Post 2020 CAP in Poland: An impact analysis

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Paper prepared for presentation for the 162nd nd EAAE Seminar
The evaluation of new CAP instruments: Lessons learned and the road ahead

April 26-27, 2018

Corvinus University of Budapest

Budapest, Hungary

Abstract

This paper aims to assess the future of CAP reforms after 2020 in Poland. We provide a comparative analysis in which the impact of uniform and coupled support scenarios are assessed and compared against alternative environmental regulation measures. An agricultural supply model AROPAj is used to highlight the difference between scenarios. Coupled support for protein and legume crops reduces inequality between farm groups. Although crop diversification increases, no drastic land use change has been noticed, thereby reducing *N*-fertiliser use and GHG emissions. Results vary according to regions and the type of farming and economic size.

Key words: Common Agricultural Policy; uniform single payment ; coupled payment ; mathematical programming model ; farm sustainability

1 Introduction

Through its accession to the European Union (EU) in 2004, Poland has profoundly changed its social and economic policies (Hykawy et al. 2005) by implementing multidimensional programs concerning, among other fields, agriculture and life in rural areas (Poczta 2005). Thus, Poland has undergone a deep transformation over the past 14 years. Employing 10.5% of the work force (EC 2017), the agricultural sector has become one of the main pillars of economy. It has actually contributed to the development of the country, propelling it to become one of the most innovative key players in the EU's agri-food industry.

The Common Agricultural Policy (CAP) has targeted more competitive and sustainable agriculture on the one hand and decent standards of living for farmers and agricultural workers on the other. The living standards of Polish farmers have changed mostly in response to CAP payments. Farmers' lives have improved, a considerable number of family farms having been rescued from bankruptcy and modernized. Besides, a generation change has occurred, by supporting the installation of young farmers (more than 12% of the country's farmers are under 35 (EC 2017)). All these changes show the importance of CAP for both farmers and the rural community. Through successive reforms, this policy has driven the application of EU strategies and economic policies according to environmental and sustainable development goals. The viability of agricultural sector is highly dependent on the 1^{st} pillar CAP entitlements and any change in allocating the latter could have a strong influence to drive agricultural productivity on one way or the other.

As in other EU countries, both Polish researchers and policy makers are speculating on the direction in which CAP after 2020 will move. According to the Polish Ministry of Agricultural and Rural Development (2017), the new reform must be consistent with the "Treaty principle of equal treatment of EU citizens", thereby requesting to equalise direct payments among the Member States (MS) or even farmers in the same country. Since historical data were lacking, Poland has chosen to apply until 2020 the Single Area Payment Scheme (SAPS) instead of the standard one, i.e. Basic Payment Scheme (BPS), which should be fully deployed up to the end of the aforementioned deadline.

Nevertheless, this latter scheme is not fair enough because direct entitlements are not uniform within the EU due to differences in productivity levels. Besides, more attention on green activities could serve the goal efficiently, tackle biodiversity loss and soil quality, and enhance resilience to climate change (Green scenario). Coupled payments should at least be maintained and extended to other sectors. For instance, given the shortage of protein and legume crops in Europe, coupled payments could be leaned toward these crops because of their important role in soil and climate protection (Coupled scenario). In the light of the above, this paper aims at selecting the policy scenario that allows to reach high levels of production and more targeted cross-compliance to improve the environmental performance of agricultural systems. To this end, the impact of three post 2020 CAP scenarios, i.e. Fair scenario, Green scenario and Coupled scenario is assessed and compared against a Business-As-Usual (BAU) baseline in Poland, according to both economic and environmental criteria.

We provide then a quantitative analysis in which the three scenarios are evaluated according to both economic and environmental criteria, depending on the type of farming and economic size. The economic evaluation leans on the FG's outcome, i.e. gross margin and land shadow price, directly resulting from AROPAj optimisation. Regarding the environmental indicators, they are mainly represented by: 1- AROPAj outputs related to GHG balance and *N*-fertiliser use, and 2- agro-ecological indices. As a matter of fact, sustainability of farms in Poland has been addressed by Wrzaszcz (2014) to build friendliness criteria of agricultural production to the environment. Thus, several agro-ecological indicators have been identified to evaluate crop rotation and animal production at the farm level. In this study, we chose the index of arable land vegetation cover and the stocking density on agricultural land. The first one corresponds to the ratio of winter crops grown on arable land. Indeed, winter crops play an important role in reducing water pollution and protecting soil from erosion, including wheat, rye, barley, triticale, cereal and legume mixture. The threshold values range from 33% to 60%. The second indicator is mainly used to constrain the intensity level and environmental load of livestock manure. According to the Polish literature, the admissible level of stocking density ranges between 1.5 and 2.5 livestock unit per hectare of agricultural land (LU/ha of Ag.L). To assess the degree of crop diversification of FG, we chose to calculate crop concentration on acreage proportion by using the Herfindahl Index (HI)[1].

2 Mathematical programming models for agricultural policy analysis

2.1 Model building in a fluid institutional environment

After several periods of implementation of CAP, discussions on future developments beyond 2020 are driven by budgetary restraint priorities and the open question of national flexibility. Expenses devoted to the CAP are subject to severe criticism, likely imposing accountability not only on equity among and within members but also social and environmental cost effectiveness. For these reasons, various studies have been undertaken to evaluate the impacts of different policy measures meant to replace current direct payment regime. Impact assessments on allocation of the Net Value Added at the farm level for main products using FADN data despite broad scope and valuable results, constitute accounting calculations based on observed crop mix ignoring farmers' response concerning restructuring of the cropping plan to minimize negative impacts of policy measures to their welfare. In order to get reliable estimates useful for policy analysis, appropriate sector and regional models are required.

Classic analytical tools such as crop supply and profit functions used for deriving conditional farm income estimates and factor demand functions require considerable amounts of data to estimate all cross-price supply elasticity. Moreover econometric estimates are valid only for the observed range of variation of relative prices and other variables. Mathematical models may fill this gap examining different future contexts not necessarily in the trend expanded from the past. This class of models can accurately represent complex technical systems and in the case of farm models to implicitly derive response functions for output, incomes, employment and other variables by means of parametric optimization (Kutcher and Norton 1982). Especially in case of substantial policy changes, MP models have been widely suggested to agricultural economists (Salvatici et al. 2000).

