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Setting Climate Action as the Priority for the Common Agricultural Policy: A Simulation Experiment

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Abstract

We quantitatively assess the impacts of re-allocating budgetary resources within Pillar 1 of the EU's Common Agricultural Policy (CAP) from direct income support to a direct greenhouse gas (GHG) reduction subsidy for EU farmers. The analysis is motivated by the discussion on the future CAP, with calls for both an increased ambition on climate action from the agricultural sector and for a more incentive-based delivery system of direct payments under strict budgetary restrictions. By conducting a simulation experiment with an agricultural partial equilibrium model (CAPRI), we are able to factor in farmers' supply and technology-adjusting responses to the policy change and to estimate the potential uptake of the GHG-reduction subsidy in EU regions. We find that a budget-neutral re-allocation of financial resources towards subsidised emission savings can reduce EU agricultural non-CO_2 emissions by 21% by 2030, compared to a business-as-usual baseline. Two-thirds of the emission savings are due to changes in production levels and composition, implying that a significant part of the achieved GHG reduction is offset globally by emission leakage. At the aggregated level, the emission-saving subsidy and increased producer prices compensate farmers for the foregone direct income support, but differences in regional impacts indicate accelerated structural change and heterogeneous income effects in the farm population. We conclude that the assumed regional budget-neutrality condition introduces inefficiencies in the incentive system, and the full potential of the EU farming sector for GHG emissions reduction is not reached, leaving ample room for the design of more efficient agricultural policies for climate action.

Keywords: *CAPRI model*; *climate action*; *Common Agricultural Policy*; *emission leakage*; *emission saving subsidy*.

JEL classifications: *Q11, Q13, Q18*.

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1. Introduction

Following an extended public consultation, in November 2017 the European Commission published a communication on the Future of Food and Farming (COM (2017)713), reflecting on its vision for the future of the Common Agricultural Policy (CAP). Although the communication does not go into detail regarding future policy options, it identified higher environmental and climate action ambitions among the top priorities of the CAP post-2020, and set the scene for the upcoming CAP reform (European Commission, 2017). The policy concept of the communication must be evaluated in the wider context of the Multiannual Financial Framework (MFF), which is negotiated in parallel with the review and modernisation of EU agricultural policies, and which determines the financial resources allocated to the CAP. The budgetary pressure on agricultural policies has increased with new challenges for the EU, such as common defence policy and migration, and the exit of a net contributor to the budget in 2019. As a result, the Commission's MFF proposal from May 2018 foresees a 6% reduction in nominal terms for the CAP budget for the next financial period 2021–2027 (European Commission, 2018a,b). Despite the unfavourable budgetary prospects, the Commission's communication as well as the legal proposal for the new CAP, published in June 2018, remain ambitious in improving all three sustainable development dimensions of the CAP: social, economic and environmental (European Commission, 2018c). Accordingly, the Commission's CAP proposal aims to provide more benefits with less budget spending.

Currently, the greening architecture of the CAP is supposed to ensure increased environmental services from farming activities, based on a combination of cross-compliance conditions for direct payments, a greening top-up and voluntary agri-environmental schemes. The greening architecture, however, is about to be replaced in the future CAP, and member states will have flexibility to tailor their national CAP implementation by choosing from a list of mandatory and optional voluntary measures (European Commission, 2018c). This increased flexibility also implies that member states can weigh the three sustainable development dimensions of the CAP rather freely, combining optional policy measures according to their specific agro-economic and agro-environmental conditions and ambitions. From a climate change perspective, the new CAP proposal stresses the ambition on climate action by supporting and incentivising farmers to utilise agricultural practices beneficial for the climate (European Commission, 2018c,d). It is not clearly outlined, however, how the new CAP design would lead to more ambitious contributions from agriculture to meet the emission reduction targets of the EU's 2030 Climate and Energy framework, a key objective identified in the communication.

In this paper we investigate a policy option that prioritises the environmental and climate dimensions of the CAP, increasing climate action uniformly across the EU, by shifting CAP resources from direct income support (with strongest links to the economic sustainability dimension) to a policy incentivising greenhouse gas (GHG) emissions reductions in EU agriculture. More precisely, we devise a simulation experiment that removes the current basic payments under Pillar 1 of the CAP, and at the same time introduces a direct payment to farmers in return for GHG emissions reductions. In line with the new delivery system sketched in the Commission's legislative proposal, the emission saving subsidy we investigate is incentive-based by design, rewarding farmers for reducing their current level of GHG emissions. Although such a policy option is not in the current policy debate, we believe our results provide a valuable quantitative insight into how and to what extent EU agricultural policy can contribute to climate change mitigation objectives. The simulation experiment is designed to answer the following research questions. To what extent could agricultural non-CO_2 emissions be reduced by a budget-neutral shift towards direct incentives for farmers to reduce emissions? What would be the implications for the viability of the farming sector, including the impacts on agricultural income and competitiveness in global food markets? How much would the EU farming system change due to the simulated re-prioritisation of CAP objectives, including the potential reduction in total agricultural output as well as the induced structural change? What would be the impact at the global scale on agricultural GHG emissions, taking into account the possible leakage of emissions to EU trading partners?

For the analysis we use the Common Agricultural Policy Regionalised Impacts (CAPRI) model, a global partial equilibrium model for agriculture. CAPRI is an interlinked system of mathematical optimisation models for agriculture and the primary food processing sectors of the EU administrative regions (NUTS-2), connected to a global model of agri-food markets. A detailed endogenous GHG emissions accounting scheme links agricultural activities to non-CO_2 (nitrous oxide and methane) emissions, the primary source of agricultural GHG emissions. CAPRI enables us to quantify the economic and environmental impacts of the above hypothetical policy option on EU farmers in detail, with regard to both geographical and sectoral disaggregation. In a comparative static analysis, simulated scenario results for introducing a GHG-saving subsidy for EU agriculture are compared to a business-as-usual scenario in the mid-term (up to the year 2030). In our analysis we only consider non-CO_2 emission reductions directly related to the UNFCCC category 'agriculture', not including, for example, CO_2 emissions and removals from Land Use, Land-Use Change and Forestry (LULUCF). The potential reduction in total emissions linked to agricultural production might be significantly higher when also taking into account emissions from energy, transport and other upstream or downstream processes of the agricultural value chain. However, from an agricultural policy perspective, it does not seem appropriate to subsidise emission reductions that are accounted for in other sectors, assuming that they are already subject to specific mitigation measures from other policy areas. This is, for example, the case for emission reductions from nitrogen fertiliser production installations, which are already included in the scope of the EU Emission Trading System.

