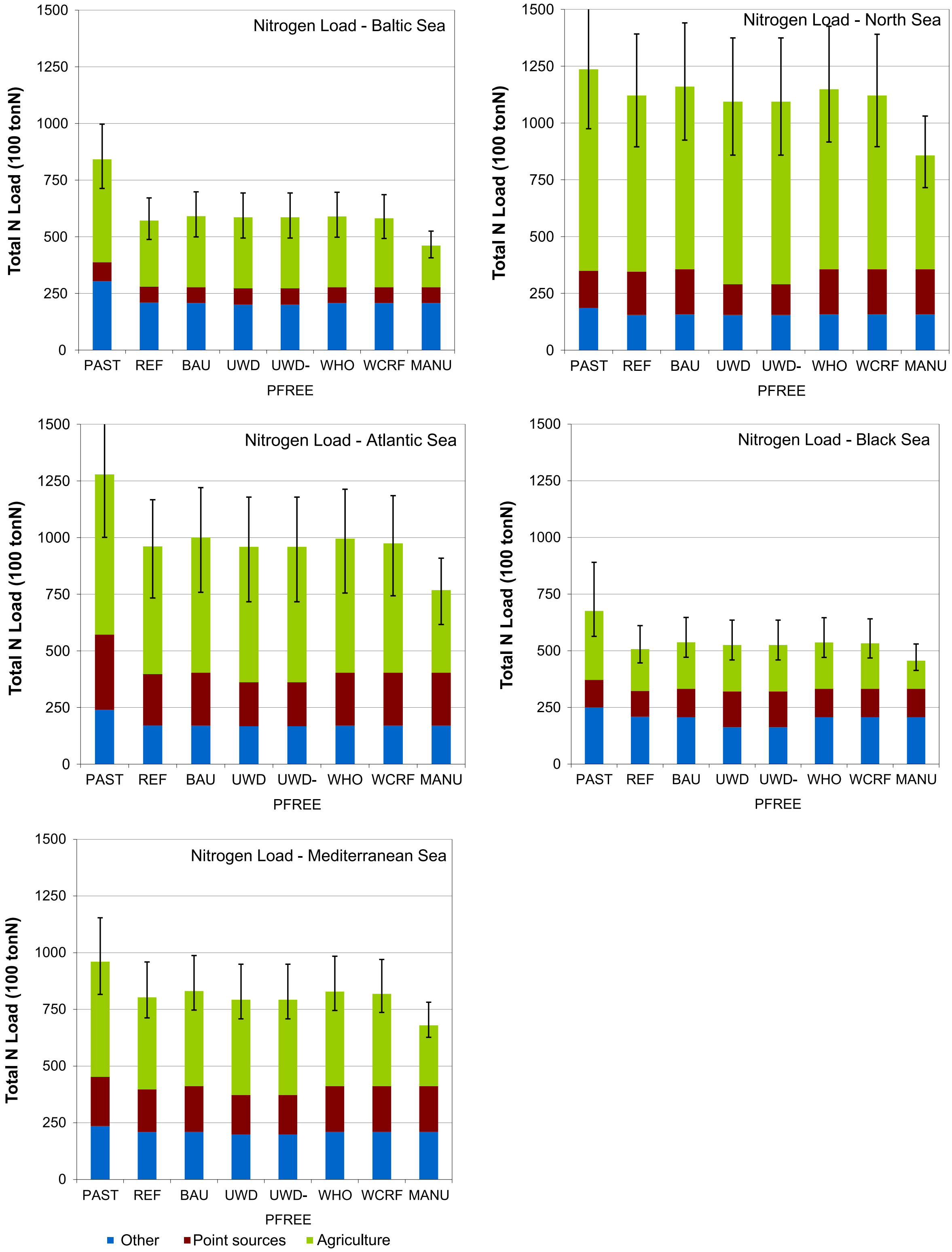


Figure 4. Nitrogen load entering all European seas under different scenarios. The bars indicate the variability related to climate (precipitation).