Methodological advances performing calibration against the base year observed variable values marked a turning point, transforming mathematical programming models in agriculture by definition of normative nature to positive models. The term 'positive' implies that, as in econometrics, the parameters of the objective function are derived from an economic behavior assumed to be rational, given all the observed conditions that generate the initial activity levels. The main difference with econometrics is that the objective function is defined ad hoc, not necessarily obeying to a strict theoretical form. Furthermore, MP models do not require a series of observations to reveal the economic behaviour, which as a drawback deprives them of inference and validation tests. Various methods manage to transform the objective function so that optimal solutions include not only crop plans on the vertices of the feasible polyhedron but also points on hyper-plans, enabling the model to approach observed levels of activities outperforming its linear programming (LP) counterparts. For this reason farm based or farm-type models that incorporate non-linear terms in the objective function can be more effective, assisting policy makers in developing targeted policy measures, thereby exploring alternative policy impacts in a reliable way. It is the case of Positive Mathematical Programming (PMP) that is the mainstream method in particular when detailed information of the production process is barely available. On the other hand, lineal programming remains an option in the case of complex models such as multi-scale agricultural systems. Then accommodation of large databases and accurate production sets may be preferable against sophisticated expressions using less informative content. The advantage of the latter to provide optimal solution identical to the observations is traded off by the ability of the LPs to deliver detailed post optimal information on primal and dual variables for various scenarios.

2.2 The environmental dimension

Mathematical programming models simultaneously enable consideration of technical coefficients in monetary as well as in physical terms, also they can incorporate biophysical relationships denoting the so-called bioeconomic models. For this reason they are readily used to estimate impacts to the environment by business or policy decisions.

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[1] HI is expressed as follows:

$$HI = \sum_{i=1}^{n} p_i^2 \tag{1}$$

where n is the total number of crops and p_i is the share of i^{th} crop of total arable land area. It takes the value of one when there is complete specialization and $1/n$ in the case of perfect diversification.

Agricultural activities are by definition involved in the environment on both the input and the output sides. Natural resources used as inputs, such as soil and water, are no longer considered abundant and infinite reserves. On the output side, beside trade-able products that feed human population, there are "by-products" that harm the environment in a systematic way, stressing ecosystems in various degrees from irreversible damage to serious but manageable degradation, in both developed and developing countries. Universal issues to cope with the move from local to the global levels, starting with water shortages and nitrogen leaching in the seventies have been followed by greenhouse gas emissions as the major concern of the last decades.

Agriculture may be less important than other sectors in terms of its overall contribution to greenhouse gas emissions, but it has a crucial role to play within a strategy for addressing climate change. Mitigation opportunities of GHGs in agriculture fall into three broad categories according to Smith et al. (2008): (a) *Reducing emissions* by more efficiently managing the flows of carbon and nitrogen in agricultural ecosystems. For example, practices that deliver added N more efficiently to crops and managing livestock to make most efficient use of feeds thus emitting less methane (CH4), (b) *Enhancing removals*. Any practice that increases the photosynthetic input of carbon (C) or slows the return of stored C via respiration or fire will increase stored C (carbon sequestration), (c) *Avoiding (or displacing) emissions*. Agriculture can produce energy from biomass that can displace fossil fuels, the major contributor to greenhouse gas emissions. Crops and residues from agricultural lands can be used as bio-energy feedstock still releasing CO2 upon combustion, but now the C is of recent atmospheric origin (via photosynthesis), rather than from fossil C. The net benefit of this bio-energy feedstock to the atmosphere is equal to the fossil-derived emissions displaced less any emissions from their production, transport and processing. Thus it is of paramount importance to include environmental modules into mathematical models for policy analysis.

2.3 The agricultural supply model AROPAj

As CAP aims at both economic and environmental goals, we apply an integrated bio-economic modelling approach in which different instruments are taken into account using an agricultural supply model AROPAj.

The AROPAj agricultural supply model belongs to the LP farm level models using extensively integer variables covering the spectrum of arable and livestock activities in European agriculture, extensively used for policy analysis (Langrell et al. 2013). The positive dimension is assumed by means of a tedious calibration process enabled by a combination of random and gradient computational methods (Baranger et al. 2008). Calibration is performed through minimization of the distance between optimal and observed values of variables by varying the set of parameters of the initial model.

Model description

The AROPAj model was successfully tested to evaluate the impacts of CAP reforms at the European scale. In the context of 2003 reform, Galko and Jayet (2011) have used AROPAj to test the impacts of multiple decoupling support scenarios on gross margins, land allocation, land shadow prices, and GHG-emissions. The same model has been extensively used to assess the interactions between agricultural activities and the environment through evaluating agro-environmental policies (Jayet and Petsakos 2013, Bourgeois et al. 2014) and climate change adaptation (Leclère et al. 2013) and mitigation (De Cara and Jayet 2011).

The model covers a large part of agricultural land uses and livestock farming sector since annual supply choices of individual representative farms are described in terms of numerous agricultural activities, i.e. land allocation, crop production and animal farming. In fact, the feasible output set is driven by multiple modules representing the behaviour of "real" farmers. In the most recent version of the model (V5-AROPAj), the main micro-economic data are acquired from the European Farm Accountancy Data Network (FADN) for 2012. If we are to test the consistency of some AROPAj results, table 1 shows that those latter are in line with FAO data. AROPAj results have been validated against FAO data, although those latter are difficult to be compared with FADN data.

Table 1: Land Area in hectares of main Polish crop activities: comparison between FAO data and V5-AROPAj results for 2012

	FAO Data	V5-AROPAj
Cropland	Poland - 2012	Polish FADN - 2012
Wheat	2 077 200	2 248 931
Barely	1 160 600	1 511 135
Maize	543 800	638 788
Oats	513 800	510 867
Rapeseed	720 308	943 524
Potatoes	373 000	420 883

The architecture of AROPAj model has been explicitly described in numerous studies (De Cara and Jayet 2000, Godard et al. 2005, Galko and Jayet 2011) as well as in a manual presented by Jayet et al. (2017). The structure is mainly based on a microeconomic approach (Arfini 2012), consisting of independent, mixed integer and LP models, each of which describes a typical farming system of an individual representative farm called farm group (FG). Dealing with an optimisation problem, each farm group k is supposed to select the supply and input demand levels that maximise its total gross margin (π_k) under a set of economic, agronomic and environmental constraints. For the k^{th} farm group, the model can be expressed as follows:

$$max_{x_k}\ \pi_k(x_k) = max\ g_k(\theta_k,\phi)\ .\ x_k \tag{2}$$

$$\begin{aligned} s.t./\ A_{k_{mn}}(\theta_k,\phi)\ .\ x_k &\leqslant b_k(\theta_k,\phi) \\ x_k &\geqslant 0 \end{aligned}$$

where x_k and g_k are respectively the (nx1) vector of activities and the (1xn) vector of gross margins for the k^{th} farm group. x_k refers to crop and animal activities that represent most of the European agriculture land and animal categories, thereby containing crops' areas, livestock, production related to each crop and to each animal category, and purchased feed. Regarding the gross margin g_k, it includes per-ton revenue and per-hectare subsidy (if there are any) minus per-hectare variable expenses. Each farm group is a price-taker and can either sell its crop production in the market or use it for livestock feed. The feasible production is constrained by the (mxn) matrix A_k referring to input-output coefficients and the (mx1) vector b_k explicating the endowments of m constraints encountered by farm group k. Those latter are about crop rotations, animal feeding and demography, livestock number, resource capacities, Nitrogen (N) balance, and CAP restrictions. Coefficients presented in g_k, A_k and b_k pertain to θ_k-parameters characterising the k^{th} farm group as well as to ϕ standing for the economic parameters related, *inter alia*, to CAP measures.