Regarding the details of the scenario assumptions, a challenging empirical question is how to calculate the unit level of the emission saving subsidy (per tonne of CO_2 equivalent emissions) so that it satisfies budget-neutrality. With budget neutrality we refer to the assumption that the emission-saving subsidy is to be financed by reallocating financial resources from Pillar 1 (direct payments), without altering the total CAP budget. To calculate the necessary budget for the incentive-based emission-reduction subsidy, farmers' adjustment in their production must be factored into the calculation of the unit rates for the subsidy. One of the main empirical contributions of the paper is to set up a methodological approach for calculating the budget-neutral level of the GHG-saving subsidy, building on standard profit maximising behaviour of farmers.

Technically, we repeatedly solve the regional models of CAPRI on a large number of different unit subsidy values, where the selection of the unit subsidies is driven by a Newton-Raphson numerical approximation method. The numerical approximation guarantees budget-neutrality by closing the gap between the necessary budgets for the emission-saving subsidies versus current direct income support. The optimal unit subsidies for GHG-savings, defined for each EU NUTS-2 region separately, are then used in the complete CAPRI modelling system to account for the price feedback from the agri-food markets. Thus, we implement a fully budget-neutral version of the GHG-saving subsidy system in the EU, with direct links to global agri-food markets.

In a dedicated sensitivity analysis we examine the inefficiencies that the budget-neutrality condition introduces in EU emission savings. We discuss the regional differences in the environmental performance of the hypothetical emission-saving subsidy system by comparing results to an alternative scenario with uniform EU-wide subsidy rates.

2. Methodological Approach and Scenario Design

2.1. The CAPRI modelling system

We use the CAPRI (Common Agricultural Policy Regional Impact Analysis) modelling system (Britz and Witzke, 2014). CAPRI is a global, comparative static, partial equilibrium model for the agriculture and the primary processing sectors. Two major components are interlinked in CAPRI via an iterative process: (i) highly detailed and disaggregated supply modules for the EU agricultural sector, and (ii) a global market model for agricultural commodities. The set of EU regional supply models are constructed following a Positive Mathematical Programming (PMP) approach. The mathematical programming approach offers a high degree of flexibility in capturing important interactions between production activities and with the environment (Heckelei *et al.*, 2012). Each representative regional farm model maximises profit under restrictions related to land availability, nutrient balances and policy obligations. The regional supply models are linked with a sequential calibration approach to a global multi-commodity agricultural market model. This interaction between the EU agricultural supply and global markets allows us to capture the price feedback to simulated policy changes. The market model is a static, deterministic, partial, spatial model with global coverage, depicting about 60 primary and secondary agricultural products, and covering about 80 countries worldwide. International trade is modelled following the Armington assumption, i.e. goods are differentiated by place of origin, covering bilateral trade flows, and setting consumer preferences for import demand according to historical trade patterns. Bilateral import prices are derived by considering trade policy measures at the border, such as tariffs, tariff-rate quotas (TRQs), variable levies and the entry-price system for fruits and vegetables. Some further market measures, such as public intervention and export subsidies, are also implemented where relevant. Linking the market and supply modules allows CAPRI to account for global market effects at the EU, national and regional scales (Britz and Witzke, 2014). CAPRI is frequently used for the *ex-ante* impact assessment of agricultural, environmental and trade policy options, such as, for example, EU milk quota removal (Witzke *et al.*, 2009), the expiry of the sugar quota system (Burrell *et al.*, 2014), possible EU trade deals (Burrell *et al.*, 2011), climate change mitigation in the agricultural sector in the EU (Pérez Domínguez *et al.*, 2016; Fellmann *et al.*, 2018) and at global level (Hasegawa *et al.*, 2018; Van Meijl *et al.*, 2018; Frank *et al.*, 2019), CAP greening measures (Gocht *et al.*, 2017), and possible future pathways for the CAP (M'barek *et al.*, 2017).

EU agricultural (non-CO_2) GHG emissions for nitrous oxide and methane are endogenously calculated in CAPRI based both on the input use and outputs of production activities. Following IPCC guidelines (IPCC, 2006), a Tier 2 approach is generally used for the calculation of activity-based emission factors, but where the respective information is missing a Tier 1 approach is applied (e.g. rice cultivation). Leip *et al.* (2010) and Pérez Domínguez *et al.* (2012) provide detailed descriptions of the emission inventories in CAPRI. The model includes a set of technological (i.e. technical and management-based) GHG mitigation options for EU farmers, focusing on technological options that are already available or will likely be available at the simulation year 2030. Implementation costs, cost savings, and mitigation potential of the modelled technological mitigation options are mainly based on data from the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) database (GAINS, 2013, 2015; Höglund-Isaksson *et al.*, 2013, 2016), and information collected within the AnimalChange project (Mottet *et al.*, 2015). The level of production activities and the use of mitigation technologies are constrained by various factors, including land availability, fertilisation requirements of the cropping systems versus organic nutrient availability, feed requirements in terms of dry matter, net energy, protein, and fibre for each animal (Van Doorslaer *et al.*, 2015; Pérez Domínguez *et al.*, 2016; Fellmann *et al.*, 2018). The technological mitigation options specifically considered in this paper are listed in Table 1, and they can be voluntarily applied by EU farmers in the baseline and the scenarios.

A detailed description of each technological GHG mitigation option is provided in Pérez Domínguez *et al.* (2012). The data provided by the GAINS database and the AnimalChange project are based on farm types (where applicable, as for example with anaerobic digestion) and are specific to production activity and level, i.e. indicating the costs for the application of the mitigation measure to one unit of the production activity (i.e. per hectare or head). For the estimation of the average cost function, CAPRI builds upon the provided costs in specific farm types which are then aggregated at regional level according to shares of these farm sizes in the region. Whether a mitigation technology is adopted and to which extent in each region is an endogenous variable and it is a function of its mitigation costs (the sum of the annualised investment cost and the operation costs), the revenue generated by it (if any, as in the case of anaerobic digestion[2]), the cost-savings (for example the costs saved by using less mineral fertiliser through the application of precision farming), and other incentives such as subsidies (or taxes) to which it is subject. Accordingly, as the agents in the CAPRI regional programming models are assumed to be profit maximisers, famers will apply a mitigation option only if marginal profit (according to a gross value added concept) increases. Detailed information on the modelling approach is provided in Fellmann *et al.* (2018), Pérez Domínguez *et al.* (2016) and Van Doorslaer *et al.* (2015).

