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Coastal eutrophication in Europe caused by production of energy crops

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HIGHLIGHTS

- We analysed future scenarios for first generation energy crop production in Europe.
- Energy crop production increases nutrient export by rivers to coastal waters.
- The relative contribution of fertilisers to nutrient export increases in our scenarios.
- Nutrient export rates differ substantially among European river basins.

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ABSTRACT

In Europe, the use of biodiesel may increase rapidly in the coming decades as a result of policies aiming to increase the use of renewable fuels. Therefore, the production of biofuels from energy crops is expected to increase as well as the use of fertilisers to grow these crops. Since fertilisers are an important cause of eutrophication, the use of biodiesel may have an effect on the water quality in rivers and coastal seas. In this study we explored the possible effects of increased biodiesel use on coastal eutrophication in European seas in the year 2050. To this end, we defined a number of illustrative scenarios in which the biodiesel production increases to about 10–30% of the current diesel use. The scenarios differ with respect to the assumptions on where the energy crops are cultivated: either on land that is currently used for agriculture, or on land used for other purposes. We analysed these scenarios with the Global *NEWS* (Nutrient Export from WaterSheds) model. We used an existing Millennium Ecosystem Assessment Scenario for 2050, Global Orchestration (GO2050), as a baseline. In this baseline scenario the amount of nitrogen (N) and phosphorus (P) exported by European rivers to coastal seas decreases between 2000 and 2050 as a result of environmental and agricultural policies. In our scenarios with increased biodiesel production the river export of N and P increases between 2000 and 2050, indicating that energy crop production may more than counterbalance this decrease. Largest increases in nutrient export were calculated for the Mediterranean Sea and the Black Sea. Differences in nutrient export among river basins are large.

1. Introduction

The use of renewable energy from wind, solar and biomass is expected to increase in the future to stabilise global climate change and to enhance energy security. Energy in biomass can be converted into liquid biofuels, like bio-ethanol and biodiesel. The Global Energy Assessment (GEA, 2012) states that renewable energies are abundant, widely available and increasingly cost-effective. However, GEA also indicates that it is a major challenge to assure the sustainability of the proposed renewable technologies. Energy from biomass could play an important role in 'decarbonising' the energy supply, assuming that the carbon in this biomass is part of the 'short' carbon cycle and does not contribute to the enhancement of CO_2 levels in the atmosphere. In the GEA-study different groups of future pathways are defined. The intermediate pathways (indicated as GEA-Mix) are characterised by a mix of efficiency improvements and cleaner supply-side technologies. These GEA-Mix pathways indicate that worldwide supply of energy from biomass (biofuels and co-processing of biomass with coal or natural gas) could grow from 45 EJ in 2005 to 80–140 EJ by 2050. In the GEA-Mix pathway liquid biofuels constitute about 80% of total fuel use in the world wide transport sector in 2100.

It is easier to switch to biofuels than to (renewable) electricity for the transport sector. Biofuels do not require major adjustments of the present fossil fuel based infrastructure for energy supply to the transport sector. This makes biofuels popular alternatives to liquid fossil fuels (petrol and diesel) presently used in the transport sector. The demand for liquid biofuels can be met by either first generation (derived from sources like starch, sugar, and vegetable oil from arable crops),

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second generation (derived from lignocellulosic materials like grassy or woody crops, agricultural residues or waste) or third generation (derived from algae) liquid biofuels (Dornburg et al., 2010). Several studies analysed the potentials of different types of biofuels (de Wit et al., 2011; Fischer et al., 2010). Currently, mainly first generation liquid biofuels are produced in Europe. Second and third generation fuels are as yet too expensive for commercial production.

The European Union aims to increase the use of renewable energy. The European Directive 2009/28/EC of 23 April 2009 on the promotion of renewable energy (EU, 2009) aims to achieve, by 2020, a 20% share of energy from renewable sources in the EU's overall consumption of energy and a 10% share of energy from renewable sources in each member state's transport energy consumption.

Growing crops for biofuel production can have negative effects on food security: energy crops compete with food and feed crops for natural resources like arable land and water (Spiertz and Ewert, 2009). The shift in agricultural production from food or feed crops towards energy crops is likely to increase food prices and endanger food security (Baffes, 2013). In addition, the production of biofuels could give rise to negative impacts on the environment. In particular negative effects on biodiversity and carbon stocks due to direct and indirect land use change have been pointed out extensively (DiMaria and Van der Werf, 2008; Fargione et al., 2008; Lapola et al., 2010; Searchinger et al., 2008). Furthermore, Erisman et al. (2010) indicate that growing first generation biofuel crops will result in increasing N_2O emissions from fertiliser use.