Over the years, AROPAj has been used to assess the impacts of the successive CAP reforms ranging from the 1992 MacSharry to the 2003 Luxembourg agreement. It was first developed for France and then has been gradually extended to the 25 EU countries. In the last model version (V_5), CAP tools describe the full decoupling scheme (when the support is provided by a single payment) with neither milk nor sugar quotas. After the accession of central and Eastern European countries to the EU, top-up payments have also been simply *via* a parameter referring to direct support for one crop or one crop group. Because of the linear model structure, CAP instruments are mainly expressed through binary or integer variables, consequently involving Mixed Integer Programming solvers.

To encourage farmers to choose environmentally-friendly production schemes, 30% of Direct Payment allocation is associated to foster the diversification in cropping system, the maintenance of permanent grasslands and the conversion of 5% of Arable Land (ArL) into Ecological Focus Areas (EFA) dedicated to sustainable modes of farming. The two last measures can be easily implemented into AROPAj by integrating a minimum surface of permanent grasslands and Arable land. However, regarding the crop diversification, constraints must be expressed through binary or integer variables.

Simulation scenarios and assumptions

Individual Polish farmers are well represented as they are clustered into farm groups based on their technico-economic orientation within each region, their economic size and their altitude class. 209 farm groups were created for Poland from 10343 individual 2012-FADN surveyed farms, representing 14.97 million hectares (Mha). They were grouped into four Polish FADN regions, i.e. Pomorze and Mazury, Wielkopolska and Śląsk, Mazowsze and Podlasie and Małopolska and Pogórze, according to 14 economic size and farming type classes. Horticulture and permanent fruit crops, e.g. vineyards and olives, are not included into AROPAj crop production activities.

AROPAj is flexible enough so that all the scenarios mentioned in section 1 can be tested. In the current situation (BAU), Single Payments (SP) are paid per hectare of eligible agricultural land, but depending on FG. In order to assess the different redistribution effects between BAU baseline and Fair Scenario (FS), we suggest replacing SP by Uniform Single Payments (USP) paid per each MS or even within EU. We proceed indeed to a homogeneous variation of USP around a chosen value from plus and minus 0 to 200€ /ha by 25 increments. For the Green Scenario (GS), two environmental constraints have been integrated into the model to mitigate GHG-emissions and reduce N-pollution. Quantities of GHG-emissions and N-fertiliser use can henceforth be limited at the FG level. For instance, in the former case, we directly assign a price to GHG-emissions. The price is varied from 0 to 200€ per tCO_2eq by increments of 10. In the case of N-pollution, we just increase the initial price of N purchased of each FG, and thereby reducing its negative environmental externalities. The N-fertiliser price increases from 0 to 200€ per tonne (t) of N purchased by increments of 10. As regards the Coupled Scenario (CS), we suggest subsidising (CP) a group of protein and legume crops, i.e. proteins, soya, and vegetable and protein fodders, that can be used either for food or feed purposes, and varying the subsidy value from 0 to 200€ /ha by 10 increments.

For better targeted measures and understanding of decision-making behaviours, it is required to consider the diversity of farming systems (Weltin et al. 2017). The impact analysis of the aforementioned scenarios is therefore distinguished according to regions, FG's technico-economic orientation and economic size, in order to analyse the behavioural differences and identify the FG's types that are the most sensitive to changes in CAP measures. For this study, we simplify the number of classification categories and thus consider that FG are distributed among only 6 Types of Farming (FT) and 5 economic sizes (ES), respectively ranging from crop production to livestock farming and from 4 000 - $<$ 15 000 to $\leqslant$ 750 000 € (Table 2).

Table 2: Simplified representation of farming type and economic size categories to which AROPAj farm groups belong

Type of farming	Designation	Number of FG
Specialist cereals, oilseeds and protein crops	FT1	29
General field & mixed cropping	FT2	38
Grazing livestock	FT3	51
Mainly granivores	FT4	36
Field crops - grazing livestock combined	FT5	24
Various crops and livestock combined	FT6	31

Average economic size (€)	Designation	Number of FG
4 000 - < 15 000	ES1	42
< 25 000	ES2	43
< 50 000	ES3	50
< 100 000	ES4	34
< 750 000	ES5	40

3 Result interpretation

In this section, we first provide a general overview of Polish agriculture as modelled by the agricultural supply model AROPAj. Then, the results of different policy scenarios are compared with one another and assessed against a baseline situation, i.e. BAU scenario and declined according to the four Polish FADN regions, FG's technico-economic orientation and economic size. The assessment criteria are mainly based on gross margins, dual value of land (fix factor endowment), land use change, agro-ecological indices, *N*-fertiliser use and GHG-emissions.

3.1 Polish agriculture as modelled in AROPAj model

Results from V$_5$-AROPAj calibrated on 2012-FADN data confirm that Poland is characterised by an important agricultural activity with an intensive crop management dominated by cereal farming with more than 70% (Table 3). As for animal rearing, it varies from one region to another. The greatest share is attributable to Wielkopolska and Śląsk (the highest livestock density per hectare of grasslands) and Mazowsze and Podlasie (the highest area of grasslands).

Table 3: Agricultural characteristics of Polish FADN regions - Results aggregated at regional level as estimated by V$_5$-AROPAj model calibrated on 2012-FADN data

	FADN Regions			
	Pomorze & Mazury	Wielkopolska & Śląsk	Mazowsze & Podlasie	Małopolska & Pogórze
Number of Farm Groups	37	65	67	40
Agricultural Land (Ag.L, ha)	2910.3	4143.3	4633.9	1343.2
Arable Land (Ar.L, % of Ag.L)	88.2	93.2	82.7	83.7
Per. Grasslands (% of Ag.L)	11.0	7.1	17.0	15.9
Fallow Land (% of Ag.L)	0.9	0.7	0.3	0.4
Economic Factors (x1000 €/ha)				
Gross Margin	1.10	1.09	1.27	1.23
Crop Diversification (% of Ar.L)				
Cereals	74.1	78.2	77.8	75.9
Root Crops	2.9	3.2	6.2	6.4
Oilseed Crops	13.1	10.7	3.8	4.5
Industrial Crops	0.1	0.3	0.7	0.5
Legumes	4.9	4.8	4.8	5.5
Fodders	4.9	11.2	8.7	7.2
Livestock Unit (LU)				
Density (LU/ha Grassland)	3.3	7.6	2.7	3.5

3.2 Impact on farm income distribution

The aim here is to assess the distribution of income between Polish FG according to different agricultural policies' scenarios. Depending on the goal they are reflecting, i.e. sustainability or environmental goals, agricultural policies play an important role on farm income distribution. Indeed, by using the gross margin (GM) as an indicator that includes the remuneration to production factor, i.e. land, and received payments or paid taxes, we show that a support in the form of coupled or uniform payments reduces the income inequality between farm groups, while an environmental regulation measure increases the inequality.