While emissions of EU agriculture are calculated on a per activity basis in the CAPRI supply model, GHG emissions for the rest of the world are estimated on a commodity basis (i.e. per kg of product) in the market model of CAPRI. Mitigation technologies are not specifically considered in non-EU countries, but technical trends are integrated, e.g. for depicting improved emission efficiency over time, using IPCC Tier 1 coefficients and FAOSTAT emission inventories within a robust Bayesian estimation framework (Pérez Domínguez *et al.*, 2012, 2016).

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[2]The adoption of anaerobic digestion generates revenue by selling heat and electricity. National estimates for power prices are provided by the PRIMES model for 2030.

Table 1
Technological GHG mitigation options available for adoption by EU farmers

Sector	Technological mitigation options
Livestock	Anaerobic digestion at farm scale, Low nitrogen feed, Linseed as feed additive, Nitrate as feed additive, Vaccination against methanogenic bacteria in the rumen, and specific breeding programmes to increase (i) milk yields of dairy cows, and (ii) ruminant feed efficiency
Crops	Precision farming, Variable Rate Technology, Better timing of fertilisation, Nitrification inhibitors, Rice measures, Fallowing histosols (organic soils), Increasing legume share on temporary grassland

2.2. Scenario design and unit rates of a GHG-saving subsidy

For the policy scenario, we investigate a policy option that removes decoupled income support under Pillar 1 of the current CAP and, in a budget-neutral manner, provides farmers a GHG-saving subsidy instead. More precisely, we remove the basic payment component of direct subsidies, either applied as Basic Payment Scheme (BPS) or as Single Area Payment Scheme (SAPS) in the member states, which clearly serves direct income support purposes. We keep those elements of the current CAP untouched that have the strongest links to the environmental or social sustainability dimensions: we keep the greening top-up of Pillar 1, which is paid upon complying with enhanced environmental conditions, and also the coupled supports for sectors and regions in competitive disadvantage and the support for farmers in areas with natural constraints, as both are assumed to contribute to the objectives of territorial balance and the maintenance of rural livelihoods (social dimension).

We aim at a fully budget neutral shift of CAP objectives in all NUTS-2 regions of the EU, i.e. the GHG-saving subsidy provided to farmers should require exactly the same budget as the current basic payment in the given region. The difficulty we face when implementing an incentive-based policy with the budget-neutrality condition is to calculate the appropriate level of GHG-saving subsidy per tonne of CO_2 equivalent. To satisfy the budget constraint, we need to factor in the farmers' responses in the calculation of the budget-neutral unit subsidy. We answer this empirical challenge by developing a framework for calculating unit subsidies based on standard profit maximising behaviour of regional representative farms of the EU.

Farmers' responses to incentivised emission savings are factored in through three main channels in our approach: (1) adopting new technological mitigation options, which we refer to as *'technology effect'*; (2) reducing agricultural production *('production level effect')*, which is mainly triggered when the marginal increase in subsidies outweighs the marginal decrease in revenues from production; and (3) changing the composition or intensity of farming activities based on current management practices *('production mix effect')*.[3]

[3]Technically the production level effect is determined as a change in GHG emissions calculated with constant (initial) emission factors. The production mix effect is calculated as the remainder of emission changes after deducting both the technology and production level effects from the totals.

In our modelling approach agricultural producers can adopt emission mitigation technologies from a pre-defined set of technological options (Table 1). The relative size of the marginal cost of adopting a certain mitigation technology compared to the marginal revenue increase from the emission-saving subsidy defines whether a technology option is adopted by farmers and to what extent (summarised in the following discussion as the adoption share of the technology in the region).

Technically we introduce a GHG-saving subsidy in the objective function of the CAPRI representative regional farm models, with the subsidy being paid on emission savings relative to initial non-CO_2 emissions from agriculture. A numerical approximation method adjusts the unit level of the GHG-saving subsidy and solves the regional models repeatedly in an iterative manner. The iterative solution process is terminated as soon as the required budget for emission saving subsidies is equal[4] to total initial basic payments, thus satisfying the budget-neutrality condition of the calculation.

Figure 1 gives a visual summary of the approximation approach. Let us define a function $F(s,0)$ for the necessary budget for the GHG-saving subsidy, where s is the unit level of the emission saving subsidy and 0 represents all other model variables. We cannot give an explicit form for $F(\cdot)$ but can only evaluate the function in selected points (s_0, $s_{1\ \ldots}$) by repeatedly solving the regional optimisation models. Assuming that the unknown $F(\cdot)$ function has no inflection points in the neighbourhood of the theoretical solution s^*, we can numerically approximate the budget-neutral unit subsidy s^*, starting from an appropriate pair of (s_0, s_1).

By solving the CAPRI regional models repeatedly during the approximation process, we take advantage of the standard CAPRI model features, including a detailed nutrient flow scheme for nutrient availability and requirement of crop and animal production, a nested land-use model and a non-CO_2 emission accounting for agricultural activities. Also taking into account the market feedback and the producer price changes implied by the policy option would technically require a link to the CAPRI market model (as the latter covers global agricultural commodity markets). The above numerical approximation algorithm should then operate simultaneously in all 226 regional units including additional iterations for the CAPRI market module. That complication would render the numerical solution infeasible, and therefore we opt for the fixed price assumption, i.e. producer prices are fixed during the numerical approximation steps. Nevertheless, the price feedback to the policy changes is taken into account in the final scenario run, when the full CAPRI modelling system is activated and the price responses from global agri-food markets are factored in.

3. Simulation Results

In the following section we first report on the estimation of regional budget-neutral GHG-saving subsidy rates, and then we turn to the economic and environmental impacts of the simulated shift of financial resources from basic payments to the EU-wide emission saving subsidy.

[4]In fact the approximation method terminates when the absolute distance between the necessary budget for the GHG-saving subsidy and total initial basic payments is smaller than a pre-defined (small) threshold.