To mitigate negative environmental effects of extensive biofuel production, the EU directive includes environmental sustainability criteria to ensure that growth of energy crops is sustainable and is not in conflict with overall environmental goals. The directive states that "*Where biofuels and bioliquids are made from raw material produced within the Community, they should also comply with Community environmental requirements for agriculture, including those concerning the protection of groundwater and surface water quality*". The sustainability criteria in the directive do not specifically address adverse eutrophication effects in coastal waters due to nutrient (nitrogen (N) and phosphorus (P)) leakages induced by the cultivation of energy crops. From an environmental point of view it is important to take this cultivation into account since energy crops probably will be grown on low input agricultural land or non-agricultural land. This could lead to enhanced fertiliser use in Europe, to higher nutrient leakages to groundwater and surface waters and, as a result, higher nutrient export by rivers. Eventually this could lead to increasing eutrophication of coastal waters. Fischer et al. (2010) estimated for an energy oriented scenario, considering substantial land use conversions including the use of pasture land, that the potential for energy crops in 2030 in EU-27 (the 27 EU member states[1] until July 1st, 2013) is 45.2 million ha, consisting of 30.5 million ha of existing arable land and 15.2 million ha of pasture land. Fertiliser input to these pasture lands was originally low and therefore the transformation of this area to agricultural land for energy crops with a higher fertiliser input could result in increase of EU-wide nitrogen fertiliser use by about 1.8 Tg N/year or 17.5% of the present total nitrogen-fertiliser use in EU-27 (Fertilizers Europe, 2013).

The purpose of this study was to explore possible effects of large-scale biodiesel production from energy crops on coastal eutrophication in European seas, through enhanced nutrient losses from agricultural land to rivers, in the year 2050. To this end, we defined a number of illustrative scenarios in which the biodiesel production increases. We assumed only first generation energy crops in our study and used a hypothetical energy crop for our calculations, which represents a typical crop that can be grown throughout Europe. The use of a hypothetical energy crop simplified our calculations, enabling us to give a transparent and systematic analysis of nutrient export to European coastal waters using a widely accepted environmental model and scenario approach as a basis, The scenarios differ with respect to the assumptions about the area that is allocated for cultivation of energy crops: either land that is currently used for agriculture, or land that currently has a non-agricultural purpose. In our scenarios, future biodiesel production equals about 10–30% of the current fossil diesel use.

2. Method

2.1. Scenario overview

We calculated nutrient export by a selection of European rivers for a number of scenarios assuming increased cultivation of first generation energy crops for the production of biodiesel. We used the Global *NEWS* models (Mayorga et al., 2010) to calculate nitrogen and phosphorus export by rivers to coastal waters. We selected river basins following Blaas and Kroeze (2014), who identified the 48 largest rivers in the 27 EU countries to study nutrient export by rivers associated in scenarios assuming large-scale cultivation of micro-algae for biodiesel on land. These EU-27 river basins were selected on the basis of their nitrogen load at the river mouth (>10 Gg/year). In our study we excluded rivers in which less than 5% of the area is used for agriculture, because these river basins are apparently less suitable for agriculture as a result of environmental conditions. As a result, 42 river basins were included in our analysis (Table 1).

The total area of the selected basins is 2.9 million km^2 while the total area of the EU-27 river basins is 4.3 million km^2 (data derived from the Global *NEWS* models; Mayorga et al., 2010; Seitzinger et al., 2010). Thus the selected river basins in this study cover about two-thirds of the area of the EU-27. The total discharge of the 42 rivers included in this study is 713 km^3/year. This is about 50% of the total European (EU-27) river discharge according to Global *NEWS*.

We analysed a baseline scenario and five alternative scenarios. Starting point of the scenario building was an estimate of the maximum amount of biodiesel that could be produced in 2050. To replace all current transport fuels by biofuels in the 27 EU countries 0.4 billion m^3 biodiesel is needed per year (Wijffels and Bardosa, 2010). If this amount of biodiesel were to be produced from first generation energy crops like rapeseed, an area of 3 million km^2 would be needed to grow these crops. This is about the total basin area of the 42 rivers in our analysis, or about two thirds of the total EU-27 area. Therefore, it is unrealistic to assume that biodiesel from a first generation energy crop will replace all fossil diesel. Our scenarios aim to produce a considerable amount of biofuel from first generation energy crops; our assumptions on land use change imply that biodiesel production increases to about 10–30% of the current diesel use.

In Europe rapeseed (North Western and Central Europe) and sunflower (Central and Southern Europe) are the main crops used for feedstock for biodiesel production. For our analyses, we assumed the production of a hypothetical first generation energy crop. N and P fertiliser input for first generation energy crops like rapeseed in Europe are generally in the range of 100–200 kg N/ha/year and 15–40 kg P/ha/year (Pimentel and Patzek, 2005; Ulgiati et al., 2004; van der Voort et al., 2008). We used a nitrogen input of 121 kg N/ha/year and a phosphorus input of 28 kg P/ha/year for this hypothetical crop, corresponding with the values given by de Vries et al. (2013) based on a study on biofuel cropping in Germany.

We used an existing Millennium Ecosystem Assessment Scenario for 2050, Global Orchestration 2050 (GO2050), as a baseline scenario (S0) for our scenario building (Table 2 and Fig. 1) (Alcamo et al., 2005; Carpenter et al., 2005; Cork et al., 2005). In our first four alternative scenarios (S1–S4) we assumed that energy crops will be grown on non-agricultural land to produce a reasonable amount of biodiesel without harming food and feedstock production too much. Another reason to

[1] The EU-27 member states until July 1st, 2013 were: Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.