To show and compare how FG income is distributed, we plot Lorenz curves for all scenarios (Figure 1) for USP and CP both equal to 150€ /ha, for 150% of *N*-price/tN and for GHG-price equals to 150€/tCO$_2$eq. The greater the distance from the diagonal equality line (drawn from (0,0) to (1,1)) to the Lorenz curve, the greater the inequality of the income distribution. It then appears that the results of Fair and Coupled scenarios are better than those of BAU and Green scenarios, but the magnitude of changes is much larger in Fair scenario. In fact, an equally-distributed support reduces more the inequality. As a matter of fact, 30% of FG earn less than 10% of the total GM, whereas 80% of FG earn more than 50%. In Coupled scenario, 30% of FG earn less than 5% of the total of GM while 80% earn more than 45%. When *N*-fertiliser and GHG-emissions prices increase, Lorenz curves are below that of BAU scenario, but raising *N*-fertiliser increases less the inequality.

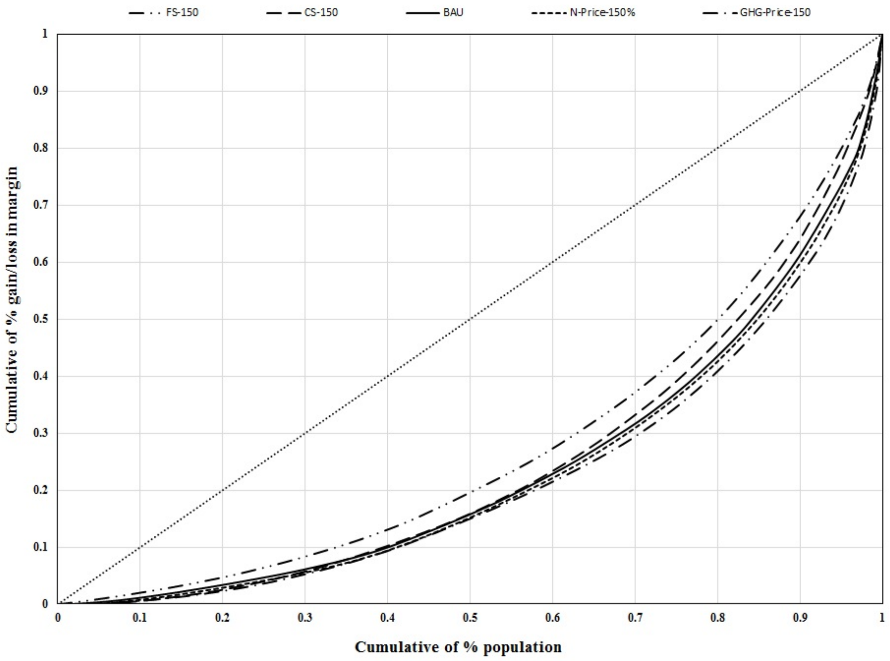

Figure 1: Lorenz curves of gain in per-farm gross margin in the case of Fair and Coupled scenarios for USP and CP = 150€ /ha and loss per-farm gross margin in the case of Green scenarios for 150% of *N*-price/tN and GHG-price = 150€/tCO$_2$eq.

3.3 Impact on production factors, i.e. the land

In AROPAj model, land resource is constrained and its dual value, i.e the so-called shadow price, corresponds to the limited endowment of land at FG level. By definition, the land shadow price is the marginal change in GM when the land endowment changes by one hectare. From table 4, we notice that a new support policy makes the farmer willing to pay higher land value because of the raise in marginal land productivity, to which a per-hectare payment is added. This is more significant for larger USP values. Though, FG react differently according to payment levels and their technico-economic orientation. For instance, in Coupled scenario, low payments result in low shadow prices which can force some FG to "lease out" land. Land shadow price increase mainly in FG with a small and mid average agricultural area (UAA) ranging between 45 and 70 ha. For animal-oriented FG, land shadow price increases slightly. On the contrary, in Fair scenario, high rates of change are more important for FG having high per-hectare livestock unit (LU) density. In the case of Green scenarios, increasing the price of *N*-fertiliser and GHG-emissions reduces land shadow price, and therefore increases the willingness of FG to "lease out" land. In fact, higher reduction rates are recorded for high price values and the magnitude of changes is more important by limiting *N*-fertiliser use. The decrease in land shadow price is higher for crop-oriented FG with an average UAA ranging between 70 and 90 ha. However, increasing GHG-emissions price decreases more significantly the land shadow price of FG characterising by a mid per-hectare LU density and an average UAA ranging between 50 and 70 ha.

3.4 Impacts on land use change

We consider the agricultural land is shared between cropland, permanent grasslands and fallow. We then propose to examine changes in these areas caused by the aforementioned agricultural policies' scenarios according to regions

Table 4: Variation in percent of average land shadow price according to FG's technico-economic orientation for different scenarios.

Deciles of total population	Livestock Unit per ha	Average agricultural area (ha)	Average land shadow price BAU (x1000 €/ha)	reduction rate							
				FS (%)		CS (%)		N-Price (%)		GHG-Price (%)	
				50	150	50	150	50	150	50	150
1	[0.00,0.02)	70.5	1.1	0.7	9.5	0.3	1.0	-8.2	-25.1	-2.2	-4.9
2	[0.02,0.07)	90.9	1.2	0.7	9.1	0.3	1.0	-8.3	-24.6	-2.4	-5.4
3	[0.07,0.16)	50.0	1.1	0.8	9.7	0.4	1.3	-7.6	-23.0	0.4	-2.5
4	[0.16,0.35)	71.0	0.9	0.8	11.6	0.4	1.2	-6.0	-19.5	-5.0	-8.8
5	[0.35,0.45)	79.0	0.9	0.7	11.7	-0.4	0.2	-6.7	-21.7	1.1	-1.8
6	[0.45,0.58)	44.7	0.9	0.7	11.5	0.9	1.6	-8.2	-22.7	-1.6	-4.8
7	[0.58,0.73)	51.4	0.9	0.7	11.6	0.3	0.9	-6.6	-19.4	-6.5	-10.3
8	[0.73,0.88)	56.6	0.9	0.8	12.6	0.3	1.0	-6.6	-20.0	-0.7	-3.9
9	[0.88,1.18)	54.9	0.83	0.9	12.7	0.4	1.2	-5.4	-18.7	-1.9	-5.4
10	[1.18,4.40]	55.2	1.0	0.9	10.4	0.1	0.5	-7.6	-19.3	4.5	1.9

and to different farming type and economic size classes (see table 2).