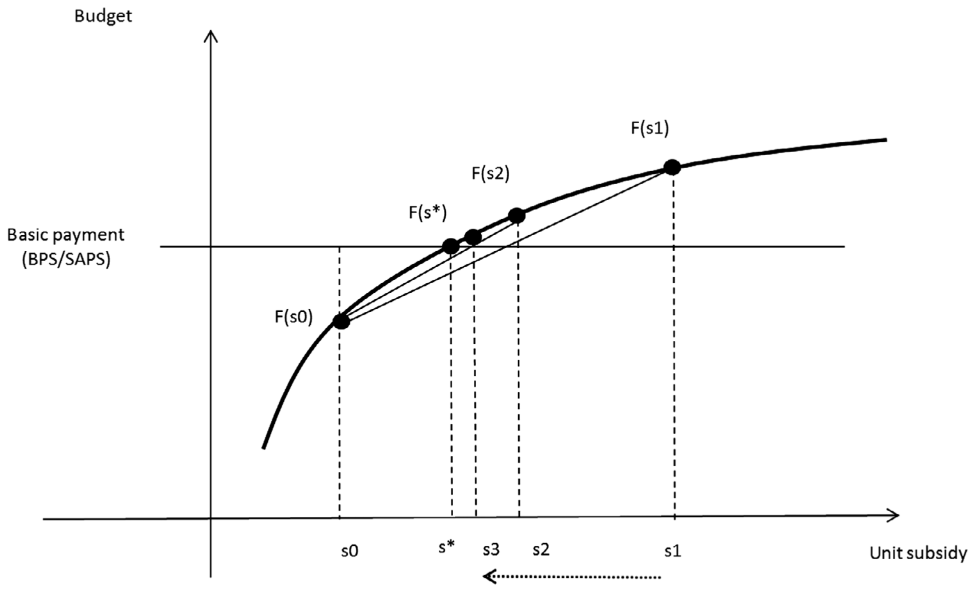

Figure 1. Newton-Raphson approximation for the budget-neutral unit subsidy rates

3.1. *Budget-neutral subsidy rates*

The estimated unit subsidy rates show large regional variation in the range of 51 to 746 EUR/t of CO_2 equivalents, with a median value of 197 EUR/t CO_2 eq. (Figure A1 in the online Appendix). The empirical distribution is skewed to the right, with a few outlier regions with unit rates of more than 500 EUR/t CO_2 eq.

Regarding the geographical differences across the EU, regions in Italy, Greece and the new member states, tend to have higher unit rates (i.e. higher subsidy rates are required per tonne of CO_2 eq.), while regions in the North tend to have lower scores. Large regional differences can also be observed within some countries, such as Germany, Poland and the UK (Figure A2 in the online Appendix). The regional differences can be explained partly by differences in the structure of the current CAP payments (in particular the weight of basic payments in total direct payments) and partly by the production structure that defines the flexibility of the regions to reduce agricultural non-CO_2 emissions. In regions with larger basic payments relative to total emissions, farmers need to be incentivised with larger unit rates for the emission saving subsidy to achieve budget neutrality. A simple linear model for the unit rates with the 'basic payment per agricultural non-CO_2 emissions' as explanatory variable gives a fairly good fit (Figure A3 in the online Appendix). This suggests increasing marginal opportunity costs of emission-savings in the EU regions, i.e. the more budget is to be transferred to emission saving subsidies the more the unit rate of that subsidy must be increased.

3.2. *Economic and environmental impacts on EU agriculture*

In the following scenario analysis we remove the basic direct payment in all EU regions and activate a non-CO_2 emission-saving subsidy with the estimated budget-

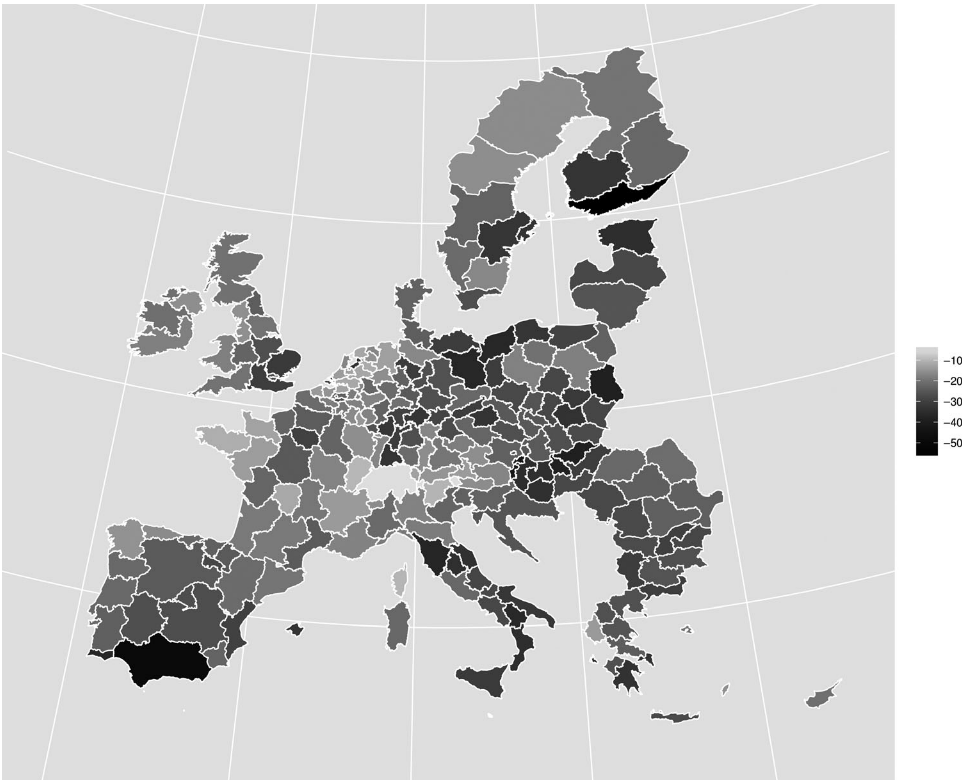

Figure 2. Agricultural non-CO_2 emissions, relative change to baseline (2030)

neutral unit rates. By activating the market module of CAPRI, the price feedback from the agricultural markets is also factored into the analysis.

As a direct effect of moving towards subsidised budget-neutral emission savings, agricultural non-CO_2 emissions would decrease by –21% at the EU aggregated level, compared to the baseline. Regional differences are substantial, with emission reductions ranging from no significant change (Malta) to –57% decrease (Andalusia in Spain and South Finland). Nevertheless, regions with higher unit subsidy rates do not correlate with the regions reducing the most emissions (Figure 2). This suggests that in many regions the rate of the emission-saving subsidy is over the tipping point of the emission reduction potential: with the available technological, production-reducing and structural options for mitigation, farmers cannot efficiently reduce their emissions further. In the next section, we further elaborate on the inefficiencies that the budget-neutrality condition introduces in our calculations, comparing the results to an alternative scenario with uniform EU-wide subsidy rates.

All analysed impacts on the farming sector, including the production level and production mix effects as well as the adoption of new technologies for decreasing emissions are substantial. Almost two-thirds (63%) of the emission savings are due to decreases and shifts in production, i.e. production level and production mix effects, while the remaining 37% is achieved by adopting technological mitigation options (Figure 6). Consequently, the EU supply of all major agricultural products decreases.