For phosphorus (figure 5), like for nitrogen, there is a slight increase of phosphorus emissions under the BAU scenario due to the increase of population and associated food needs. The full implementation of the Urban Waste Water Directive (UWD scenario) increases slightly the load from point sources in the Baltic and Black Seas due to the increased connexion rate, while simultaneously reducing the emissions from scattered dwellings. On the other hands, in the North and Atlantic Seas, where connexion rates were originally already quiet high, the full implementation of the

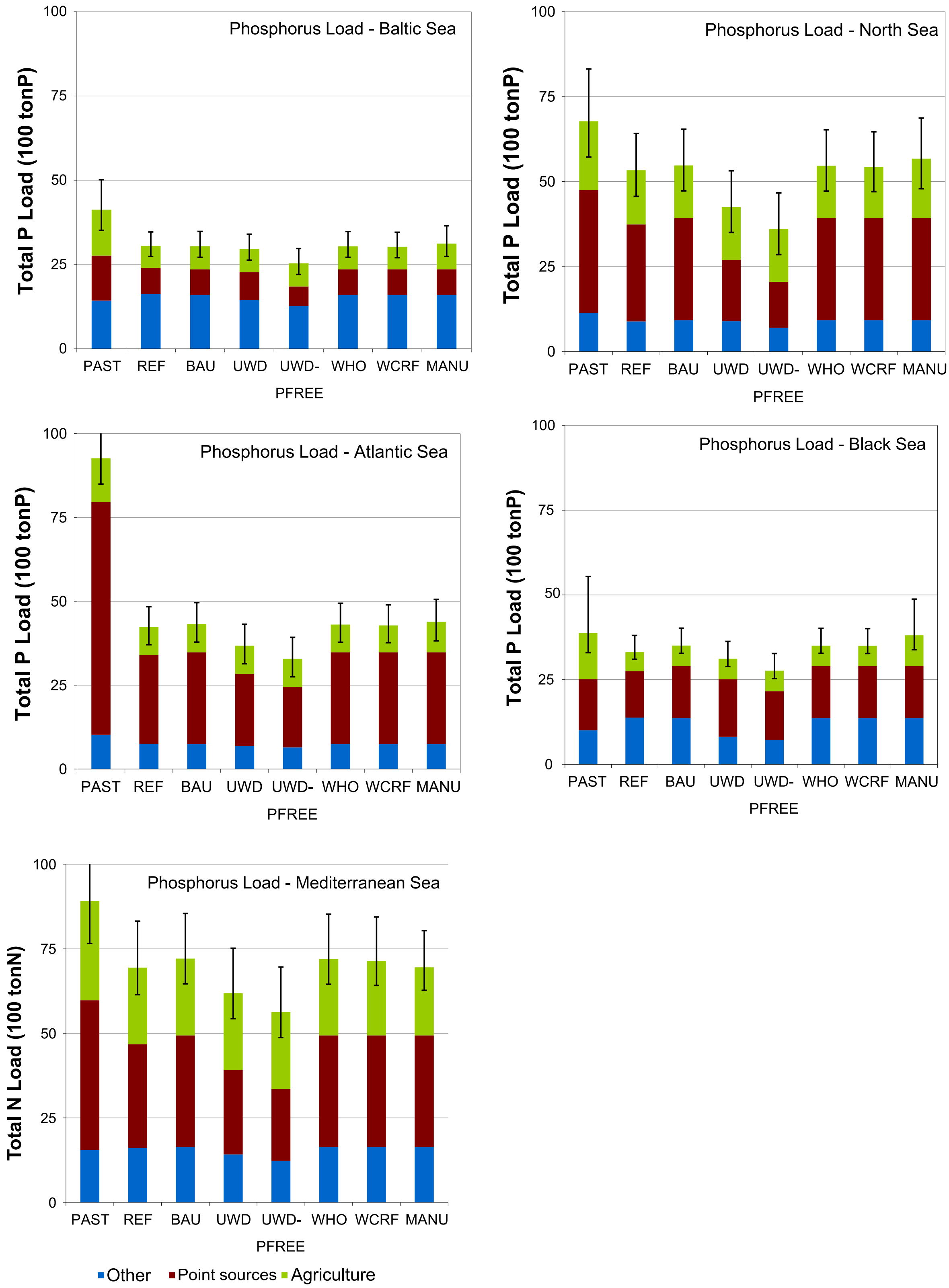


Figure 5. Phosphorus load entering all European seas under different scenarios. The bars indicate the variability related to climate (precipitation).