At the regional level, we notice, from figure 2, arable land increases slightly in Coupled scenario, more particularly in Pomorze & Mazury and Mazowsze & Podlasie, regions characterised by important areas of grasslands and fallow. However, for different levels of N-fertiliser and GHG-emissions prices, arable land decreases at the expense of grasslands and fallow. This is mainly due to the decrease in areas allocated to N-high consuming and GHG-emitting crop activities. The magnitude of these changes are higher in Pomorze & Mazury and Mazowsze & Podlasie. Likewise, for different economic size and farming type classes, arable land increases in Coupled scenario and decreases for high prices of N-fertiliser and GHG-emissions. Changes are mostly more important for small and mid-sized FG (ES1, ES2, ES3) and for FG characterised by high grazing activities (FT3, FT5).

As regards the arable land, it represents six aggregated uses, i.e. cereals, root and industrial crops, oilseeds, legumes and fodders. Cereals refer to wheat, maize, barely, oat, rye and other cereals. Sugar beet and potatoes are gathered into root crop category. Tobacco is referred to industrial crops, while oilseeds include sunflower, rapeseed and soya. Finally fodders refer to protein and vegetable fodders, fodder maize and other fodders.

Figure 3 shows changes in land use allocation of arable land for different policy scenarios and according to Polish FADN regions and to farming type and economic size classes. In Coupled scenario, cereals record a slight decrease at the expense of fodders, in Mazowsze & Podlasie and Małopolska & Pogórze, in small and mid-sized FG (ES2, ES3) and in high grazing FG (FT3, FT5). The same goes for high levels of GHG-emissions price. However, for high N-fertiliser price, cereals increase in Mazowsze & Podlasie, Małopolska & Pogórze and Wielkopolska & Śląsk, and decrease at the expense of oilseeds and legumes in Pomorze & Mazury. We also notice an increase in cereals' area for all ES and FT categories, but small-sized (ES1, ES2) and high-grazing FG are more sensitive to low N-fertiliser price. As regards oilseeds, they mainly decrease for high N-fertiliser price in high-sized (ES4, ES5) and crop-oriented FG (FT1, FT2). A decrease in fodders is also recorded in regions characterised by high grassland area and in high grazing FG. Legumes increase in Mazowsze & Podlasie and Pomorze & Mazury, in small and mid-sized FG and those characterised by high grazing and livestock activities (FT3, FT6).

3.5 Agro-ecological assessment

Regarding the environmental indicators, they are mainly represented by: 1- agro-ecological indices, i.e. Herfindahl Index (HI), winter crop ratio and stocking livestock density and 2- AROPAj outputs related to GHG balance and N-fertiliser use.

Agro-ecological indicators

Tables 5, 6, and 7 present the three aforementioned agro-ecological indicators according to different policy scenarios in Polish regions and to farming type and economic size categories.

At the regional level, a coupled support encourages FG to integrate more crops into their farming systems. That explains the decrease of HI in all regions, especially in high crop-oriented ones, i.e. Pomorze & Mazury. However, with increasing N-fertiliser price, FG show more specialisation by taking high N-consuming crops off from their fields, while changes in crop diversification are more ambiguous when GHG-emissions are constrained. In fact, for low levels of GHG-emissions price, HI decreases in some regions, i.e. Pomorze & Mazury and Małopolska & Pogórze (unlike in Mazowsze & Podlasie), but increases as the price moves progressively to higher values. Regarding the index of arable land vegetation cover, ratios are below 50% of threshold value chosen in this study. subsidising protein crops and legumes decreases winter crops' area, whereas this latter increases for high values

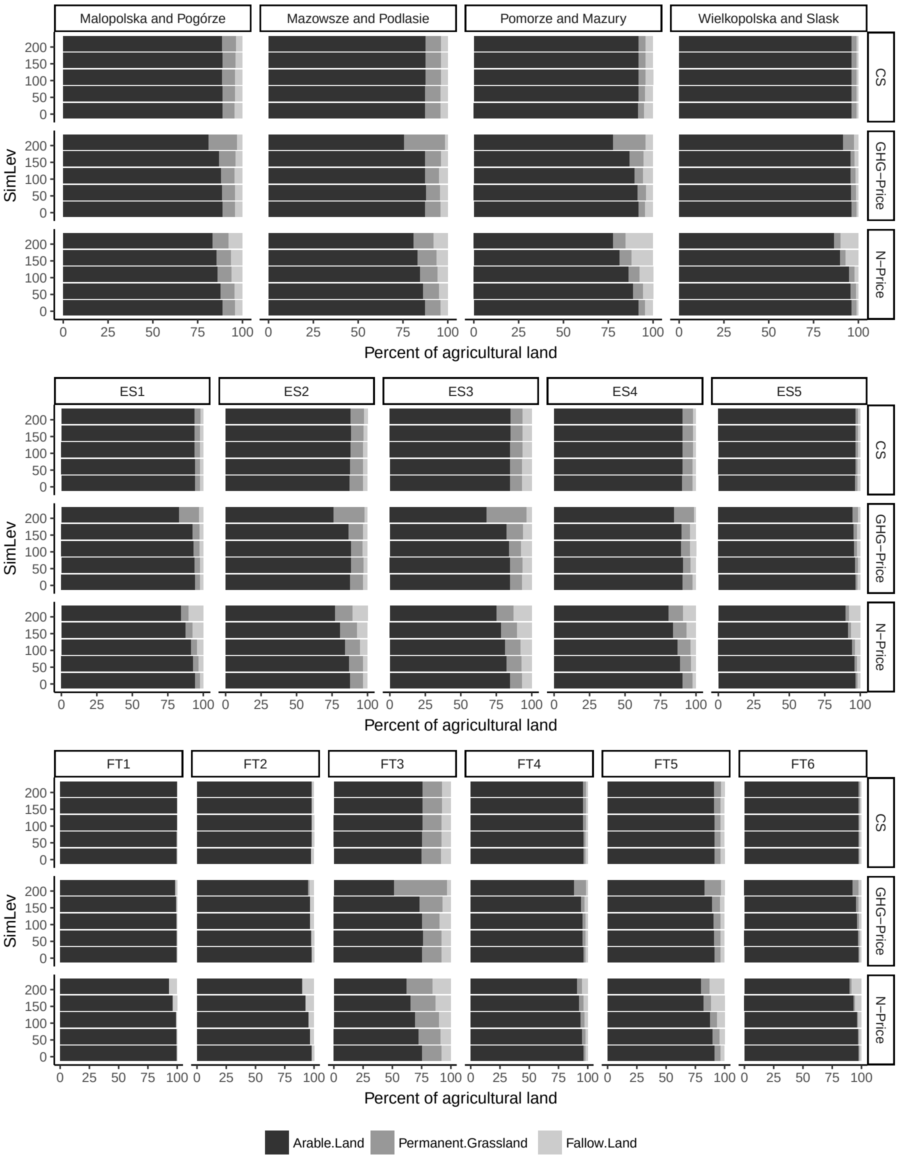

Figure 2: Changes in percent of agricultural land allocation to arable land, permanent grasslands and fallow land for different policy scenarios and according to Polish FADN regions, farming type and economic size.

of *N*-fertiliser and GHG-emissions prices. The stocking density is also below the chosen threshold value, i.e. 2 LU/ha. In Coupled scenario, Its value decreases. This is also the case when GHG-emissions price increases. However, the stocking density per hectare increases when *N*-fertiliser price goes up.