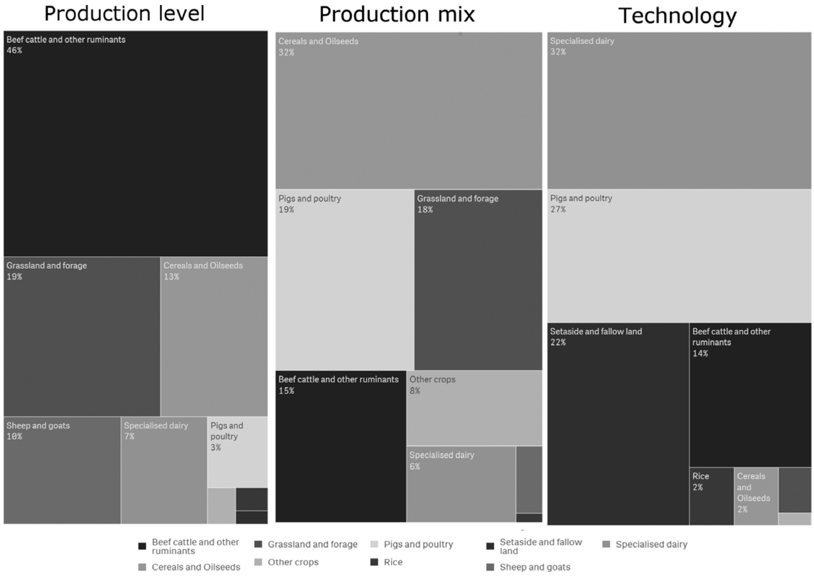

Figure 3. Production level, production mix and technology effect in the budget neutral scenario by share of agricultural activity groups

In terms of land use changes, total utilised agricultural area decreases by –5.6% (with fodder activities suffering the biggest decrease), leading to a substantial increase in set aside areas and fallow land (+34%). With regard to animal activities, the ruminant meat sector is the most affected[5] (–10% decrease in herd size and –9% in production), but pig production is also negatively affected (–2.7% decrease in pig meat supply). The production decreases lead to price increases for all commodities (except fodder) in the EU, which are most pronounced for beef (+30%) and sheep & goat meat (+21%). Moreover, the EU production decreases are mainly compensated by increasing imports and decreasing exports, leading to a worsening of the EU net trade position, as for example the EU net exports of cereals and pork decrease by 10 million tonnes (–32%) and 723 thousand tonnes (–27%), respectively, and EU net imports of beef increase by 209 thousand tonnes (about 350%). The price increase especially affects the consumption of beef (–6%) and sheep & goat meat (–1%), leading to a shift towards the consumption of the relatively cheaper poultry (+1%) and pork meat (+0.2%), resulting overall in a slight decrease in total EU meat consumption (–0.6%) (Table 2).

We further break down the reduction of EU agricultural non-CO_2 GHG emissions by effect (production level, production mix, technology) and by agricultural activity groups, introducing the following categories for animal and cropping activities (Figure 3): specialised dairying, sheep and goat, beef cattle and other ruminants, pigs and poultry, cereals and oilseeds, grassland and forage, set aside and fallow land, rice, and

[5]Changes in the marginal cost of production largely define production effects in the PMP framework of CAPRI. The parameterisation of the quadratic cost functions of the meat sectors are based on animal herd and production statistics, unit values, variable cost estimations, supply elasticities and a cost-minimising feed mix from the CAPRI database (Britz and Witzke, 2014).

Table 2

Changes in supply, producer prices, human consumption and net trade for the EU-28 (relative or absolute change compared to baseline)

	Net production (% change)	Producer price (% change)	Human consumption (% change)	Net trade (1,000 t)	Net trade (% change)*
Cereals	–7.5%	6.2%	–0.1%	–10,479	–32%
Oilseeds	–5.3%	6.5%	–1.3%	–786	–6%
Fodder	–10.5%	–38.1%	Na	Na	Na
Total meat	–3.0%	13.2%	–0.6%	–1,285	–42%
Beef	–8.9%	29.9%	–6.0%	–209	–350%
Sheep and goat	–10.8%	20.5%	–0.9%	–99	–34%
Pork	–2.5%	9.3%	0.2%	–723	–27%
Poultry	–0.3%	5.3%	1.1%	–254	–35%
Raw milk	–1.8%	10.4%	–0.5%†	–387†	–9%

Notes: Na, not applicable.
*The worsening of the net trade position is indicated as a percentage decrease.
†Dairy products.

other crops. The production level effect is most pronounced for beef cattle and other ruminants, reflecting a strong decline in beef supply. The reduced demand for feed implies strong production level effects also for the grassland and forage activities, whereas areas of cereals and oilseeds decrease to allow for fallowing histosols (peaty soils). The production mix effect is, in general, bigger for larger categories including many individual types of activity, as the production mix (land allocation and the composition of the herd) can change significantly in the aggregate (see, for example, cereals and oilseeds in (Figure 3). In the case of grassland activities, the significant production mix effect reveals a move towards more extensive use of grasslands. The largest technology effect can be attributed to the dairy sector, which adopts milk yield increasing breeding programmes, feed additives that increase feed efficiency and vaccination against methanogenic bacteria in the rumen. The large technology effect for the pigs and poultry sectors is due to the adoption of anaerobic digestors on the farms, while fallowing large histosol areas is reflected in the technology effect for set aside and fallow land activities. The technology effect in beef cattle and other ruminants can be attributed to the adoption of breeding programmes aiming at increases in ruminant feed efficiency. For sheep and goat meat the production level effect is dominant, as they decrease supply without significant adoption of technological mitigation options. On the contrary, the specialised dairy farming is mostly adjusted by adopting milk yield and feed efficiency related mitigation technologies, without significantly reducing the total EU milk supply.

The reduction in methane and nitrous oxide emissions lead to environmental co-benefits related to nitrogen (N) surplus and phosphate emissions. At the EU average, the projected initial N surplus[6] of 63 kg N/ha decreases to 46.2 kg N/ha in the budget

[6]The farm-level N surplus in CAPRI is approximated with the Gross Nitrogen Balance, including all N losses from housing, manure storage and management, and also soils.

neutral scenario. The decrease in N surplus is mainly due to smaller N losses from mineral fertiliser (driven by an increase in set aside and fallow land, and increased mineral fertiliser use efficiency) and decreasing gaseous N losses from manure. Total EU ammonia emissions decrease by about 6.5% compared to the reference scenario, mainly due to the decrease in ammonia losses from manure, which is attributable to both the drop in animal numbers and the adopted mitigation technologies.

