INTERNATIONAL CONFERENCE OF AGRICULTURAL ECONOMISTS
ICAE
29th | Milan Italy 2015
UNIVERSITÀ DEGLI STUDI DI MILANO AUGUST 8 - 14
AGRICULTURE IN AN INTERCONNECTED WORLD

Spatially Explicit Evaluation of the Agri-environmental Impact of CAP

Adrian Leip[1], Maria Bielza[1], Claudia Bulgheroni[1,], Pavel Ciaian[2], Matiyendou Lamboni[1], Renate Koeble[1], Maria-Luisa Paracchini[1], Jean-Michel Terres[1], Franz Weiss[1], Heinz-Peter Witzke[3]

[1]European Commission, Joint Research Centre (JRC), Institute for Environment and Sustainability, Ispra (VA), Italy
[2]European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies, Seville, Spain
[3]EuroCARE, Bonn, Germany

A specific challenge when analysing the effectiveness of the new CAP, is to identify the localized environmental impacts of policies, especially of the new 'greening' measures. Agri-environmental indicators (AEI) are routinely used to monitor changes in environmental quality in general and the environmental impacts of CAP greening in particular and allow identifying hot- and cold-spots of environmental pressures. This paper proposes a methodology for the spatially explicit evaluation of agri-environmental impacts of CAP, which allows integrating environmental impact analysis into agro-economic models, with an application to CAPRI. We have developed an approach to estimate the impacts of CAP policy at high spatial resolution level using Bayesian disaggregation procedures taking into consideration local environmental conditions. We cover modelling of the following environmental indicators: nitrogen balances and emissions (GHG and reactive nitrogen), soil erosion, biodiversity friendly farming practices, farmland bird index, agricultural landscape structure, and an indicator related to environmental compensation zones. The paper shows the simulation results for a set of CAP greening scenarios to illustrate the capabilities of the developed methodology and potential environmental impacts of the greening measures.

1 Introduction

Though the Common Agricultural Policy (CAP) expenditure as share of the European Union (EU) budget has substantially decreased over the past three decades, the CAP remains a policy that accounts for 40% of the whole budget. In the EU, agricultural area covers slightly less than half of the territory; therefore the CAP is a policy that can have a major impact on the environment. The concern about its actual and potential impacts has considerably grown since the 1992 MacSharry reform, and the need to monitor and anticipate such impacts has grown alongside. With the adoption of the 2013 CAP reform, the environment concerns received an enhanced focus being materialised by explicitly linking the agricultural support to “agricultural practices beneficial to the climate and environment” (so called *'CAP greening'*). Agro-environmental indicators have been identified as useful tools to perform this task, especially since they allow for the assessment of territorial impacts. The monitoring and evaluation of CAP performance is carried out through indicators (EC 2000, 2006, 2001), that often have a spatial dimension to better account for specificities of European landscapes and regions. But while the overall economic performance of the CAP has been evaluated in prospective terms since the late ‘90s (EC 1998), the ex-ante assessment of environmental impacts has lagged behind, requiring one step further: the translation of CAP provisions into management practices and the assessment of the specific impacts of the latter on environmental media (soil, water, air).

This paper develops methodology for the spatially explicit evaluation of agri-environmental impacts of CAP within the agro-economic CAPRI model. The paper starts with the presentation of a modelling chain that, uses pure agro-economic results from CAPRI model, integrates an environmental component in the model through Bayesian disaggregation techniques of some key variables (crop distribution, yields, livestock density), and allows for the calculation of selected agri-environmental indicators by a combined use of external data sources and environmental modelling. In the subsequent sections the paper shows the simulation results for a set of CAP greening scenarios to illustrate the capabilities of the developed methodology and potential environmental impacts of the greening measures. Finally, the paper discusses the relevance of the selected indicators, methodological challenges and some implications for the CAP greening simulation results.

2 CAPRI model

CAPRI is a comparative static partial equilibrium model for the agricultural sector developed for policy and market impact assessments from global to regional and farm type level. The core of CAPRI is based on the linkage of a European-focused supply module and a global partial equilibrium market module (Britz and Witzke, 2012).

The supply module covers a detailed representation of production activities for EU, Norway, Western Balkans and Turkey. It represents all agricultural production activities and related output generation and input use at regional (NUTS2)[1] or farm type level (Gocht and Britz, 2011).[2] From methodological point of view, the supply module consists of independent non-linear programming models. Each programming model (at NUTS2 or farm type level) optimizes income under economic, environmental and policy constraints. With respect to policy implementation, the different policy instruments of Pillar I and Pillar II of the Common Agricultural Policy (CAP) are depicted in detail for the EU. Prices are exogenous to the supply module and are provided by the partial equilibrium market module.

The global partial equilibrium market module is a spatial, non-stochastic global multi-commodity model for about 50 primary and processed agricultural products, covering about 80 countries or country blocks. It is defined by a system of behavioural equations representing agricultural supply, human and feed consumption, multilateral trade relations, feed energy and land as inputs and the processing industry; all differentiated by commodity and geographical units. On the demand side, the Armington approach (Armington, 1969) assumes that the products are differentiated by origin, allowing the simulation of bilateral trade flows and of related bilateral and multilateral trade instruments, including tariff-rate quotas. This sub-module delivers the output prices used in the supply module and allows for market analysis at global, EU and national scale, including a welfare analysis.

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[1] 280 NUTS2 regions are represented. “Nuts” stands for Nomenclature of Units for Territorial Statistics and refers to the territorial subdivisions of Member States of the EU.

[2] The programming models are a kind of hybrid approach, as they combine a Leontief-technology for variable costs covering a low and high yield variant for the different production activities with a non-linear cost function which captures the effects of labour and capital on farmers’ decisions. The non-linear cost function allows for perfect calibration of the models and a smooth simulation response rooted in observed behavior.

3 Methodology: estimation of environmental indicators

3.1 Estimation of spatially disaggregated environmental indicators

3.1.1 General methodology

The estimation of spatially disaggregated environmental indicators is done in successive steps as illustrated in Figure 1. Briefly, *a priori* shares and associated uncertainty of land for each spatial unit used to grow one of the crops in the CAPRI data base are estimated using external data sources and regional land share models (Kempen *et al.* 2005, Lamboni *et al.* n.d.). These data are processed within CAPRI using regional crop area data and the most likely distribution of crop land is estimated using the Highest Posterior Density (Heckelei *et al.* 2008) approach. Successively, crop yield, irrigation share, and livestock density estimates for each spatial unit and crop are added using previous results. For example, production of fodder in the vicinity of a spatial unit is determining the likeliness of high (or low) livestock densities in this unit. As a last step, the nitrogen (N) budget for each crop-spatial unit combination (or simulation entity, SE, (Leip *et al.* 2011c)) making sure that crop needs plus over-fertilization equals the total input by mineral and organic fertilizer additions, biological N fixation, atmospheric deposition or any other source of N.

The obtained data base is used to calculate a large array of agri-environmental indicators.

Each of these steps is briefly described in the following sections.

3.1.2 Estimating a priori distribution of crops

A priori land use shares are estimated following the approach developed by Kempen *et al.* (Kempen *et al.* 2005, Leip *et al.* 2008, Kempen 2013). The disaggregation procedure is done in two steps. In the first step, the share of a specific crop is regressed on natural conditions (soil, relief, climate) using the information from LUCAS observations points (EC 2003b). The estimated coefficients are then used to predict land use choices in each homogeneous spatial unit (Kempen 2013). The regression is done with a locally weighted binomial logit model, independently for all crops and Corine Land Cover classes (EEA 2000) in each NUTS2 region. The results (means and variances) are probabilities of finding a specific crop at a specific point, which can be interpreted as crop share. Explanatory variables included in the regression were soil type, existence of drainage and stones, slope, elevation, rainfall, and temperature sum over the vegetation period. Discounting of distant LUCAS points was done with a tri-cube weighting function (Kempen 2013).

In a second step, the results from the first steps are constrained to obtain crop areas in each spatial unit that sum-up over all spatial units in the NUTS2 region to the total area of that crop in the region according to data from the Farm Structure Survey 2000 (EC 2003a), and that sum-up over all crops and non-agricultural land in the spatial unit to the total area of the unit. This is done using the Highest Posterior Density approach (Heckelei *et al.* 2008).