At the FG level, in Coupled scenario, HI decreases in all FT classes and in some FG characterised by high animal activity, i.e. grazing livestock and granivores (FT3, FT4 and FT5). However, by increasing *N*-fertiliser price, FG become more specialised, particularly those that belong to FT3 and FT5 categories. Regarding the ratios of winter crops' area, they are above 50% of threshold value regarding high crop-oriented FG (FT1 and FT2). They decrease in Coupled scenario and for some FT categories (FT3 and FT4) for high values of *N*-fertiliser price, while increasing for high values GHG-emissions prices, especially in FG having high granivores density. The stocking density of all FT categories is lower than 2 LU/ha. In Coupled scenario, density value increases slightly in FG belonging to FT2 category. This is also the case when N-fertiliser price goes up. However, increasing GHG-emissions price reduces significantly the stocking density per hectare for FT3 and FT5 categories.

Changes in agro-ecological indicators depend also on economic size of FG. All ES categories show more diversification in Coupled scenario and in some small and mid-sized FG (ES1, ES2 and ES3) for different values of GHG emission price. However, in this case, HI increases in high-sized FG. An increase in *N*-fertiliser price moves HI to higher values, mainly for ES1 and ES4 categories. As regards winter crops' ratios, they are all above 50% of threshold value. In Coupled scenario, ratios decrease for all ES categories, except for the highest-sized one

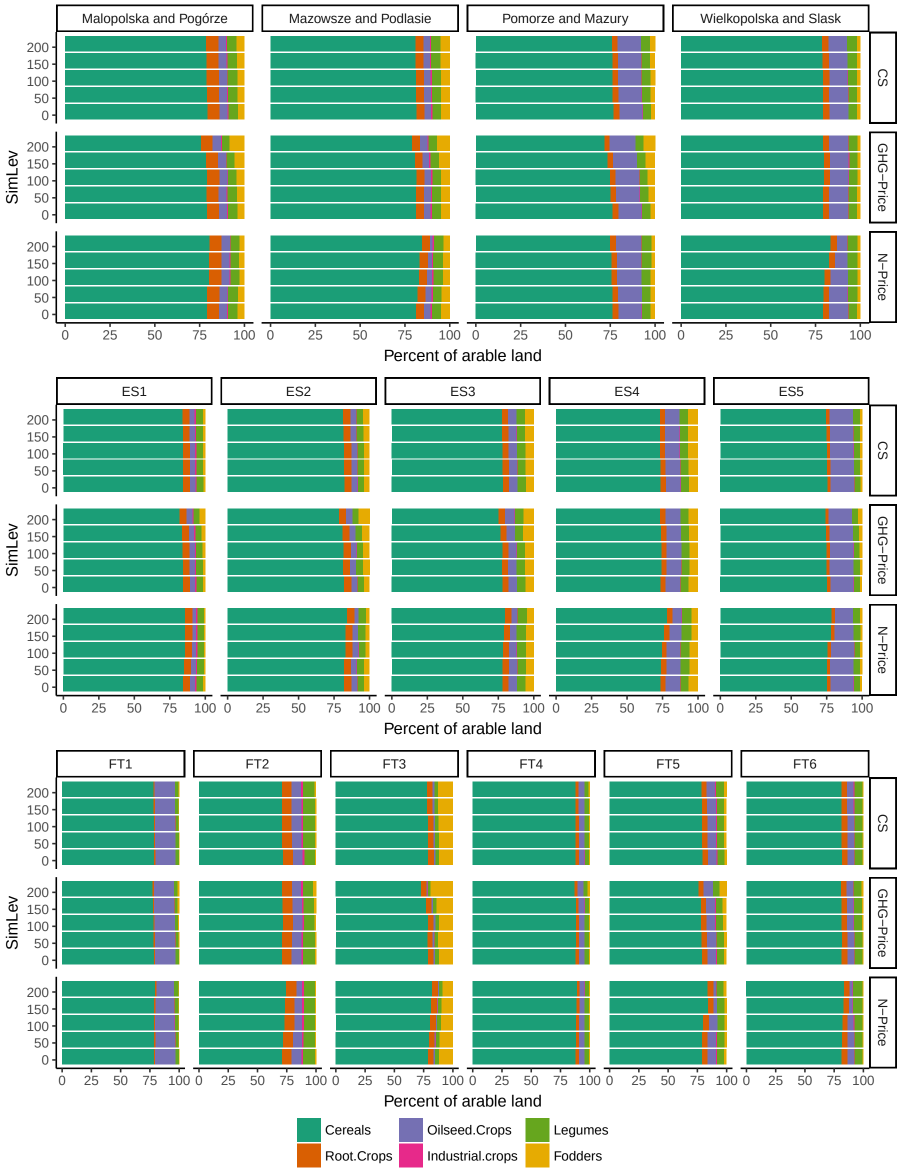

Figure 3: Changes in land use allocation in percent of arable land for different policy scenarios and according to Polish FADN regions, farming type and economic size classes.

(ES5). However, in Green scenarios, they increase for ES2, ES3 and ES4 categories. Regarding the density stocking, changes are insignificant in Coupled scenario and for different levels N-fertiliser price. However, increasing GHG-emissions price reduces significantly the stocking density on small and mid-sized FG.

N-fertiliser use and GHG emissions

Here, the results are ordered according to the utilised agricultural area (UAA) and the initial ratio of livestock density (LU/ha) in order to provide indicators related to: 1) the importance of crop activity and animal breeding in the total FG activity, and 2) the effort of each FG category to reduce N- fertiliser use and GHG-emissions. Tables 8 and 9 show respectively how the effort is varying .

Regarding N-consumption, a coupled support policy decreases the N-fertiliser use in most of FG, except for those characterised by high density of LU on small UAA (4^{th} decile) and by low LU on mid UAA (7^{th} and 9^{th} deciles). The highest reduction rate is achievable in FG with the lowest UAA (44 ha). In the case of increased N-price, 10% of the lowest UAA FG face high level of reduction and the least animal-breeding FG face low level of reduction. As those latter are mainly crop-oriented, significant reduction rates are feasible at high N-price. For different GHG-emissions price, 7^{th} and 10^{th} deciles (least animal-oriented FG) face low reduction rate. 20% of FG having the highest LU on small UAA (4^{th} and 5^{th} deciles) are more responsive to reduce N-fertiliser use. However, 30% of FG characterised by small UAA and mid-level animal activity use more N-fertilisers.