In line with previous literature, the unilateral mitigation effort of the EU leads to emission leakage effects, fuelled by the relative emission efficiency of the EU agricultural sector (see, for example, Caro *et al.*, 2014; Barreiro-Hurlé *et al.*, 2016; Fellmann *et al.*, 2018; Himics *et al.*, 2018). Emission savings of the EU are partially offset by increasing emissions in other parts of the world (Figure 4), mainly in the EU's main trading partners. The limited leakage effect (20%) is due to the relatively protected EU agricultural markets for those commodities where the EU is in a strong net importer position (e.g. beef). Our scenario does not include any change (liberalisation) in trade policies, and therefore the tariff and other quantitative (e.g. Tariff Rate Quota) restrictions limit the expansion of EU imports, even if EU agricultural supply decreases significantly. As a consequence, EU trade protection contributes to the limitation of emission leakage and hence to the more than 1% decrease in global non-CO_2 emissions from agriculture. At the downside of the limited expansion possibilities for EU imports, the price impacts on the EU domestic markets are pronounced, decreasing also consumer welfare.

The GHG-saving subsidy turns out to over-compensate farmers with a positive impact on farmers' income at the aggregated EU level (+5.8%). Nevertheless, a substantial re-allocation of agricultural income can be observed within EU regions and within agricultural sectors, with both winners and losers of the changing subsidy scheme (Figure 5). Some regions take advantage of the general, EU-wide price increase, and the increased production efficiency (e.g. milk yields) induced by the adoption of technological mitigation options. In other regions the negative quantity effect dominates and triggers substantial income losses for the agricultural sector.

Due to the relatively inelastic demand for food, and to the trade protection of EU agri-food markets, decreasing agricultural supply leads to a general increase in producer prices. Although consumer price margins for food products are generally large, the price increase still triggers a –2.5% decrease in consumer surplus from food consumption. As agricultural income does not decrease, and taxpayers' costs of EU agricultural policies do not change due to the budget-neutrality condition, consumers take over the negative welfare implications of the scenario in our partial equilibrium framework[7] and pay the price of the simulated increased climate action in agriculture.

3.3. Implications of the budget-neutrality condition

The subsidy rates in section 3.1 are calculated by imposing the budget-neutrality condition. Farmers in a given region are incentivised to reduce emissions to such an extent that the total payments to farmers for emission-savings are equal to the current basic payment envelope allocated to the region. The subsidy rates are therefore not

[7]The partial equilibrium framework of CAPRI is not able to capture the changes in factor incomes. We assume zero transaction costs for the implementation and monitoring of the emission saving subsidy in the scenario, which is treated as a lump sum transfer from tax payers to farmers.

optimal from a pure emissions reduction point of view. To illustrate this issue, we perform an additional simulation exercise with an alternative scenario setup, depicting an EU-wide uniform emission saving subsidy scenario. The alternative scenario includes the same removal of basic payments as in the budget-neutral case, but the GHG-saving subsidy rates are set uniformly to the EU average subsidy rate of 182 EUR/t of CO_2 eq.

Simulation results indicate that the reduction in agricultural emissions is slightly larger in the case of the uniform subsidy than in the budget-neutral case (–22% vs. –21% at the EU average), with more emissions being reduced due to the application of the technological mitigation options (Figure 6), while the required budget is –3.5% smaller. The uniform rate is therefore a little more efficient in reducing emissions in terms of the necessary budget. The budget-neutrality condition also introduces inefficiencies with respect to agricultural income, as the increase in agricultural income in the uniform subsidy scenario is also slightly higher (+6.7%). Thus it seems possible to design more efficient policy options (at least at the EU aggregated level) by moving away from the current status quo of the regional pattern of CAP basic payments when aiming at GHG emissions reduction in the EU′s agricultural sector.

A direct comparison of our results with abatement costs for agricultural non-CO_2 emissions in the EU in other studies is difficult, because the costs can vary a lot due to differences with respect to the approach taken (using market equilibrium models, farm-scale analysis, engineering approaches, etc.), projection year, baseline emissions and reference points (Eory *et al*., 2018). For example, De Cara and Jayet (2011) found that a 10% reduction target in EU agriculture could be reached by 2020 at marginal abatement costs between 32 and 42 EUR/t CO_2 eq (depending on the assumed baseline emissions) under a cap-and-trade system for EU agriculture. In a different setting De Cara *et al*. (2005) indicate costs of 55 EUR/t CO_2 eq for an 8% reduction target by 2020 compared to 2005. Höglund-Isaksson *et al*. (2012) indicate a reduction of 9% compared to baseline emissions in 2030 with a carbon tax of 57 EUR/t CO_2 eq, and –20% at a carbon tax of 180 EUR/t CO_2 eq in 2050. In a study done with the CAPRI model, Pérez Domínguez *et al*. (2016) analyse, among others, a scenario without mitigation targets but subsidies for the adoption of mitigation technologies in addition to current CAP payments. This scenario shows a unit rate of 278 EUR/t CO_2 eq for a 15% reduction of agricultural emissions in the EU. The considerably higher unit rate can be explained by the scenario assumption that, unlike in our analysis, farmers are not remunerated for reducing emissions, but are just subsidised for the application of mitigation technologies independent of the mitigation achieved, which also leads to high adoption rates of technologies that are not very cost-effective in terms of their mitigation potential.

Considering the differences in the approaches and scenario assumptions taken, our abatement costs seem to be in line with the costs in other studies, as they show relatively high abatement costs due to inefficiencies in the incentive system of a regional budget-neutrality condition. Accordingly, in our analysis, the higher abatement costs per unit in the scenario with budget neutral subsidy rates (197 EUR/t CO_2 eq for an emissions reduction of 21%) compared to the scenario with a uniform subsidy rate (182 EUR/t CO_2 eq for a 22% emissions reduction) indicate that emission abatement costs are decreasing if higher flexibility in the policy mechanism is given, which is also confirmed by the lower costs indicated in other studies that assume more market oriented policies such as carbon taxes and cap-and-trade systems.