3.1.3 Estimating a posteriori distribution of crops in CAPRI

In CAPRI, *a priori* estimates are used and re-constrained to be consistent with the base year regional estimates available in the CAPRI data base. For ex-ante analysis, base year crop shares are used as a priori estimates. With this step-wise approach, CAPRI is able to give estimates of land use change not based on dynamic evolvement of land use pattern, but by determining the most probable distribution of crop shares in space by recovering regional areas, based on a priori probability density functions specific to crop, region and land cover class at different time slices (Britz *et al.* 2011).

3.1.4 Estimating yield and irrigation shares

Estimating yield and irrigation shares is closely interlinked. The area of irrigateable area (EC 2003a, 2008) and the percent of irrigated area estimated by FAO (Siebert *et al.* 2007), that provide data on irrigation shares, are combined with simulations of crop yields under irrigated and rain-fed conditions (Orlandini and van der Goot 2003) which were available for six crops (barley, grain and fodder maize, potatoes, pulses, sugar beet, sunflowers, and soft wheat). Levels of irrigations are thus estimated in consistency with observed aggregated yields per administrative region (Leip *et al.* 2008).

3.1.5 Estimating livestock densities

In the absence of pan-European observations at high spatial resolution, livestock densities were estimated by regressing animal numbers from the Farm Structure Survey (EC 2003a) against crop shares, crop yields, climate, slope, elevation and economic indicators for group of crops as revenues or gross margins per hectare. *A priori* livestock densities are obtained as distance-weighted averages from the regression results (Leip *et al.* 2008). Separate models for land-based livestock (ruminants:

cattle, sheep and goats) and “land-free” livestock (monogastric animals: pig and poultry) are applied together with constraints to recover total animal numbers at the regional level.

3.1.6 Estimating farm management

CAPRI estimates at the NUTS 2 level various nitrogen budgets (Leip *et al.* 2011a, 2011e): the animal N-budget (N in feed intake = N excretion + N retention), the manure N-budget (N excretion = N deposited on grassland + N lost in housing and manure storage + N applied) and the soil N-budget (N crop export = N input by mineral fertiliser and manure + N in atmospheric deposition + biological N fixation + N mineralised from soil organic matter – N lost to the environment). This information is used to estimate farm management in term of nitrogen application at the level of the spatial units. It is assumed here that estimated flow fractions (excretion factor, volatilization factors, emission factors etc.) are constant over the NUTS2 region but that flow rates vary with spatial location as a function of local productivity (with the exception of atmospheric deposition). No re-distribution of nitrogen across different crops is allowed so that the N flows rates per crop type re-aggregate to the regional values.

While total crop N input is proportional to crop N uptake in the spatial unit, the shares of manure, crop residues, and mineral fertilizer application are estimated successively. Manure application rages and manure deposition by grazing animal depend on manure availability that is obtained from the LU density in the current and surrounding spatial units up to a distance of 10 km, as no transport of manure for larger distances is assumed, discounting manure availability of surrounding spatial units with the square root of the distance. However, very large (>250 kg N ha^{-1} yr^{-1}) and very small (<5 kg N ha^{-1} yr^{-1}) manure application rates are not allowed. For crop residues a similar approach is followed accounting for the fact that a part of the crop residues is not left on the field but rather used as bedding material and is thus returned with manure. The remaining N crop need is ‘filled’ up with mineral fertiliser, accounting also for biological N fixation, and taking into consideration minimum shares of N application that must come from mineral fertilizer.

Greenhouse gas and reactive nitrogen emissions from animals and emissions from manure management systems vary according to the density of livestock units (of ruminants or all animal types), whereby conversion of animal heads to livestock units is done using the LU factors from Eurostat. Greenhouse gas and reactive nitrogen emissions from nitrogen input flows (mineral fertiliser, manure, crop residues) are calculated in proportion to the respective flows.

3.2 Estimating agri-environmental indicators

Currently, the following agri-environmental indicators are calculated for each spatial unit: GHG emissions, NH3 emissions, nitrogen balances using different concepts/boundaries (Leip *et al.* 2011a), soil erosion, biodiversity friendly farming practices, agricultural landscape structure, an indicator related to environmental compensation zones, and an energy-output indicator. A farmland bird index is under development.

3.2.1 GHG emissions

GHG emissions are calculated according to IPCC (2006) methodologies and categories. Emission sources considered are (i) CH4 emissions from enteric fermentation; (ii) CH4 and N2O emissions from manure storage and management; (iii) N2O emissions from agricultural soils (Leip *et al.* 2010, Weiss and Leip 2012, Leip *et al.* 2014, Doorslaer *et al.* 2015). N flows in agriculture is calculated according to the MITERRA model (Velthof *et al.* 2009). Emissions of CH4 and N2O are converted to total GHG emissions, expressed in CO_{2eq}, using the Global Warming Potentials of IPCC (2007).

3.2.2 Nitrogen surplus

Soil surface budget (inputs net of all emissions of reactive nitrogen to the atmosphere), soil budget (all inputs net of emissions prior to application), and the land budget (including all gaseous emissions) are calculated on the basis of the assumption that each spatial unit is interpreted as a ‘farm unit’. Currently, N soil stock changes cannot be quantified in CAPRI.

$$NS_{land} = N_{exc} + N_{min} + N_{atm} + N_{biofix} - N_{uptk} - N_{cres} \qquad \textit{Equation 1}$$

$$NS_{soil} = NS_{soil} - E_{hm} \qquad \textit{Equation 2}$$

$$NS_{surf} = NS_{soil} - E_{appl} \qquad \textit{Equation 3}$$

NS_{land} = Land N-budget nitrogen surplus [kg N ha^{-1} yr^{-1}]
NS_{soil} = Soil N-budget nitrogen surplus [kg N ha^{-1} yr^{-1}]
NS_{surf} = Soil surface N-budget nitrogen surplus [kg N ha^{-1} yr^{-1}]
N_{exc} = Nitrogen excretion per UAA [kg N ha^{-1} yr^{-1}]
N_{min} = Mineral N application rate per UAA [kg N ha^{-1} yr^{-1}]
N_{atm} = N input by atmospheric deposition per UAA [kg N ha^{-1} yr^{-1}]
N_{biofix} = N input by biological fixation per UAA [kg N ha^{-1} yr^{-1}]
N_{uptk} = N uptake in harvested crop products incl. grass per UAA [kg N ha^{-1} yr^{-1}]
N_{cres} = N uptake with *net* crop residues removed from the soil per UAA [kg N ha^{-1} yr^{-1}]

E_{hm} = N losses (as N2, N2O, NH3, NOx, and N runoff) in housing and manure storage and management systems per UAA [kg N ha^{-1} yr^{-1}]
N_{appl} = Nr losses (as N2O, NH3, NOx, and N runoff) from the soil surface after application of mineral fertilizer or manure, or manure deposition by grazing animals per UAA [kg N ha^{-1} yr^{-1}]

3.2.3 Risk of soil erosion by water

Risk of soil erosion by water is calculated following the Revised Universal Soil Loss Equation (RUSLE, Renard *et al.* 1997), the indicator predicts the potential average annual rate of erosion on a unit of land based on rainfall pattern, soil type, slope length, crop system and management practices (Equation 4)

$$SEW = K \; x \; LS \; x \; R \; x \; C \; x \; P \qquad \textit{Equation 4}$$

A = potential long term average soil loss [t ha^{-1} yr^{-1}]
K = soil erodibility factor [t·ha·h (ha·MJ·mm)$^{-1}$]
LS = slope length-gradient factor [-]
R = rainfall and runoff factor [MJ·mm ha^{-1} ·h^{-1} ·yr^{-1}]
C = crop-management factor [-]
P = support practice factor [-]

Of these factors, only the crop-management factor is sensitive to CAPRI data, all others have been pre-processed and stored in a database at a resolution of 1 km x 1 km.

The data are aggregated to the regional level by calculating the share of UAA in one of three soil erosion in three classes: <0.5 tons ha^{-1}; 0.5 - <5.0 tons ha^{-1}; >5.0 tons ha^{-1}.

3.2.4 Agricultural landscapes

The indicator for agricultural landscape structure (Paracchini and Capitani 2011) is composed of two dimensions, describing the (i) dominance and internal structure of the agrarian landscape in the context of the wider landscape matrix; (ii) the diversity of the landscape in terms of number of crop categories[3]. Each component is classified in three classes. Then the combination of these classes gives the final landscape indicator class (see Table 1).