Table 5: Agro-ecological indices according to different policy scenarios for Polish FADN regions. Calculations from AROPAj outputs.

		FADN Regions			
	Scenarios	Pomorze & Mazury	Wielkopolska & Śląsk	Mazowsze & Podlasie	Małopolska & Pogórze
Herfindahl Index (%)	BAU	15.5	14.7	19.2	15.7
	CS-50	-1.1	-0.2	-0.2	-0.4
	CS-150	-1.5	-0.7	-1.0	-0.8
	N-Price-50	2.1	-0.5	0.6	-1.8
	N-Price-150	12.4	4.8	3.3	1.4
	GHG-Price-50	-1.9	-	0.9	-3.6
	GHG-Price-150	1.2	1.9	-4.1	-3.0
Winter Crops (% of Ar.L)	BAU	46.1	48.7	36.2	43.9
	CS-50	-	-0.2	-0.2	-0.1
	CS-150	-0.2	-0.4	-0.6	-0.3
	N-Price-50	0.3	-0.3	-0.1	-
	N-Price-150	0.1	-0.2	0.2	-
	GHG-Price-50	-0.1	0.1	1.4	4.8
	GHG-Price-150	1.4	2	2.7	7.2
Stocking density (LU/ha of Ag.L)	BAU	0.4	0.5	0.6	0.6
	CS-50	-	-	-0.4	-
	CS-150	0.1	-	-0.3	0.1
	N-Price-50	0.8	0.1	-	1.0
	N-Price-150	1.4	0.3	0.5	1.5
	GHG-Price-50	-4.8	-3.5	-6.9	-2.7
	GHG-Price-150	-9.1	-7.8	-12.6	-5.4

The same tendency is also observed when GHG-emissions are concerned. In Coupled scenario, GHG-emissions decrease slightly in most of FG, except for those with low LU on mid UAA (5^{th} decile). Increasing N-fertiliser use has more ambiguous impact on GHG-emissions levels. It appears that 20% of the least animal-oriented FG achieve the highest reduction rates. The same goes for deciles with the smallest UAA area and significant livestock numbers. Nevertheless, GHG-emissions increase in the 7^{th} and 8^{th} deciles characterised by higher density of LU on small UAA. For different GHG-emissions price, the 6^{th} decile faces the lowest reduction rate, having the smallest UAA area. 10% of FG with the least animal-oriented production also face low reduction rate, but higher rates are achieved in 20% of the most animal-oriented FG and in those with mid UAA (ranging between 70 and 80 ha) and significant livestock activity (4^{th} and 5^{th} deciles).

4 Discussion and concluding remarks

This study is a first attempt to apply the agricultural supply model AROPAj for Poland in order to test and evaluate the sensitivity of FG for different agricultural policies' scenarios. It has been shown that AROPAj offers large capacities to provide indicators on the sustainability and the friendliness-to-environment degree of Polish FG. Economic results, agricultural productivity and agro-ecological and environmental indices have been assessed, according to FADN Polish regions and to different FT and ES categories.

Regarding the economic aspects, the gross margin (GM) indicates the well-being of each FG as well as how the income is distributed. Results showed GM varies according to policies' scenarios. As a matter of fact, at FG level, a support policy, i.e. Fair and Coupled scenarios, increases GM thereby reducing the inequality between FG, but the magnitude of change is higher if payments are equally-distributed. This is in line with several studies that have shown direct payments reduce inequality (Keeney 2000, Mishra et al. 2009), contrary to environmental regulation measures. For instance, raising N-fertiliser and GHG-emissions prices increases inequality, but it is less important in the former case. Furthermore, the reader may notice there is no large difference in income distribution between scenarios. This is because we considered GM of representative FG rather individual income, inequality measure being highly sensitive to data aggregation (Deppermann et al. 2016). For this reason, it is important to assess and compare the income distribution between regions as well as between FT and ES categories.

The assessment of land shadow prices pointed out FG react differently depending on payment levels, prices of N-fertiliser and GHG-emissions and their technico-economic orientation. We then showed large uniform and coupled payments make the farmer willing to pay higher land value because of the raise in marginal land productivity. Thus, land shadow prices increase mainly in high-livestock density FG in Fair scenario, and in FG with small and mid UAA. Nevertheless, low coupled payments result in low shadow prices, thereby increasing the willingness of FG to "lease out" land. This applies also to the Green scenarios, more importantly by limiting N-fertiliser use. In this case, the decrease in land shadow price is higher in crop-oriented FG, while the increase is more significant in FG with mid-livestock density and UAA.

Changes in land use allocation occur for the different agricultural policies, mainly in Green scenarios. Although,

Table 6: Agro-ecological indices according to different policy scenarios for six farming type classes. Calculations from AROPAj outputs.

		Farming type					
	Scenarios	FT1	FT2	FT3	FT4	FT5	FT6
Herfindahl Index (%)	BAU	18.4	13.6	19.7	23.8	14.2	17.6
	CS-50	-	-1.2	-0.4	-	-0.7	-0.1
	CS-150	-0.4	-1.5	-1.5	-0.5	-0.7	-0.3
	N-Price-50	-0.4	0.4	3.4	0.4	-1.0	0.5
	N-Price-150	1.9	5.7	13.2	3.4	9.8	8.1
	GHG-Price-50	-0.5	-0.7	-1.0	-2.5	-1.6	-0.3
	GHG-Price-150	0.1	0.5	-2.9	-2.2	-2.3	0.9
Winter Crops (% of Ar.L)	BAU	54.0	51.7	31.3	36.4	41.8	43.3
	CS-50	-	-0.2	-0.3	-	-0.3	-
	CS-150	-0.1	-0.1	-1.6	-0.2	-0.3	-0.1
	N-Price-50	0.7	0.2	-0.2	-2.3	2.1	1.1
	N-Price-150	1.6	4.1	-4.0	-2.7	5.7	2.2
	GHG-Price-50	0.3	0.5	-1.5	5.3	1.0	2.1
	GHG-Price-150	1.2	0.8	1.7	7.8	1.9	3.7
Stocking density (Average of LU per ha of Ag.L)	BAU	0.02	0.1	0.8	1.4	0.4	0.5
	CS-50	-	0.3	-0.1	-	-	-
	CS-150	-	0.3	-0.1	-	-	0.2
	N-Price-50	0.6	0.2	0.3	0.2	0.9	0.3
	N-Price-150	2.5	1.5	0.9	0.2	2.6	0.4
	GHG-Price-50	-3.8	-4.4	-8.8	-1.6	-8.3	-2.2
	GHG-Price-150	-9.5	-10.0	-17.8	-3	-16.7	-4.6

a coupled support policy leads also to land use change (LUC) in favour to arable land in regions characterised by high grassland availability, the decrease in grassland areas doesn't exceed 5% for all FT and ES categories. Notice, this threshold value has to be treated with caution because agricultural area was not aggregated within regions. It would then better to decline activities' areas according to FG's technico-economic orientation and economic size within each region.

