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A grassland strategy for farming systems in Europe to mitigate GHG emissions—An integrated spatially differentiated modelling approach

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A B S T R A C T

This paper assesses the impact of an EU-wide policy to expand grassland areas and promote carbon sequestration in soils. We use the economic Common Agricultural Policy Regionalized Impact (CAPRI) model, which represents EU agriculture using 2450 mathematical programming farm-type models in combination with the biogeochemistry CENTURY model, which provides carbon sequestration rates at a high resolution level. Both models are linked at the NUTS3 level using location information from the Farm Accounting Data Network. We simulated a flexible grassland premium such that farmers voluntary and cost efficiently increase grassland area by 5%. We find that the GHG mitigation potential and the costs depend on carbon sequestration rates, land markets and induced land use changes, and regional agricultural production structures. In Europe, the calculated net effect of converting 2.9 Mha into grassland is a reduction of 4.3 Mt CO2e (equivalents). The premium amounts to an average of EUR 238/ha, with a total cost of EUR 417 million for the whole EU. The net abatement costs are based on the premium payments, and account on average EUR 97/t CO2e. However, substantial carbon sequestration (28% of total sequestration) can be achieved at a rate of EUR 50/t CO2e. Carbon sequestration would be most effective in regions of France and Italy and in Spain, the Netherlands and Germany. Larger farms and farm-types specialized in 'cereals and protein crops', 'mixed field cropping' and 'mixed crop-livestock' farming systems have the highest mitigation potential at relatively low costs.

1. Introduction

The agricultural sector is both a source and a sink of greenhouse gases (GHG). In this context, agricultural soils play a major role, as they contain a large stock of terrestrial carbon in the form of soil organic carbon (SOC), which can increase or decrease, depending on factors such as plant productivity, climatic conditions and farming practices. In the roadmap for transitioning to a low-carbon economy (EC, 2011) the European Union (EU) envisages the reduction of net CO_2 equivalent (CO2e) emissions from agricultural soils and forests through targeted measures. A key goal of the strategy is to enhance SOC levels across the EU by 2020. In addition to restoring wetlands and peat lands, promoting low-tillage farming practices, reducing erosion and encouraging re- or afforestation, the EU has introduced 'greening' elements into the post-2013 Common Agricultural Policy (CAP) to promote, among others, the maintenance of permanent grasslands. This policy prevents CO2 release from soils, preserving the SOC stock of grasslands. Compared to arable land, the soils of grasslands are usually characterized by high SOC stocks. However, because in most Member States (MS), demand for urban areas decreases agricultural area, also grasslands are expected to decrease further. This trend was observed in the EU between 1990 and 2012, with a decrease in arable land and permanent crops of 15% and a decrease of grassland area of 19% (FAOSTAT, 2014). A review of more than 100 experimental studies worldwide (Conant et al., 2001) identifies the conversion of arable land into grassland as an effective carbon sequestration (C-sequestration) measure. Vleeshouwers and Verhagen (2002) quantified the effects of conversion in Europe using the bio-physical CESAR[1] model and

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[1] Carbon Emission and Sequestration by Agricultural land use.

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concluded that the C-sequestration potential of increasing grassland area is large. Similarly, Ogle et al. (2004) and Freibauer et al. (2004) presented reviews of studies that show positive effects of grassland conversion on SOC. Although SOC changes with the conversion of arable land into grassland have been quantified by many studies, the economic effects induced by enhancing grasslands, such as changes in prices, production, trade and indirect emissions have not been assessed in the literature; consequently, it is difficult to draw conclusions about abatement costs. There is also a need to identify the locations in Europe in which specific C-sequestration measures are most effective (Freibauer et al., 2004).

In this paper, we develop a modelling approach to assess the economic implications of a grassland increase of 5% in the EU27.[2] Specifically, we quantified the amount of carbon that could be sequestered and related abatement costs. The economic effects were assessed using the partial equilibrium CAPRI model and its farm-type supply module (Gocht and Britz, 2011), which accounts for the high variability of agriculture. We allowed different farm-types (different specializations and sizes) to adjust differently to reach the 5% target at the NUTS2 level.[3] The adjustment is cost efficient and hence depends on the production costs of each simulated farm-type. The C-sequestration and abatement costs for each farm-type were calculated using C-sequestration rates from the biogeochemistry CENTURY model. These rates depend on soil characteristics and climatic conditions and are distributed at a high spatial resolution in Europe. As the location of the farm supply models in CAPRI is not directly known,[4] we approximate the spatial distribution of farm-types using information from the Farm Accountancy Data Network (FADN) in order to overlay the sequestration rates obtained via CENTURY (see, e.g., Lugato et al., 2014a,b).