The final result is a *qualitative* zoning where the agricultural landscape is dominant and diverse or dominant and characterized by few crops (i.e. rice fields, vineyards, olive groves etc.), as opposed to areas of more mosaic landscapes (i.e. alpine pastures, urban fringe etc.). At the NUTS 2 level, dominance is expressed as the total area of spatial units with at least 50% UAA and diversity is expressed with the Shannon index calculated over the crops *c*.

$$ALS_{div} = -\sum_{A_c>0}\left(\frac{A_c}{A_{UAA}} \cdot log_{10}\left(\frac{A_c}{A_{UAA}}\right)\right) \qquad \textit{Equation 5}$$

3.2.5 Biodiversity-friendly farming practices

The concept of ‘Biodiversity-Friendly Farming Practices’ (BFP) refers to the causality between farming activity and its potential impact on biodiversity. It is closely linked to the concept of High Nature Value (HNV) farmland, but rather than identifying those areas where agriculture supports biodiversity, it scores (in a qualitative way) the degree to which any farming system supports biodiversity, from a lower to a higher degree. BFP is calculated as aggregation of three sub-indicators, related to the main agricultural land uses: arable farming, grassland and permanent crops (see Figure 2). An index is calculated for each agricultural land use through agricultural management intensity (estimated through N input or stocking density) (Paracchini and Britz 2010). For permanent crops, two sub-indices are calculated, giving specific attention to olive groves.

The score for arable land (BFP_a) is the geometric mean of a modified Shannon index [0 to 10] to measure simultaneously changes in crops diversity and evenness in crop distribution (based on 22 crop categories) and an index calculated from the total N input (mineral fertilizer and manure) according to a step-wise decreasing linear function with breaking points at 30 kg N ha;1 yr^{-1} (class 8), 100 kg N ha;1 yr^{-1} (class 5), and 200 kg N ha;1 yr^{-1} (class 1).

The score for grassland (BFP_g) is based on a score calculated from livestock stocking density (LU ha^{-1}) according to a function as shown in Figure 3. HNV conditions are defined if the score is ≥8.

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[3] Aggregation of the 40 crop activities modelled in CAPRI into 19 crop categories relevant from a landscape perspective: cereal, citrus fruits, corn, flowers, fruit orchards, vineyards, grassland, legumes, ligneous/woody, nursery, olive groves, other industrial crops, paddy rice, rapeseed, root crops, sunflower, fibre crops, tobacco, vegetables.

HNV farmland of permanent crops (BFP_p) is normally associated with presence of old trees, permanent vegetative soil cover, and a very low (or zero) use of pesticides and fertilizers. CAPRI can only quantify the effect of N input using the same multistep linear function as for arable crops.

The final aggregated indicator for all three agricultural land uses is obtained by adding the three components on arable crops (a), grassland (g) and permanent crops (p), weighted by their share to UAAA

$$BFP = \sum_{i=\{a,g,p\}} \left(\frac{A_i}{A_{UAA}} \cdot BFP_i \right) \qquad \textit{Equation 6}$$

3.2.6 Environmental compensation zones

The indicator provides information on the proportion of agricultural land that is not currently used for production (as defined by ‘land that was previously set-aside’, fallow land) based on available CAPRI crops nomenclature.

This indicator is a first and imperfect proxy to assess the impact of the ‘Ecological Focus Area’ brought forward by the European Commission as a means of greening Direct Payments under the CAP 2014-2020.

3.2.7 Energy output

Energy content output from agricultural land is associated to the production of food, feed, prunings, and removal of crop residues from cereals (straw) and permanent crops.

3.3 Setting up of the scenario

The 2013 CAP reform introduced significant changes to the implementation of direct payments (DP). A key element of the reform is the introduction of a stronger linkage of the DP to “agricultural practices beneficial to the climate and environment” (so called 'CAP greening'). Member states must assign 30% of their first pillar budget to the 'greening' payment. The farmer only receives the full greening payment if the 'greening' requirements (or measures) are respected.

These requirements include the compliance with a minimum level of crop diversification, the maintenance of permanent grassland and the provision ecological focus area (EFA).

In this paper we consider five scenarios. First we simulate the impact of the three greening measures separately, i.e. the crop diversification (*Crop diver*.), the maintenance of permanent grassland (*Grassland*) and the provision ecological focus area (*Set-aside*). Then we combine all greening measures in one scenario (*Greening all*). Alongside the four policy scenario, we consider reference (baseline) scenario which assumes no change in CAP (i.e. pre-2013 CAP reform is assumed) and is simulated for 2020.[4]

The implementation of *crop diversity measure* in CAPRI was done through the Shannon index using the single farm records from the FADN. This measure targets crop allocations at the farm level due to the strong aggregation bias if regional or country data are used. Regional or country level models are thus not able to model this measure. The reason is that the measure imposes restrictions on land allocation at farm level and its impact is farm specific. CAPRI reduces the aggregation problem through modelling farm types at NUTS2 level. Farm type layer in CAPRI represent aggregated farm groups over large number of individual farms. Hence, basing the analysis of the crop diversity measure solely on the farm type module in CAPRI would still significantly bias the simulated effects downward.

We therefore use single farm FADN records to address the aggregation problem. The single FADN records and farm types in CAPRI are linked through the Shannon diversity index[5]. The Shannon index summarises crop diversity in a single indicator which can be easily transferred from single farm observations in FADN to the regional models in CAPRI. Second advantage is that it captures the effects of both key elements of the crop diversity measure: i.e. the number of crops and (in) equality of crop shares on land. The main disadvantage of this approach is that Shannon index does not link specific crops between individual FADN level and the CAPRI regional models such that the information of which crops are most affected by the measure are lost. More precisely, the link between the FADN and CAPRI was done in two steps.

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[4] The key data sources used to construct CAPRI baseline include *the Prospects for Agricultural Markets and Income in the EU*, published yearly by DG Agriculture and Rural Development (DG ARGI), historical trends, and expert information.

[5] For percentages of crops i in total land p(i) the Shannon index is – Si p(i) * ln(p(i)), see Gallego J., Escribano P., Christensen S., 2000, Comparability of landscape diversity indicators in the European Union, pp 84-97, http://ams.jrc.it/publications/pdfs/diversityCORINE_MARS.pdf

In the first step, a land optimization model was run for each FADN farm unit to simulate the land allocation effect of the crop diversity measure. The objective function of the optimization model represents the minimization of the square difference between the actual arable crop area and the simulated area subject to crop diversity constraints (i.e. minimum 3 crops requirement, upper thresholds of crop shares) and land endowment constraint. Then, the Shannon index was calculated for both actual land use data and the simulated results. The difference between the actual and the simulated values of the Shannon index represents the land allocation adjustments that farms need to undertake to fulfil the crop diversity requirements.

In the second step, the difference between the actual and the simulated Shannon index obtained in the first step was introduced as a land use constraint in the NUTS2 models of CAPRI. For each of them, crop diversity measure is introduced as an adjustment of arable crop area represented through conditioning land allocation to be in line with the crop diversity as indicated by the simulated Shannon index relative to the baseline level of the Shannon index.

The *permanent grass* land area to maintain was specified as the average between the base year (average for 2007-2009) and the 2020 baseline value. In this way it is expressed that the greening policy should reduce the loss of grassland compared to the reference run.

The *ecological focus area* was set at 5% of the arable area. Only set-aside and fallow land were considered for the ecological focus areas. We did not account for other type of land eligible as ecological focus area (e.g. terraces, buffer strips), hence the effect of this scenario will likely overestimate the actual effect.

4 Results

We present the results for the indicators that are calculated at NUTS 2 level (i.e. GHG and NH3 emissions, N budget, and Shannon Index) for scenarios calculated for each greening element separately (crop diversification, grassland, ecological focus area) and for all greening elements simulated in one scenarios synchronously (greening all)[6]. The indicators calculated only at the HSMU level are presented for the greening all-scenario only[7].

Overall, the all-greening scenario had largest impact on the level of set-aside and fodder activities maintaining total cattle population almost constant, which affected almost exclusively beef cattle

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6 As explained above, this scenario considers all three greening measures: crop diversification, grassland, ecological focus area.

[7] Baseline *res_2_0420tstcal_HPW*.gdx, scenario *res_2_0420MTR_GREEN_birdindex*.gdx, May 2013.

for EU27. Variations across countries were large though, with some countries also decreasing set-aside areas.

Table 2 and Table 3 show relevant input data expressed per ha (Table 2) or in absolute terms (Table 3). Input of nutrients generally decrease with the decrease of crop production and thus nutrient export, similarly to use of electricity, gas and other fuels, and the consumption of pesticides. Accordingly, also the N surplus decreases, albeit to a lesser degree than the nutrient export with crop products. As such, the greening measures lead to a slight extensification, increasing (very slightly) the nutrient surplus per kg of crop product exported from agricultural land.