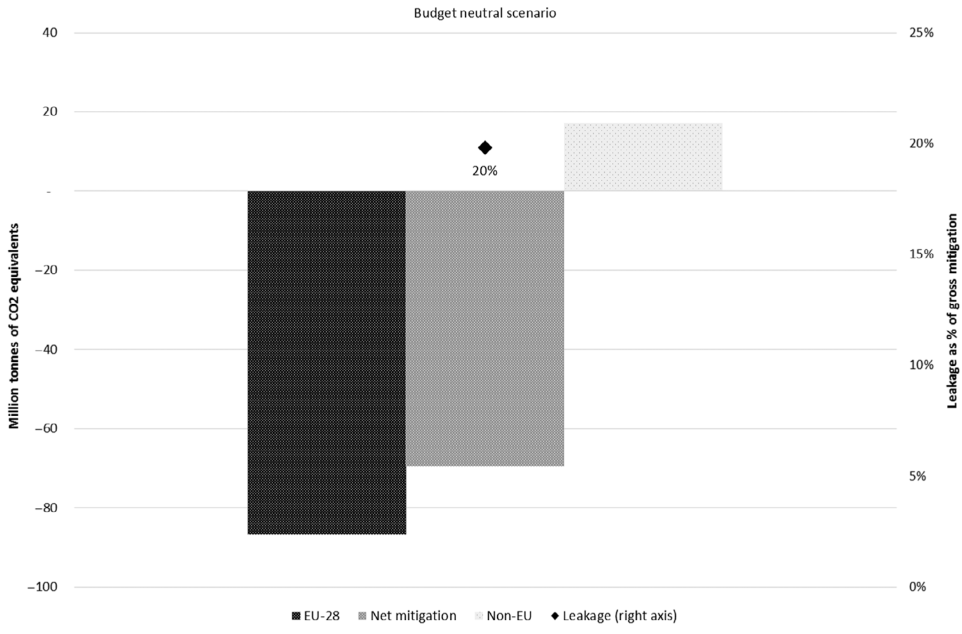

Figure 4. Emission leakage as a percentage of gross mitigation

3.4. Implications of the fixed price assumption

Turning towards the limitations of our approach, we assess the bias that the fixed-producer price assumption during the numerical approximation introduces in the estimation of the budget-neutral subsidy rates. The introduction of an emission saving subsidy for farmers triggers both a decrease in agricultural supply and changes in production systems towards more emission efficient farming practices. If production level effects dominate and agricultural markets are sufficiently isolated, prices might increase significantly. Assuming higher producer prices, *ceteris paribus*, the necessary incentive to cut agricultural emissions to the same degree also needs to increase, leading to higher unit subsidy rates. More emission efficient technologies also come at a significant adoption cost, pointing also to the direction of increasing producer prices and thus higher unit subsidy rates. Our budget-neutral unit subsidy rates, calculated under the fixed price assumption, are therefore likely to be underestimated by design.

Deviations from the budget-neutrality condition at the regional level support the above argumentation on the estimation bias. The budget-neutrality condition is only imposed during the numerical approximation for deriving the subsidy rates per tonne of CO_2 equivalent. On the other hand, budget neutrality is not enforced in the scenario runs, with the CAPRI market model and therefore the price feedback already incorporated. In fact, the positive price feedback from the market implies that farmers in our simulation exercise take up somewhat less emission-saving subsidies than the current basic payment envelopes would allow. The deviation from the budget-neutrality condition is region specific, but the distribution follows a clear tendency. While the deviations during the numerical approximation are close to zero (within an error range of 5%, with a –0.8% deviation from the EU average), regional deviations increase substantially during the scenario runs, shifting the distribution of the

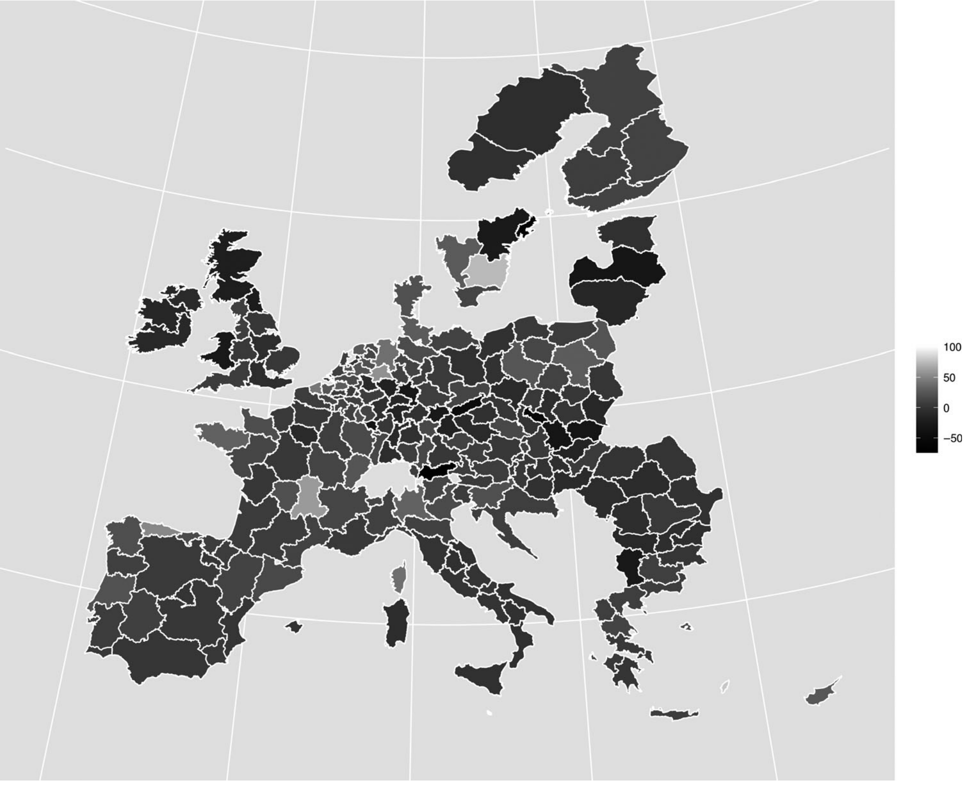

Figure 5. Agricultural income (marginal gross value added), percentage changes relative to baseline (2030)

deviations to the left and making it much flatter (Figure A4 in the online Appendix). The leftward shift of the budget-neutrality deviations reflects that farmers do not utilise the entire budget available for emission saving subsidies, and reduce non-CO_2 emissions less due to the price feedback. Putting it differently, larger emission-saving subsidies might be paid for farmers without increasing the necessary budgetary resources.

4. Conclusions

For this paper we conduct a simulation experiment to quantitatively assess the impact of a policy that removes the current basic (direct) payments of Pillar 1 in the CAP and instead provides farmers with a GHG-saving subsidy. In the simulation we aim at a fully budget neutral shift of CAP resources in all EU NUTS-2 regions, i.e. the GHG-saving subsidy provided to farmers requires exactly the same budget as the current basic payment in the given region. This strong budget-neutrality condition is motivated by the current discussion on the future CAP post-2020, pointing in the direction of a shrinking future CAP budget. Results presented include simulated impacts on commodity balances, producer prices, trade, income and welfare implications, and changes in agricultural non-CO_2 GHG emissions in the EU and the rest of the world.