Directive, including higher treatment levels, yields a significant high reduction of the phosphorus loads. A further ban of phosphorus based detergents (UWD-PFREE scenario) decreases quite significantly the loads of phosphorus emitted from point sources. As for nitrogen, the WCRF diet scenario is more efficient than the WHO diet scenario in reducing the phosphorus load. The optimized manure scenario (MANU scenario) results in a slight increase of the phosphorus loads due to the fact that the manure was redistributed based on nitrogen requirements. However, with the separation of the manure in the liquid (high nitrogen content) and solid phase (high phosphorus content), it should be possible to perform a dual optimization based on nitrogen requirements and on phosphorus crop requirements.

The impact of the various scenarios on the nitrogen and phosphorus concentrations discharged in the European seas (sea outlet) is shown in figure 6. It can be clearly seen that the manure management (MANU scenario) is the most efficient in reducing nitrogen concentration for all seas while the full implementation of the Urban Waste Water Directive associated with the ban of phosphorus based detergents (UWD-PFREE scenario) is the most efficient for reducing the concentration of phosphorus entering all the European Seas. The highest relative reduction of phosphorus and nitrogen are obtained in the Atlantic Sea with a reduction larger than 30% for phosphorus, when implementing fully the Urban Waste Water Directive and banning P-based detergents, and a reduction of more than 20% in nitrogen concentration, when implementing a better management of manure.

Considering both nitrogen and phosphorus, the results of this study are in line with those found by Oenema *et al* (2009), who reported a decrease of nitrogen leaching by up to 35% by 2020 compared to the baseline (year 2000), when implementing a balanced fertilization for EU27. Our results also agree with those reported by Humborg *et al* (2007) who found the implementation of the Urban Waste Water Directive more efficient in reducing phosphorus load than nitrogen load, and that banning P based detergents could lead to a further significant reduction for phosphorus loads.

4. Discussion

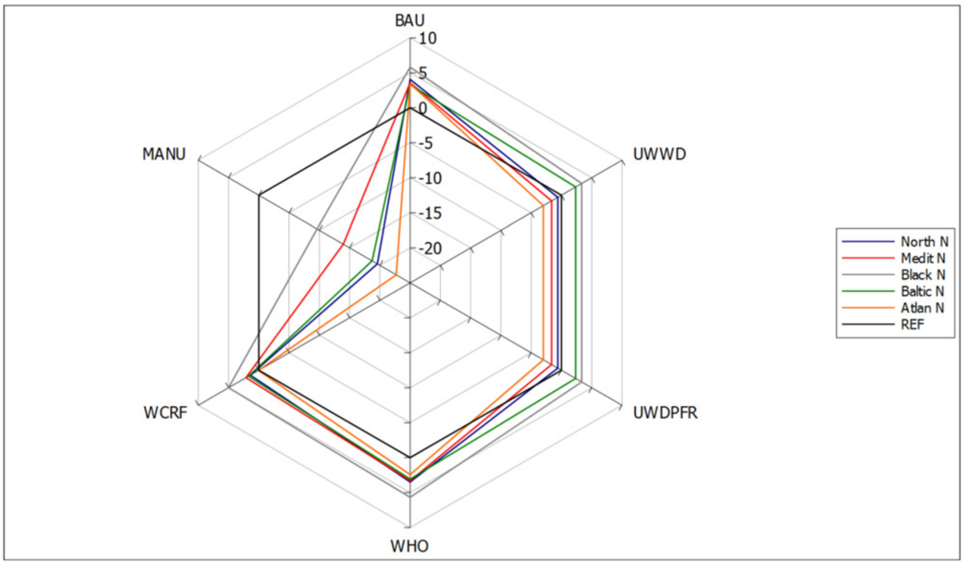
Despite large efforts to reduce nitrogen and phosphorus loads entering the European Seas, large nutrients amounts are still emitted in Europe's waters endangering the ecological health of aquatic ecosystems (see results for the baseline scenario REF above). A large body of legislation is strictly regulating the emission of these two nutrients, complemented by international initiatives, such as the OSPAR Convention (OSPAR 2008), the HELCOM Convention and the Baltic Action Plan (HELCOM 2007), that have been put in place few decades ago to reduce nutrients loads, however with sometimes limited success. Accordingly, it seems that far-reaching changes or innovative management approaches are needed to finally reduce the nitrogen and phosphorus loads entering all European Seas. Our results indicate that fully implementing the Urban Waste Water Directive could significantly reduce the emission of phosphorus emitted from point sources. Further banning P-based laundry detergent in all EU countries, as already done in some MSs, could further reduce significantly the phosphorus load, decreasing the phosphorus concentration in surface waters by an additional 10%. This measure is beneficial for the environment and would also reduce the treatment cost of water.