Table 4 and Figure 6 show the split of emission contributing to the total N surplus, which show higher decreases of emissions linked to mineral fertilizer inputs, and details on changes of GHG emissions. Generally, the grassland and crop diversification scenarios show only little impact on the indicators, with largest contribution coming from the set-aside element, which remains as expected still below the greening all scenario in terms of effect.

Table 5 reports the Shannon diversity indicator at MS level and aggregated for EU27. Surprisingly the simulated crop diversity impacts appear to be largest for the set-aside scenario likely driven by the expansion of land set-aside which contributes to crop diversity to a larger extent than the actual crop diversification requirement (i.e. crop diversification scenario). The grassland scenario reduces crop diversity. The overall impact of CAP greening (Greening all) is an improvement of crop diversity at EU level by 1%, while at MS level the change varies between 0% and 9%.

Table 6 shows selected agri-environmental indicators calculated at EU27 level, at MS level and at NUTS2 level. Spatial heterogeneity is very large. In particular for the environmental compensation zones, some NUTS2 regions with a very low initial level of ECZ show a very large increase at country or regional level. Overall, the simulation results indicate a small but positive overall trend with highest impact for the ECZ (+8%) and a decrease of soil erosion of approximately -2%. Some regions (25) show also an increase in potential soil losses by water erosion, while 195 NUTS2 regions show a decrease.

5 Discussion

5.1 Relevance of the indicators

Agri-environmental indicators are used as an alternative to the direct measurement of the impact of agriculture on the environment (Bielza *et al.* 2015). Frameworks of agri-environmental indicators include the state-response-models (OECD 1998), indicators sets based on intervention logic to capture the causal chain from the budgetary input to the impact and preliminary used for the evaluation of policies (such as the CAP), Life Cycle Impact Assessment (e.g. Goedkoop *et al.* 2013), or ecosystem assessment frameworks (Millennium Ecosystem Assessment 2003).

The agri-environmental indicators described here have been selected on the basis of relevance for current policy evaluation system, thus on the basis of indicator sets defined on the basis of intervention logic.

The most relevant sets include:

- The Common Monitoring and Evaluation Framework (CMEF, DG AGRI 2006), developed for the evaluation of the impact of the CAP in the 2007-2013 CAP programming period, in particular for the rural development interventions. For the new programming period 2014-2020, a new Monitoring and Evaluation framework (M&E) for the mandatory assessment of the entire CAP (both pillars) is mandatory is under definition (EC 2014).
- OECD in cooperation with Eurostat and FAO has developed a comparative set of agri-environmental data which allows describing the current state and trends of the environmental conditions in agriculture across 34 OECD countries for the period 1990-2010 (OECD 2013).
- Based on the adoption of 28 agri-environmental indicators to assess the interaction between the CAP and the environment (EC 2006), Eurostat maintains a set of agri-environmental fact sheets developed and compiled by various institution of the European Union.

Table 7 gives an overview of the indicators and their relevance for this three sets of agri-environmental indicators.

5.2 Methodological challenges

5.2.1 Update of a priori land use shares

The agricultural land use map that is currently providing the *a priori* crop shares for the spatial units is based on data that centre around the year 2000. With the current base year of CAPRI (2008) it is likely that the a priori shares used in the analysis are not fully accurate. Lamboni *et al*.(n.d.) propose an update of the method developed by Kempen *et al.* (2005, Leip *et al.* 2008) based on land use data centred around the year 2008 (Corine 2006, LUCAS 2009) and thus closer to the current CAPRI base year. The method distinguishes itself from the Kempen-method mainly by applying multinomial logit models for each NUTS 2 region; by using Corine land cover classes as explanatory variables rather than developing models for different Corine LC classes/NUTS 2 combinations; by constraining agricultural land for each spatial unit by land not available for agriculture (forests, large urban areas, water bodies and bare soils) (Leip *et al.* 2011d); by using an updated version of spatial units (HSU; Leip *et al.* 2011d); by using a different algorithms to defining the optimum 'bandwidth' (selecting the LUCAS points that are considered for each multinomial logit model). Model parameters estimated in a first step are calibrated with a Bayesian approach exploiting the availability of medium-scale data (NUTS3) from the FSS 2010 data base. The model has shown to satisfactory predict all major crops, but predictions of less frequent crops in a NUTS still need to be improved before the data can be used as *a priori* data for CAPRI disaggregation. Lamboni *et al*.(n.d.) already suggest a few improvements to the model, i.e. by introducing biophysical constraints to the presence of crops (e.g. flat area for rice, maximum altitude for cereals, etc.) or to relax the condition for selecting LUCAS points to increase the variance in the data used for model generation in each NUTS2 region.

5.2.2 Yield

The spatial distribution of crop yield is currently based in CAPRI on simulations that have been carried out for each Soil Mapping Unit (SMU) for six crops under water limited (rain-fed) and irrigated (potential yield) conditions. However, the yield-water availability relationship is rarely linear, so a substitution of the dual set of data with multi-point crop water response curves is likely to improve the estimates of irrigation shares and yields.

5.2.3 Soil stock changes

Carbon in above and belowground biomass and soil carbon are important pools for carbon and have the potential to significantly influence the net anthropogenic CO2 emissions. Land use and land management are often associated with ‘typical’ levels in carbon stocks, and land use and land management changes lead thus to changes in carbon stocks. Usually losses of carbon occur at a higher rate than the accumulation of carbon, but often an equilibrium time of 20 years is assumed (IPCC 2006). Factors such as climate, tillage (full, reduced, no-till), land use (permanent crop, annual crop, set-aside, grassland or forest land) input level of carbon with crop residues and manure are important factors determining the equilibrium level of carbon in the soil (IPCC 2006). Some processes such as degradation of organic material in organic soils and accumulation of carbon in permanent and well managed grasslands can span over a long time period and might be considered as being related to land use rather to land use change, with respect the time periods considered in most studies (Soussana *et al.* 2007, 2009, Weiss and Leip 2012, Lugato *et al.* 2014a). Soil organic matter is beneficial for soil fertility, increasing soil moisture retention capacity, improving soil structural properties and beneficial for soil biological activity; measures to increase soil organic matter and thus soil organic carbon are considered positive even though some technologies such as no-till still need to prove their effect on the carbon levels and the reduction of the net GHG emissions (Velthof *et al.* 2011, Powlson *et al.* 2014). Measures that help accumulating SOM in soils or that reduce SOM depletion will be significant elements in climate change mitigation strategies for the agriculture sector. Quantification of soil carbon stock changes with the IPCC (2006) methodology can provide first estimates.

Changes of SOM are also potentially important for the N soil budget; under European conditions, changes of soil N stocks are often considered to be small with respect to total N input and output flows. However, Özbek and Leip (2015) have shown that this does not hold for Turkey, where regions with extensive agriculture suffer soil N depletion while areas of intensive agriculture experience accumulation of SOM and soil N. A quantification of soil N stock changes in CAPRI, for example based on the approaches suggested by Özbek and Leip (Özbek and Leip 2015).

5.2.4 Improving flow of carbon through the agricultural system

Using IPCC (2006) methodology to estimate C stock changes has the drawback that generic factors for land use and land management are largely insensitive to the drivers that are quantified in the

CAPRI model. Figure 4 illustrates schematically the flow of C through agricultural systems. In comparison to the flow of N through agricultural systems, C turnover is characterized by very large flows at a short (daily) cycle: photosynthesis converting atmospheric CO2 with the help of sun energy, and respiration (of plants, animals, bacteria and fungi) when the energy is made available for the organisms (SCHULZE *et al.* 2010). Changes in soil C stocks – or the net ecosystem carbon balance (NECB) – depend on the quantity and quality of organic C inputs, the net primary production (NPP, photosynthesis – autotrophic respiration), loss pathways to the hydrosphere by leaching and erosion, to the atmosphere by release of volatile organic compounds or by fire, heterotrophic respiration and harvest of biomass (Ciais *et al.* 2010). Most of the flows though can be captured on the basis of data available to CAPRI with the exception of two flows: rhizodeposition and soil respiration. Rhizodeposition is the release of organic material from root to the soil matrix, due to various processes (Jones *et al.* 2009, Kuzyakov and Domanski 2000). Soil respiration is the outcome of SOM mineralization, releasing nutrient and minerals (being thus available for plant uptake, Janzen 2006) and returning CO2 to the atmosphere (Schlesinger and Andrews 2000, Raich and Tufekciogul 2000). Changes in soil C stocks – or the net ecosystem carbon balance (NECB) depend on the quantity and quality of organic C inputs, and farm management (e.g. tillage, crop type and rotation) and environmental (e.g. temperature, precipitation, soil characteristics) conditions and need to be estimated with process-based models (such as the CENTURY or RothC models, Lugato *et al.* 2014b, Falloon and Smith 2002, Gottschalk *et al.* 2012).