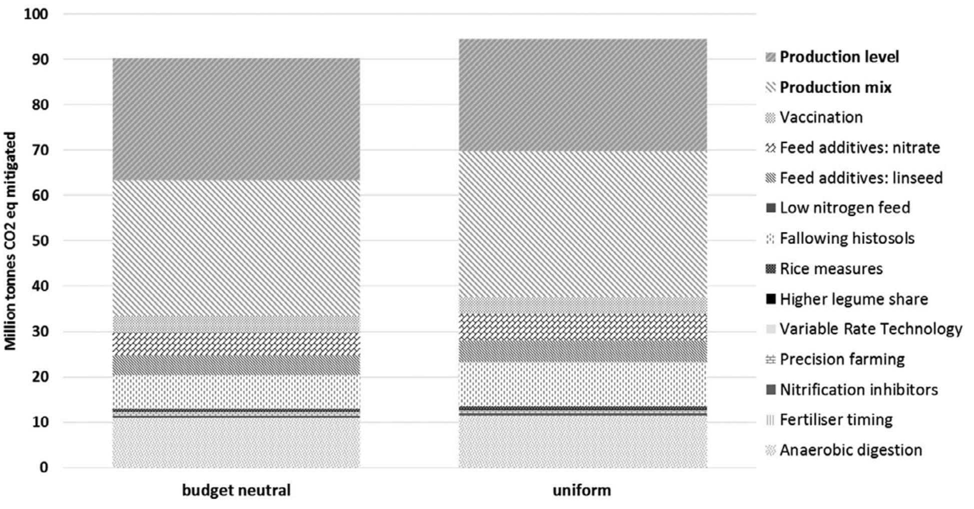

Figure 6. Production level, production mix and technology effects using budget-neutral or uniform subsidy rates

Note: The projected total EU agricultural non CO_2 GHG emissions in the reference scenario are 432 mio t CO_2 eq. The mitigation effects linked to genetic improvement measures cannot be analysed in isolation and are included in the mitigation achieved by changes in the production mix.

The full utilisation of the available budget for GHG-saving subsidies in our modelling framework is achieved by setting the unit rate of the subsidy with a numerical approximation method and, at the same time, calculating farmers' emission savings according to a profit maximisation behavioural assumption. The estimated unit subsidy rates for a regional budget-neutral emission reduction subsidy in the EU show large regional variation in the range of 51 to 746 EUR/t CO_2 eq, with a median value of 197 EUR/t CO_2 eq. The regional differences can be explained by a combination of both (a) differences in the structure of the current CAP payments (in particular the weight of basic payments in total direct payments), and (b) the production structure that defines the flexibility of the regions to reduce agricultural non-CO_2 emissions. Regarding the former effect, we find that in regions with larger basic payments relative to total emissions, farmers need a larger unit rate to arrive at a budget-neutral shift to emission saving subsidies. Regarding the flexibility of the production systems, we also find some evidence that regions have decreasing efficiency in reducing agricultural non-CO_2 emissions. After reaching a tipping point, the full utilisation of the available budget for the GHG-saving subsidy can only be ensured in our modelling framework by increasing the unit rate over-proportionally.

The simulated shift towards subsidised budget-neutral emission savings leads to a decrease in EU agricultural non-CO_2 emissions of 21% compared to the baseline in 2030. Regional differences are substantial, but regions with higher unit subsidy rates do not correlate with the regions reducing the most emissions. This suggests that in many regions the available technological and production-reducing options for mitigation are not sufficient for an efficient further emissions reduction. At aggregated EU level, 63% of the emission reduction is achieved by decreases and shifts in production, whereas 37% is due to the adoption of the technological mitigation options. As a consequence, EU supply decreases significantly for almost all major agricultural products, most pronounced for beef meat as well as sheep and goat meat activities.

Assuming a relatively emission efficient EU agriculture, scenario results show that emission savings in EU agriculture are partially offset globally due to increasing agricultural production in less emission efficient trading partners of the EU. Although the simulated emission leakage effect is limited (20%) it reveals that a more ambitious contribution of agriculture to combat global warming requires discussing future European agricultural policy in a wider context: both geographically and with regard to the political landscape. Coordination between agricultural, environmental and trade policies (international trade being the transmitter of leakage effects) seems to be a challenge for the CAP discussion that needs to be taken into account when streamlining the delivery system of agricultural subsidies.

The budget-neutral subsidy rates are, by design, sub-optimal from a pure emission reduction point of view. This is clarified with an alternative scenario that includes the same removal of basic payments, but the GHG-saving subsidy rates are set uniformly to the EU average subsidy rate, without aiming for budget neutrality. The uniform subsidy leads to a larger emission decrease (–22%) than the budget-neutral subsidy (–21%), with a 3.5% lower budget. This indicates that more efficient policy options can be designed for GHG emissions reduction in the EU′s agricultural sector by moving away from the current regional pattern of CAP basic payments.

The subsidy, as implemented in our scenarios, favours those farmers who can reduce their current emissions the most, without taking into account the relative emission efficiency of current[8] farming practices throughout the EU. It can be argued that this scheme penalises farmers who had already invested in emission-efficient technologies, and therefore require above average financial incentives to achieve further GHG reduction. Policies that target technological development explicitly might lead to a dominant technology effect and to relatively small reductions in agricultural supply, without the significant land abandonment impacts indicated in our simulation results. In CAPRI the relative GHG-efficiency of current farming practices is only represented at an aggregated regional level, with differences in the production technologies of regional representative farms, limiting therefore the scope of discussion of this issue here.

While discussing how mitigation in the agricultural sector performs compared to other sectors in terms of costs is beyond the scope of this paper, we believe that our results allow assessment of the potential of the CAP to increase its contribution to GHG emissions reduction efforts and wider environmental benefits. We also conclude that taking the current status quo of the regional pattern of CAP basic payments as a benchmark for direct agricultural GHG emissions-reduction policy options would be suboptimal in terms of budgetary efficiency.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure A1. Budget-neutral rates for the GHG-saving subsidy, all CAPRI regional units (histogram and kernel density estimation of the empirical distribution).

[8]The comparative static analysis has been performed in year 2030, based on a projection of agricultural farming practices according to a business-as-usual baseline.

Figure A2. Regional distribution of budget-neutral unit subsidy rates (EUR/t of CO_2 eq.).

Figure A3. Budget-neutral unit subsidies vs. basic payment per agricultural non-CO_2 emissions in the baseline, all CAPRI regional units.

Figure A4. Relative deviations from the budget neutrality condition with and without taking into account the price feedback from the agricultural commodity markets.

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