The results obtained when implementing the two diet scenarios may appear in contradiction with the recent research debate on reducing meat consumption. Indeed, there is a large body of literature arguing that reducing meat intake will lead to a reduction of the emission of reactive nitrogen in the environment (Westhoek *et al* 2014). However, in our application there is little or no impact on nitrogen and phosphorus emission. We analysed the outcome of the CAPRI model as far as animal production is concerned (table 2).

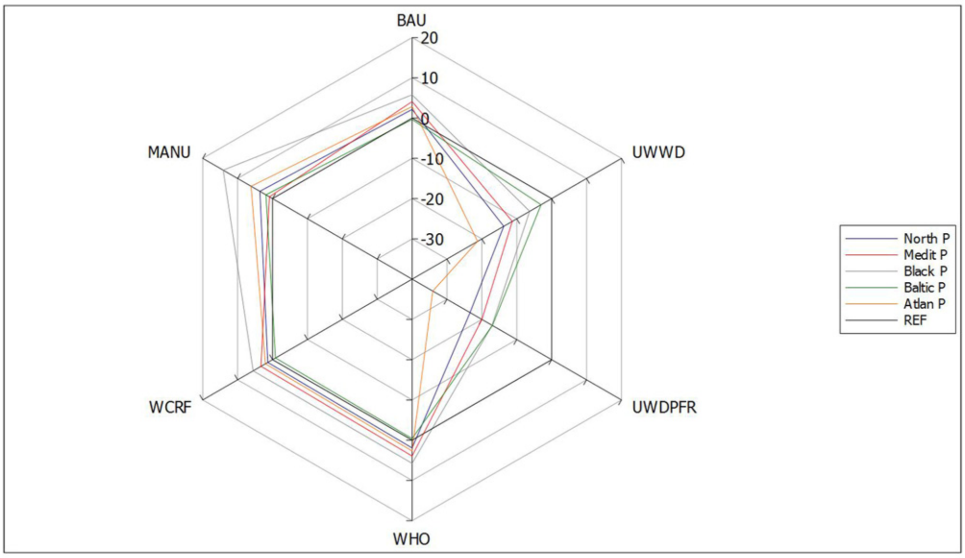
Despite the large decrease in the beef and pork demand (consumption) in the WHO and WRCF scenarios the production of meat estimated by the model CAPRI decreases in proportionally smaller amounts. For instance, according to CAPRI, a decrease by 34% of beef and 37.5% of pork demand results only in a decrease of the production by 7.6% and 21.5% for pork and beef, respectively. That clearly indicates that a decrease of the European demand for beef and pork meats is not followed by a similar decrease of production at the EU-scale; the accompanying price drops allow higher exports. In particular, Europe is simulated to become a net exporter of beef under the WHO and WCRF scenarios (while at present it is considered an importer). For pigs, the EU27 shows already a net export which increases further in the WHO and WCRF scenarios according to CAPRI. The scenarios hence provide examples of pollution swapping, similar to the discussion of induced land use change in the case of biofuels (Searchinger *et al* 2008), in our case study the EU absorbs, as a consequence of changing diets in the EU, larger emission linked to food consumption taking place in the rest of the world. Changing diets can have a beneficial impact on the environment if efforts are coordinated at the global scale. These results also show the importance of running modelling exercises under realistic agro-economic scenarios accounting for perspective changes of agricultural policies and trade options.

The scenario linked to improved management of manure (MANU scenario) shows the highest reduction potential of all scenarios considered. Indeed, the nitrogen surplus in Europe exceeds environmentally sustainable levels. In 2008, the net nitrogen excess for EU27 was around 8.5 10^6 tons of nitrogen (EUROSTAT 2014), the mineral nitrogen fertilizer consumption 11 10^6 tons and manure production by livestock around 9.6 10^6 tons of nitrogen, with a total crop removal of nitrogen amounting to 16 10^6 tons. This clearly indicates that this excess could be significantly reduced by using manure as a fertilizer instead of considering it as a waste. Without considering other contributions to nitrogen input, such as crop fixation, crop residues or atmospheric deposition, the amount of applied fertilizer both organic and synthetic exceeds the removal by 29%, leading automatically to excessive losses of nitrogen either as nitrate to waters or as greenhouse gas emissions.