For different levels of *N*-fertiliser and GHG-emissions prices, areas allocated to certain crop activities decrease, more particularly at the expense of high carbon stock land, mainly grasslands. While increasing *N*-fertiliser price disadvantages growing high *N*-consuming crops, i.e. oilseeds and legumes, against cereals, high levels of GHG-emissions price disadvantages growing high GHG-emitting crops, i.e. fodders, cereals and oilseeds against legumes. In Coupled scenario and for high levels of GHG-emissions price, LUC is mostly more important in small and mid-sized and high-grazing FG. However, for high *N*-fertiliser price, the major LUC occurs in high-sized and crop-oriented FG. Furthermore, subsidising legumes and protein crops fosters crop diversification, whereas an environmental regulation measure increases specialisation. Regarding the index of arable land vegetation cover, ratios decrease in Coupled scenario for animal-oriented FG (mainly with grazing livestock and granivores' activities) and for all ES categories, except for high-sized FG. While stocking density increases by limiting *N*-fertiliser use, it decreases for high GHG-emissions price, more specifically in high-grazing and small and mid-sized FG. All these features have led to changes in *N*-fertiliser use and GHG emissions. It then appears the relationship between FG's technico-orientation and reduction in *N*-use and GHG-emissions vary according to policies' scenarios. Reduction rates are more important in Green scenarios than in Coupled scenario. For high *N*-fertiliser and GHG-emissions prices, crop-oriented and intensive animal-oriented FG achieve high reduction rates.

Table 7: Agro-ecological indices according to different policy scenarios for five economic classes. Calculations from AROPAj outputs.

		Economic size				
	Scenarios	ES1	ES2	ES3	ES4	ES5
Herfindahl Index (%)	BAU	18.2	18.4	16.1	13.9	15.5
	CS-50	-0.3	-0.1	-0.5	-0.8	-0.5
	CS-150	-0.4	-1.0	-1.2	-1.2	-1.2
	N-Price-50	1.4	-1.7	-0.4	0.9	-
	N-Price-150	6.6	4.9	4.6	8.2	0.5
	GHG-Price-50	-0.7	-3.7	-2.0	1.4	-0.1
	GHG-Price-150	-0.3	-3.5	-3.8	2.1	1.4
Winter Crops (% of Ar.L)	BAU	43.6	38.7	41.4	43.1	47.9
	CS-50	-0.4	-0.2	-0.4	-	0.2
	CS-150	-0.4	-1.3	-0.7	-0.2	0.1
	N-Price-50	1.7	0.3	-1.1	1.6	0.3
	N-Price-150	1.8	0.1	-0.5	1.7	4.4
	GHG-Price-50	0.6	1.1	-0.1	3.1	0.7
	GHG-Price-150	1.5	2.8	3.4	5.2	1.6
Stocking density (Average of LU per ha of Ag.L)	BAU	0.3	0.5	0.5	0.6	0.9
	CS-50	-	-0.2	0.1	-	-
	CS-150	-	-	0.1	-	-
	N-Price-50	0.2	1.0	0.3	-	0.1
	N-Price-150	0.8	1.6	0.6	0.6	0.2
	GHG-Price-50	-6.2	-6.3	-5.3	-6.8	-1.6
	GHG-Price-150	-10.2	-12.7	-11.5	-12.8	-4.2

Table 8: Variation in percent of average *N*-fertiliser quantities according to FG's technico-economic orientation for different scenarios.

Deciles of total population	Average agricultural area (ha)	Livestock Unit per ha	Average *N*-fertiliser use	Reduction rate					
			BAU (tN)	CS (%)		N-Price (%)		GHG-Price (%)	
				50	150	50	150	50	150
1	44.7	[0.45,0.58)	12.6	-1.7	-1.5	-8.4	-21.0	8.4	5.8
2	50.0	[0.07,0.16)	18.7	-0.1	-0.2	-2.1	-8.6	-9.7	-9.9
3	51.4	[0.58,0.73)	12.0	0.0	-0.4	0.0	-11.2	6.3	2.6
4	54.9	[0.88,1.18)	12.1	0.0	0.7	0.3	-12.8	-26.9	-25.9
5	55.2	[1.18,4.40]	8.5	-0.2	-0.9	-5.3	-15.5	-20.6	-22.5
6	56.6	[0.73,0.88)	13.3	1.1	0.8	-6.9	-15.2	26.1	26.8
7	70.5	[0.00,0.02)	31.5	-0.1	-0.2	-2.9	-9.9	-0.1	-0.9
8	71.0	[0.16,0.35)	18.8	-0.6	-0.8	2.0	-6.9	-9.6	-13.6
9	79.0	[0.35,0.45)	26.3	3.4	3.0	2.6	-18.8	-15.2	-17.8
10	90.9	[0.02,0.07)	42.6	0.3	-0.1	-2.1	-7.3	-3.3	-5.3

Table 9: Variation in percent of average GHG-emissions according to FG's technico-economic orientation for different scenarios.

Deciles of total population	Livestock Unit per ha	Average agricultural area (ha)	Average GHG emissions	Reduction rate					
			BAU (tCO_2eq)	CS (%)		N-Price (%)		GHG-Price (%)	
				50	150	50	150	50	150
1	[0.00,0.02)	70.5	21.3	-0.1	-0.8	-3.5	-19.4	-1.2	-14.7
2	[0.02,0.07)	90.9	41.4	-0.5	-0.9	-6.3	-16.3	-5.3	-19.7
3	[0.07,0.16)	50.0	25.8	0.1	-0.1	-0.5	-7.5	-7.2	-25.4
4	[0.16,0.35)	71.0	86.8	-1.3	-1.5	3.4	-1.0	-13.2	-39.1
5	[0.35,0.45)	79.0	114.3	3.3	2.4	0.9	-6.1	-24.3	-36.2
6	[0.45,0.58)	44.7	77.6	-2.9	-2.1	-13.4	-15.2	16.3	-9.3
7	[0.58,0.73)	51.4	104.8	-0.1	-1.3	5.4	4.7	-7.0	-21.4
8	[0.73,0.88)	56.6	141.5	-2.0	-2.8	-0.6	-0.4	43.1	10.8
9	[0.88,1.18)	54.9	178.8	0.0	-0.2	3.4	2.0	-34.3	-44.0
10	[1.18,4.40]	55.2	172.0	-0.2	-0.7	-3.4	-4.2	-26.7	-28.0

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