5.3 Interpretation of spatially disaggregated data

Even though many indicators are driven by fine-grained variables such as soil-weather-management combinations it is not always adequate to perform quantification of agri-environmental indicators at high spatial resolution. First, in many cases the availability of observations to develop spatially is scarce. Leip *et al.* (2011b) showed that for the estimation of sub-continental N2O emissions from agricultural soils in Europe, the use of empiric or process-based models does not improve the match to independent (top-down) estimates compared to using default IPCC emission factors, but process understanding remains important for the assessment of mitigation measures or identifying emissions hotspots. However, the need of spatial analysis might arise also from a policy perspective (‘intervention logic’) and the spatial distribution of relevant activity data (in combination with emission factors) becomes at least as important as the spatial distribution of emission factors themselves. To this aim, the use of existing (but confidential) data to improve the spatial distribution of farms and their activities (Gocht and Röder 2014, Röder and Gocht 2013) remains a priority.

There are three main motivations to go through the effort of dis-aggregating environmental drivers to high spatial resolution to estimate agri-environmental indicators:

1. For several indicators (such as potential for soil erosion, landscape structure) an assessment at aggregated scale is meaningless as the environmental impact is non-linear or asymmetric, so that the aggregated impact cannot be predicted at the aggregated scale directly.
2. Often, information on the *distribution* of the environmental impact in space is more relevant that the average value and the identification of hot or cold spots using percentiles, shares of activities (area, livestock heads, applied mineral fertilizer etc.) above/below certain impact thresholds or just the shape of the distribution (homogeneous, multimodal, etc.) can give important hints for defining adequate policies (see Figure 5).
3. Many environmentally relevant policies are most efficiently defined at a spatial level which is different than the administrative level; this can be protected areas, areas delimited by natural borders (e.g. watersheds), areas with natural constraints, etc.

5.4 Greening of the CAP

The limited positive impact of the greening scenarios showed in previous section is mainly due to modest improvements in intensive cropping areas and in livestock farming regions. For example, in intensive cropping areas a decrease in the area for crops requiring high N fertilisation rate (wheat, maize) is expected, together with a larger area for ecological focus area (with no or lower fertiliser application). In livestock farming regions, a smaller number of animals will lead to a lower production of N from manure (beef meat activities -190.000 hds, -1.1%; pigs -680.000 hds, -0.25%; and sheep and goat -587.000 hds, -0.5%) which can be spread on a larger grassland area (+1.2m ha, +2.1%). On the opposite extreme, there are some regions where there is an increase of N soil surplus balance after the greening scenario. This is the case of Aragon (+1.56%), where a larger cereal area is expected (+3%), in particular of barley and wheat (+640.000 ha), which comes from a reduction of set-aside and fallow surfaces (-650.000 ha, -7.5%). The reason behind this is unclear but could be to comply with the crop diversification requirement and the definition of a “crop” used in these CAPRI simulations.

Figures 7-9 show some results at high spatial resolution, zoomed for illustration into individual countries. For example, Figure 7 shows the N surplus balance for Belgium at NUTS2 and HSMU level respectively. The Greening measures globally show a limited positive impact on Biodiversity-friendly farming practices. Most of the EU27 area would be affected by a slight change in between -2 or +2 in the 1-10 BFP index. Spain shows a mixture of both, with bigger changes. As can be observed in Figure 8 (right panel), the general trend is consistent with the EU trend, i.e 90% of the UAA has changes between -2 and +2. However, 5% of Spanish HSMU shows a decrease in BFP (< -2 points) and 2.3% of HSMU shows an increase in BFP (> +2 points). The decrease in BFP is due to an increase in arable land (cereals, oilseeds, fodder and other arable). Given that the UAA does not increase, this arable land increase is produced by the reduction of setaside and grassland. Bigger arable land areas mean also more N-input, which affects negatively the BFP. This also applies at NUTS2 level for regions with the strongest BFP decrease: there is an increase in arable crops in general, and in particular oilseeds (in the eastern regions of Murcia and Comunidad Valenciana) and secondarily cereals.

The up-scaled BFP is an average BFP calculated on the total UAA at NUTS2 level. It is useful for policy assessment but it loses the added value of the detailed scale and the link with biophysical and local environmental conditions. This can be observed by comparing Figure 9 (left and right panel). Figure 9 shows that globally, greening measures results in an increase in FBP, with an increase of more than 2 points in all regions in Spain. However, this global view ignores the fact that in some areas BFP can even disappear (decreases from -5.00 to -9.99 points in Figure 9).

6 Conclusion

The CAPRI spatial modelling framework can offer illuminating insights for providing policy-relevant assessment on the environmental impact of agricultural production and agricultural policy. Spatial processing of data is indispensable for several agri-environmental indictors and provides important ancillary information for others to help in the policy decision process. In particular, spatially disaggregated data can provide essential information if peak emissions rates are to be targeted rather than (national) totals. In particular it is possible now to assess the percentage of such critical threats in larger regions, rather than reporting the regional average result on some indicators only. Yet, efforts have to continue to improve the accuracy of the high resolution data sets.

The EU wide provision of spatially disaggregated environmental results from the CAPRI model may be considered an important achievement form various angles, against the alternative approach to run small scale assessment that may certainly go into depth in their case study region and optimally adjust to the regional data availability.

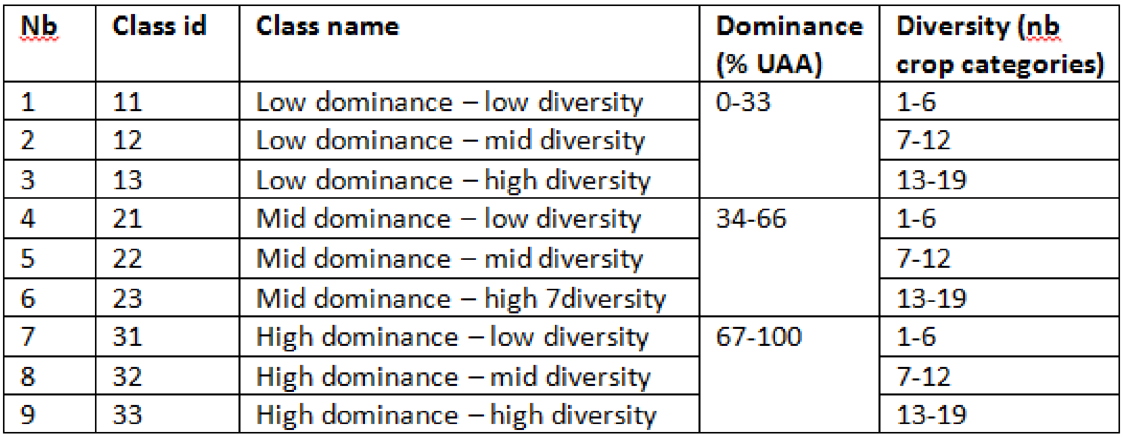
- Completeness: coverage of the whole EU are is an evident benefit from the policy making perspective
- Comparability: Even though the accuracy in single regions may be questioned a key benefit is its reliance on standardised estimation procedures that permit to identify regional differences beyond the differences introduce by specific regional data sources or case study methodologies
- Embedding of the scenarios in an EU wide and in fact global modelling effort (as CAPRI also covers non-EU market regions) ensures that regional scenario results are fully consistent up to the market level.

Disclaimer

The authors are solely responsible for the content of the paper. The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Parliament or the European Commission.