To the best of our knowledge, this is the first application of spatially explicit C-sequestration rates in an economic farm-type model at the EU level that is not linked at the regional aggregate but spatially mapped based on the approximated locations of farm-types using FADN information. As the environmental and economic effects depend strongly on the farming system, the implemented approach consequently yields less biased GHG abatement cost estimates compared to a regional approach.[5] Furthermore, the approach quantifies the complete GHG balance in agriculture by taking into account C-sequestration and at the same time induced GHG emissions (e.g., CH4, N2O) by the herd size and land use changes resulting from an increase in grassland area.

This paper is structured as follows: First, we describe the CAPRI economic model and explain how we derived the locations of the farm-types using FADN to spatially assign the SOC rates (obtained from the biogeochemistry CENTURY model). To better explain our spatially explicit mapping, we compare it to a standard mapping at a lower resolution. We then describe the scenario and present the results. We begin with the analysis of land use changes and analyse changes in trade, commodity prices and supply. We present the findings on C-sequestration and discuss the impact on emissions, and we complete the results section by presenting the abatement costs of CO2 emissions. In the discussion, we validate our results by comparing them to other studies and provide initial policy recommendations. We conclude by summarizing the key results and provide directions for further research.

[2] Croatia is not yet incorporated in the CAPRI farm model.

[3] Currently we have 270 NUTS2 regions in the EU27. The 5% target needs to be realized by all farms in a NUTS2 region. We have chosen this resolution as many agri-environmental programs and greening measure for maintaining grassland of the CAP are evaluated at this regional level.

[4] Below NUTS2 resolution.

[5] An evaluation at the regional level, instead of farm-type level, would result in higher aggregation errors and therefore can hide effects of interest and bias the real CO2 abatement costs.

Table 1
The dimensions of farm-types in the CAPRI model.

i) Type of farming	ii) Economic size class
Specialist cereals, oilseed and protein crops (FT13)	< 16 ESU
General field cropping + Mixed cropping (T14_60)	≥ 16 ≤ 100 ESU
Specialist horticulture (FT2)	> 100 ESU
Specialist vineyards (FT31)	
Specialist fruit and citrus fruit (FT32)	
Specialist olives (FT33)	
Various permanent crops combined (FT34)	
Specialist dairying (FT41)	
Specialist cattle + dairying rearing, fattening (FT42_43)	
Sheep, goats and other grazing livestock (FT44)	
Pig and poultry (FT5)	
Mixed livestock holdings (FT7)	
Mixed crops-livestock (FT8)	

ESU = Economic Size Unit; Each ESU is equivalent to EUR 1200 gross margin.

2. The economic model

To analyse land use, price and production effects, we used the CAPRI model and its farm-type supply module. The model has been recently applied to assess direct payment harmonization in the CAP (Gocht et al., 2013), effects of Rural Development Programmes (RDP) (Schroeder et al., 2015) and effects of CAP greening measures (Zawalińska et al., 2014). CAPRI is a comparative static partial equilibrium model, which iteratively links the farm-type supply modules with the global multi-commodity market module. The 2450 farm-type supply models in CAPRI are representative of the EU27 (Gocht and Britz, 2011). The farm-type module mainly aims to capture heterogeneity within a region in order to reduce aggregation bias when simulating the response of the agricultural sector to policy and market signals, with a specific focus on farm management, farm income and environmental impacts. The farm-type supply model was built from the FADN and the Farm Structure Survey (FSS) data. It consists of independent non-linear programming models for each farm-type, representing the activities of all farms of a particular type and size class. The model captures the premiums paid under the CAP in detail, including nutrient balance (nitrogen, phosphorus and potassium) and a feeding module covering animal nutrient requirements. In addition to the feed constraint, other model constraints relate to arable land and grassland. Grass, silage and manure are assumed to be non-tradable and receive internal prices based on their substitution values and opportunity costs. The farm-types are characterized along two dimensions as depicted in Table 1: (i) 13 production specializations (types of farming) and (ii) three economic farm size classes in terms of Economic Size Units (ESU, equivalent to EUR 1200 gross margin). In total, this leads to 39 possible farm-types. However, as not all farm-types can be modelled in each NUTS2 region, we apply a selection approach that ensures that the selection of farm-types maximizes the representation of the region in terms of Utilized Agricultural Area (UAA) and Livestock Units and that the total number of farm-types included in the model at the EU27 level is not over 2450 (Gocht et al., 2014). The remaining farms (at the NUTS2 level) build up the residual farm-types, which are also represented by a mathematical supply model.

Each farm-type has its own land supply (Gocht et al., 2014) and, thus, its own shadow prices for alternative land uses (agricultural land versus non-agricultural land). The CAPRI model has a GHG emission module (Leip et al., 2010 Pérez-Dominguez et al., 2012), which has been used to assess GHG emissions and to analyse environmental options to mitigate GHG emissions in several studies: Leip et al. (2010) and Weiss and Leip (2012) used a life-cycle approach to assess the contribution of livestock production to GHG emissions in the EU. Leip et al. (2014) assessed the nitrogen footprint of food products, while Shrestha et al. (2013) employed the