Despite providing valuable insights on impact of alternative scenarios on nutrient losses, caution should be given about the outcomes of the modelling framework, due to the assumptions made and some limitations of the models' parameterization and representation of the reality. Even though GREEN has been validated extensively, the model



Relative change of nitrogen concentration (%) according to the scenario type for all European seas



Relative change of phosphorus concentration (%) according to the scenario type for all European seas

Figure 6. Impact of the different scenarios on nitrogen (top graph) and phosphorus (bottom graph) concentrations in water discharged in the European seas. The relative increase (+) or decrease (−) of nitrogen or phosphorus concentration is computed with respect to the reference scenario (REF scenario, black line). The colours refer to the different seas.

Table 2. Change in beef (suckler cows + adult cattle for fattening) and pork production in the WHO and WCRF scenario compared to the BAU 2020 baseline.

	BAU	WHO [% of BAU]	WCRF [% of BAU]
Beef herd [1000 heads]	26 776	−1.50%	−7.60%
Pigs [million heads]	250 067	−3.30%	−21.50%

performance is still controlled by the availability and the quality of the monitoring data. The calibration of the model relied on a network of about 2000 monitoring stations, quite a large number, but very limited when considering that the whole Europe is represented as a network of about 33 000 catchments. Some other limitation is due to the process representation of the intrinsic transport time of the various nitrogen and phosphorus forms. With regard to the whole modelling framework of this study, we feel that the major limitation comes from the various spatial and temporal scales used to derive the scenarios and the forcing to the various models (see table 1). For instance, in CAPRI key parameters driving the results such as reaction of crops to changes in economic incentives are econometrically estimated from past observation (Jansson and Heckelei 2011). A challenge is the lack of statistical data on nitrogen and phosphate use per crop at regional level; these data are statically estimated applying a Bayesian approach distributing total mineral fertilizer use at national level and manure amounts estimated from herd sizes, using data from expert questionnaires on typically application rates for crops at national level. The storylines for the diets scenarios are developed at supra-national scales with no time line. These storylines are then converted in crop share and fertilizer use at national and regional scale by the CAPRI model, which then feeds the GREEN model in which all these data is further downscaled at the catchment scale, introducing at each step of disaggregation additional layers of uncertainty. This is however always the case when the linkage between various models is done through external forcing and when the model developed for different scopes are combined. We must further note that the application of CAPRI to the dietary scenarios is a rather typical use case of that economic model (Tukker *et al* 2011).

5. Conclusion and way forward

The results of this study clearly indicate great potential for reducing nitrogen and phosphorus pressures on European surface waters by measures that have already being identified and for which legislation or recommendations are already been formulated. The Urban Waste Water Directive is part of the policy agenda of all EU MSs, with neighbouring countries also adopting similar approaches. In 2012, the European Commission adopted the regulation no 259/2012 which limits the use of phosphates in detergents placed on the market in all EU MSs; however, allowed implementation periods are relatively long. A similar approach has also been agreed by the International Commission for the Protection of the Danube River for the whole Danube basin (ICPDR 2009). Codes of good agricultural practices developed under the new Common Agriculture Policy can contribute significantly to the optimization of manure reuse. Finally, changes in the diet, already advocated by different researches, need to be accompanied by changes in the level of intensification of livestock production in order to be effective. We hence conclude to no new legislation is required to reduce nutrient in European waters, and the efficiency of many already existing measures have been largely documented. Indeed, what is asked for is a strict implementation of the existing legislation, and when required to go beyond the European legislation. For example, Denmark clearly demonstrated that required reduction of nutrients in surface and groundwater can be achieved without affecting the economic sustainability of agricultural activities (Kronvang *et al* 2009). Finally, it is important to note that this study has focused solely on nutrient emissions as a pressure, and reducing nutrient loads will not guarantee the successful achievement of the good ecological status as required by the Water Framework Directive. Other pressures, not included in our assessment, that might prevent achieving the goals set by the WFD include chemical contaminants, hydromorphological pressures, etc (EEA 2012). In order to study the successful implementation of the WFD scenarios considering multiple pressures on aquatic ecosystems, as well as models including biotic components should be used.

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