Tables and Figures

Table 1. Classification of land dominance and crop diversity for the agricultural landscape indicator



Nb	Class id	Class name	Dominance (% UAA)	Diversity (nb crop categories)
1	11	Low dominance – low diversity	0-33	1-6
2	12	Low dominance – mid diversity		7-12
3	13	Low dominance – high diversity		13-19
4	21	Mid dominance – low diversity	34-66	1-6
5	22	Mid dominance – mid diversity		7-12
6	23	Mid dominance – high 7diversity		13-19
7	31	High dominance – low diversity	67-100	1-6
8	32	High dominance – mid diversity		7-12
9	33	High dominance – high diversity		13-19

Table 2. Input use in EU27 (% change relative to baseline)

	Mineral Fertilizer Consumpt., N [kg N/ha]	Mineral Fertilizer Consumpt. P [kg P_2O_5/ha]	Consumption of Pesticides [Euro /ha]	Energy, Electricity [Euro/ha]	Energy, Gas [Euro/ha]	Energy, Fuels [Euro/ha]	Crop/livestock pattern, grass land density – [ratio]
Crop diver.	-0.22	3.43	-0.02	-0.12	0.07	0.03	-0.37
Grassland	-0.21	3.45	-0.18	-0.05	-0.01	-0.04	1.78
Set-aside	-1.54	2.93	-0.84	-1.34	-0.03	-0.79	-0.69
Greening all	-1.97	2.55	-1.15	-1.49	-0.08	-0.88	1.23

Table 3. Gross Nutrient (NPK) budgets (GNB) in EU27 (% change relative to baseline)

		Input with mineral fert.	Input with manure (excret)	Input with crop residues	Biol. N fixation	Atm. N depos.	Nutrient export (crop products)	Surplus total
Crop diver.	N [1000 t N]	-0.26	-0.34	-0.34	0.35	-0.03	-0.27	-0.28
	P [1000 t P2O5]	-0.17	-0.26	-0.26			-0.22	-0.25
	K [1000t K2O]	-0.07	-0.37	-0.25			-0.25	-0.32
Grassland	N [1000 t N]	-0.21	-0.24	0.09	-0.23	-0.01	-0.14	-0.15
	P [1000 t P2O5]	-0.20	-0.18	0.08			-0.12	-0.09
	K [1000t K2O]	0.49	-0.26	-0.10			-0.04	-0.11
Set-aside	N [1000 t N]	-1.44	-0.83	-1.13	-2.00	0.01	-1.22	-0.89
	P [1000 t P2O5]	-1.41	-0.69	-1.11			-1.16	-0.62
	K [1000t K2O]	-1.49	-0.86	-1.43			-1.27	-0.93
Greening all	N [1000 t N]	-1.78	-0.89	-1.08	-1.18	0.07	-1.40	-0.93
	P [1000 t P2O5]	-1.68	-0.75	-1.07			-1.33	-0.52
	K [1000t K2O]	-1.23	-0.93	-1.66			-1.38	-0.89

Table 4. Nitrogen Surplus in EU27 (% change relative to baseline)

	Crop diver.	Grassland	Set-aside	Greening all
N-Surplus total (1000 t)	-0.28%	-0.15%	-0.89%	-0.93%
Gaseous N-losses from mineral fertilisers (1000 t)	-0.16%	-0.19%	-1.30%	-1.55%
Gaseous N-losses from manure (1000 t)	-0.25%	-0.13%	-0.66%	-0.71%
Run-off of N from mineral fertilizer (1000 t)	-0.24%	-0.24%	-1.41%	-1.70%
Run-off of N from manure (1000 t)	-0.28%	-0.15%	-0.64%	-0.70%
N Surplus at soil level (1000t N,P2O5,K2O)	-0.30%	-0.14%	-0.91%	-0.90%

Table 5. Shannon diversity index (% change relative to baseline):

	Crop diver.	Grassland	Set-aside	Greening all
EU-27	0.26	-0.26	1.04	1.00
Belgium	0.34	-0.37	2.55	2.22
Denmark	1.36	-0.01	-0.05	1.82
Germany	0.22	-0.45	2.53	1.96
Austria	0.13	-0.36	1.38	1.00
Netherlands	0.46	-0.34	2.36	2.38
France	0.39	-0.22	1.61	1.49
Portugal	0.50	0.12	0.91	1.40
Spain	0.47	-0.02	0.18	1.15
Greece	0.62	-0.03	0.27	1.09
Italy	0.78	-0.09	0.79	1.63
Ireland	1.25	-0.83	3.00	2.75
Finland	0.63	0.01	0.09	2.20
Sweden	0.82	0.18	0.89	2.14
United Kingdom	1.60	-1.05	0.75	1.75
Czech Republic	0.14	-0.07	2.07	2.03
Estonia	0.41	-0.31	1.65	1.74
Hungary	0.50	-0.02	0.85	1.36
Lithuania	0.30	-0.35	2.71	2.23
Latvia	0.41	-0.38	0.60	0.92
Poland	0.25	-0.13	1.54	1.50
Slovenia	0.11	-0.36	2.65	1.85
Slovak Republic	0.06	-0.40	2.30	1.86
Cyprus	0.81	-0.01	0.23	4.88
Malta	1.10	-0.02	-0.11	8.76

Table 6 Impacts of greening measure on environmental indicators from 2020 baseline scenario (% change)

Indicator	EU27 average impact	MS maximum positive impact	MS maximum negative impact	NUTS2 maximum positive impact	NUTS2 maximum negative impact
Biodiversity friendly farming index	0.7	6.4	-1.0	17.9	-5.6
Soil erosion average loss per ha	-1.5	0.1	-4.7	30.7	-33.4
Soil erosion total loss	-1.8	0.1	-4.7	30.7	-33.4
Environmental Compensation Zones: share ECZ/arable land	8.2	1046	-10.0	5734	-30.8
Environmental Compensation Zones: share ECZ/UAAR	7.7	890	-7.9	5566	-16.7
Agricultural landscape: dominance	0.4	7.4	-1.9	63.1	-6.0
Agricultural landscape: shannon diversity index	0.4	2.6	-0.2	10.4	-1.4

Table 7. Relationship of environmental indicators calculated in CAPRI at high spatial resolution with three main sets of agri-environmental indicators

	CMEF[8]	OECD[9]	Eurostat[10]
Greenhouse gas emissions	Baseline 26: Climate change/air quality: greenhouse gas emissions from agriculture	IV. Environ. Impacts of agriculture-4: Greenhouse gases; *Gross agricultural greenhouse gas emissions*	AEI 19 - Greenhouse gas emissions (pressure). Main indicator: GHG emissions from agriculture (kilotonnes of CO2 equivalents per year); Supporting indicator: Share of agriculture in total GHG emissions
Nutrient surplus	Baseline 20: Water quality: Gross Nutrient Balances	III. Use of farm inputs and natural resources-1. Nutrient use: *Nitrogen balance, Nitrogen efficiency*	AEI 15 - Gross nitrogen balance (pressure). Main indicator: Potential surplus of nitrogen on agricultural land (kg N per ha per year); Supporting indicator: -
Risk of soil erosion by water	Baseline 22: Soil: Areas at risk of soil erosion	IV. Environ. Impacts of agriculture-1. Soil quality: *Risk of soil erosion by water, Risk of soil erosion by wind*	AEI 21 - Soil erosion (pressure). Main indicator: Areas with a certain level of erosion; Supporting indicator: Estimated soil loss by water erosion (tonnes per ha per year)
Agricultural landscape	-	IV. Environ. Impacts of agriculture-1.Landscape. *Structure of landscapes; Landscape management; Landscape costs and benefits*	Proxy for: AEI 28 - Landscape – state and diversity (state). Main indicator: Dominance and internal structure of agrarian landscape; Degree of influence on land cover and state due to human (agricultural) activities; Social awareness of the agrarian landscape Supporting indicator: -
Biodiversity friendly farming practices	Baseline 18: Biodiversity: HNV farmland and forestry’	IV. Environ. Impacts of agriculture- 6 Wildlife Habitats: *Intensively-farmed agricultural habitats; Semi-natural agricultural habitats*	AEI 23 - High nature value farmland (state). Main indicator: Share of estimated HNV farmland on total UAA; Supporting indicator: Estimated area of HNV farmland
Environmental compensation zones	-	IV. Environ. Impacts of agriculture- 6 Wildlife Habitats: *Semi-natural agricultural habitats*	-
Energy output	-	IV. Environ. Impacts of agriculture- 6 Wildlife Habitats: *Intensively-farmed agricultural habitats;*	-

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[8] http://ec.europa.eu/agriculture/rurdev/eval/guidance/note_f_en.pdf

[9] http://www.oecd.org/agriculture/sustainable-agriculture/1890235.htm

[10] http://ec.europa.eu/eurostat/web/agri-environmental-indicators/indicators-overview

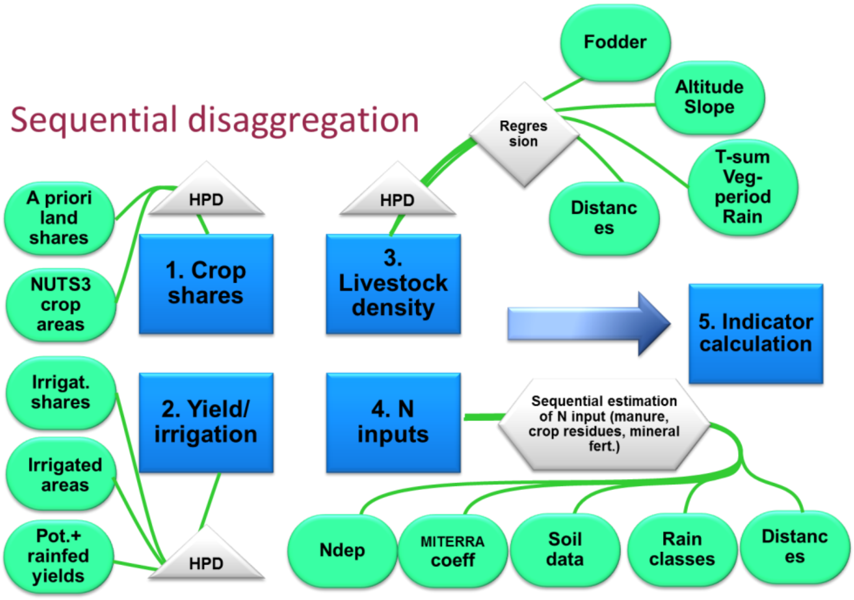

Figure 1. General schematization of the disaggregation of CAPRI regional data for the calculation of agri-environmental indicators at high spatial resolution

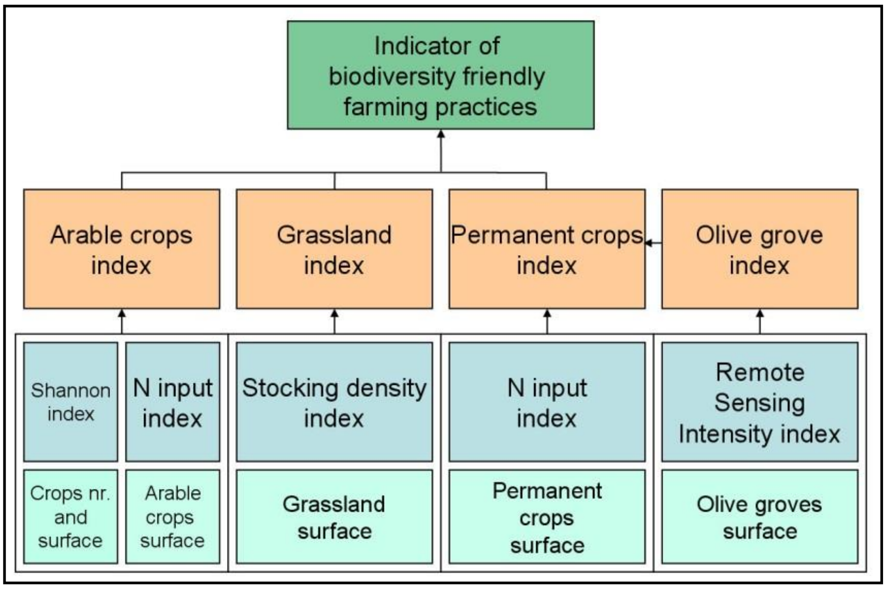

Figure 2. Composition of the Biodiversity Friendly Farming Indicator

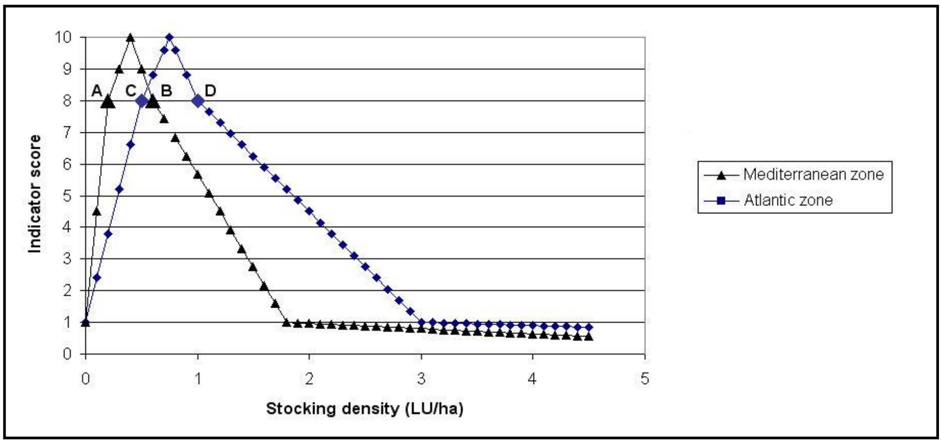

Figure 3. BFP_g score as a function of stocking density for Mediterranean and Atlantic climate conditions.

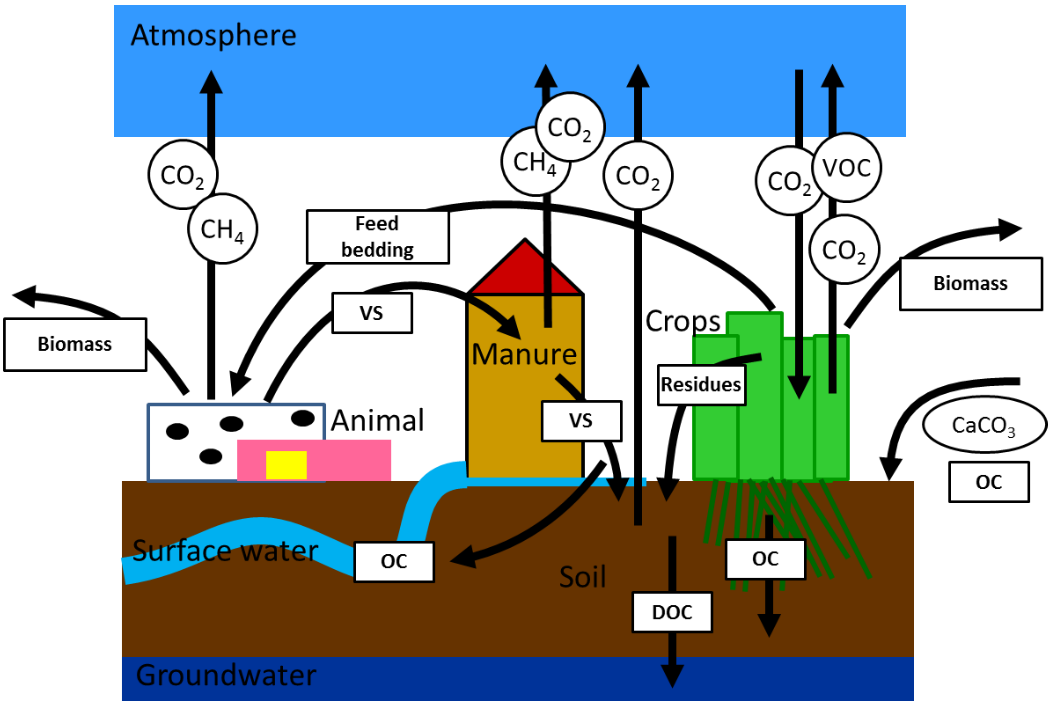

Figure 4. Schematization of the flow of carbon in agriculture. Acronyms: VS: Volatile Solids; OC: organic carbon; DOC: dissolved organic carbon

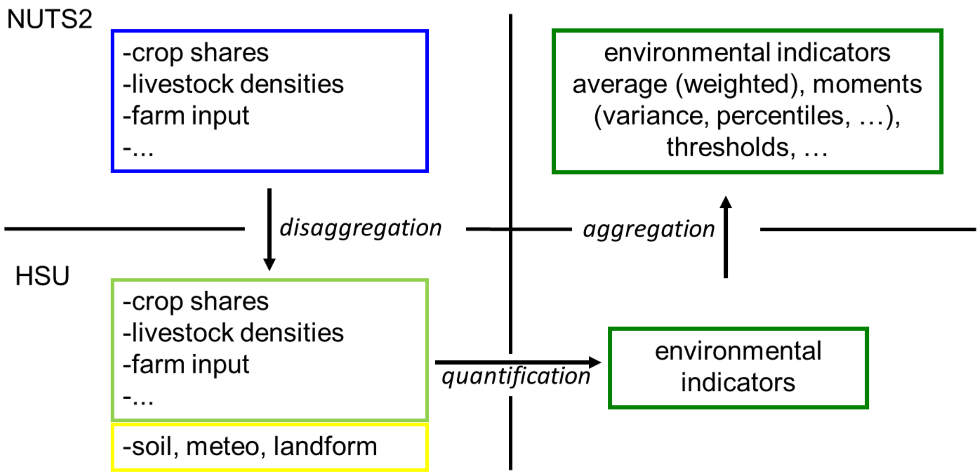

Figure 5. Flow of information

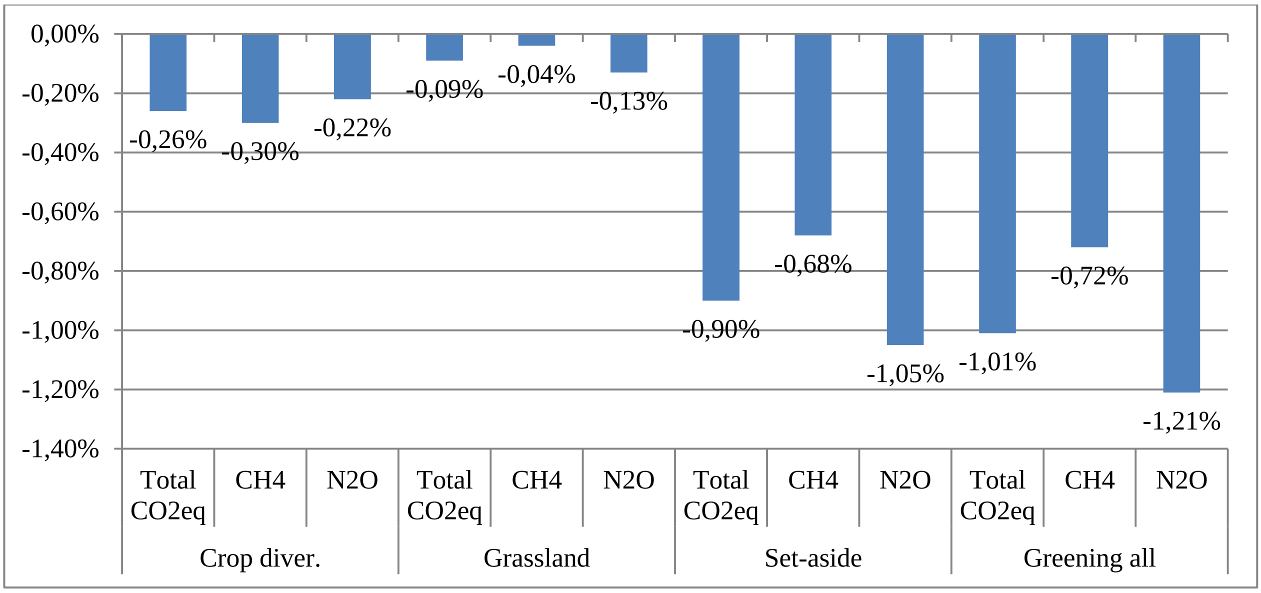

Figure 6. CO2 emissions in EU27 (% change relative to baseline)

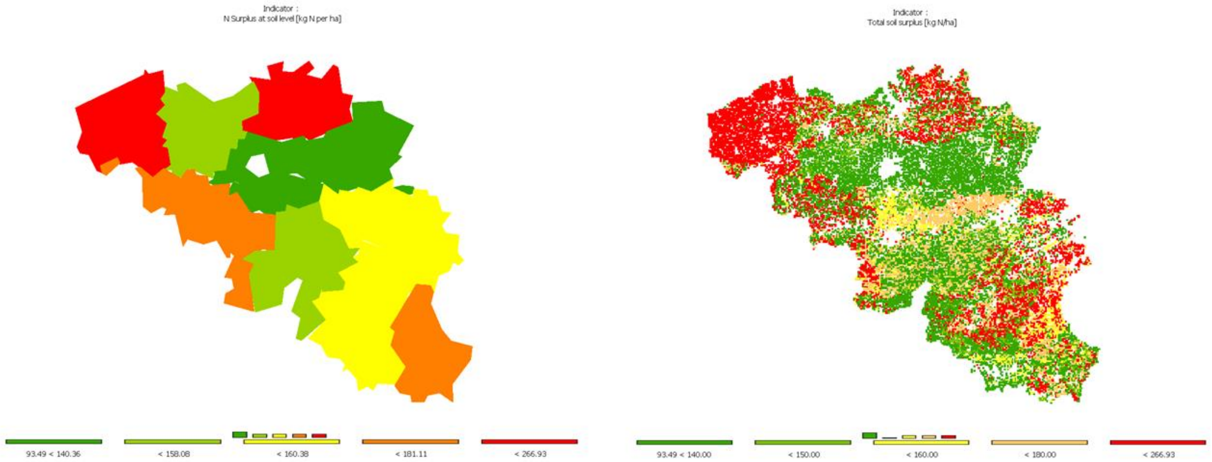

Figure 7 Left: N surplus balance per NUTS2 in Belgium. Right: N surplus balance per HSMU in Belgium

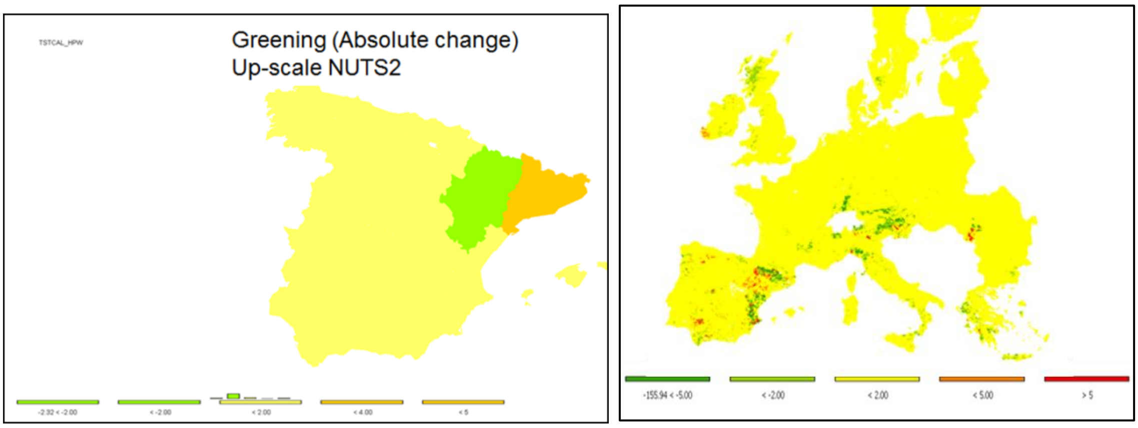

Figure 8 Left: Absolute change of soil erosion in Spain by NUTS2 region. Right: Absolute chaneg in soil erosion in Europe per HSMU.

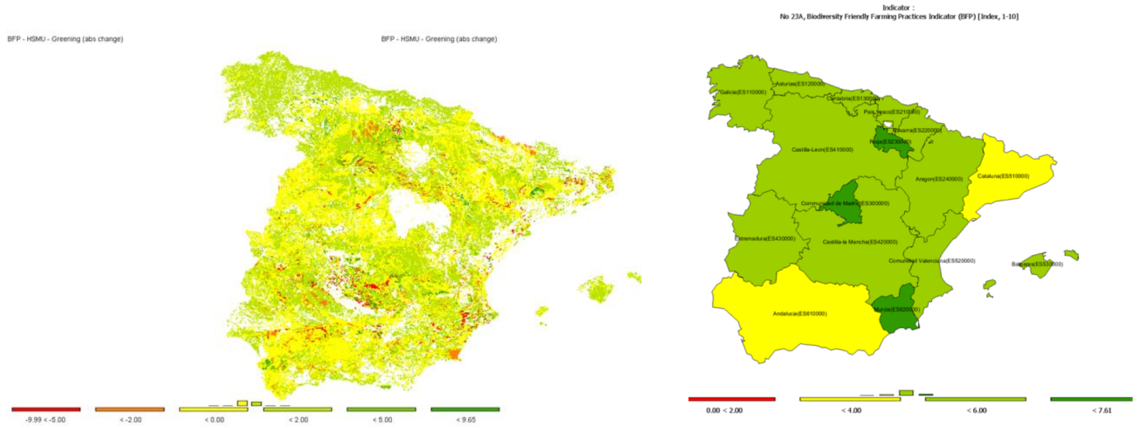

Figure 9 Spain – Greening effect on FBI at HSMU. Right: Spain – greening effect on FBI at NUTS2

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