Greening the CAP: what implication of crop diversification for farming systems in economic terms

Ben Fradj N.[1], Jayet P.-A.[2], Rozakis S.[1,3], Georganta E.[4], Arampatzi P.[3], Jędrejek A.[1], Kozak M.[1]

[1] Institute of Soil Science and Plant Cultivation, State Research Institute, Dept. of Bioeconomy and Systems Analysis, 24-100 Pulawy, Poland

[2] UMR Economie Publique, INRA, AgroParisTech, Université Paris-Saclay, 78850 Thiverval-Grignon, France

[3] School of Environmental Engineering, Technical University of Crete, Akrotiri, Chania Crete, 73100, Greece

[4] International Hellenic University, 14th km Thessaloniki - Moudounia, 57001 Thermi, Greece

Abstract

This paper aims to assess the impacts of 2013 CAP reform in Poland. We provide a comprehensive approach to modelling crop diversification options at farm group level. Belonging to the category of mathematical programming tools, AROPAj model is used to determine the number and mix of crops that may be efficiently cultivated. We consider an energy fast-growing plantation, i.e, willow, to enlarge the potential number of eligible crops. In this respect, we explore the impacts of crop diversification when the number crop limit and the payment benefiting areas planted with willow vary.

1 Scientific Context

After a succession of CAP reforms, several studies have been undertaken to assess the impacts of various policy instruments. In most cases, impact assessments (IA) on farm net benefit stem from calculations based on observed crop mix neglecting farmers' response regarding the adjustment of cropping plans to cope with a potential decrease in their welfare. Appropriate models are therefore required to generate trustworthy estimates useful for policy analysis. For instance, farm models have been extensively used to replicate farmers' decisions and assess policy impacts, their specification depending on the modelling approach (Reidsma et al. 2018, Kremmydas et al. 2018). So far, mathematical programming (MP) models are widely applied for ex-ante and ex-post farm-level evaluation of farmers' choices, following a policy change (Reidsma et al. 2018, Espinosa et al. 2016, Arfini 2012, Salvatici et al. 2000).

The methodological advances in agricultural economics and computer science have resulted in the development of positive mathematical programming (PMP) models and the extension of linear programming (LP) models (Espinosa et al. 2016, Baranger et al. 2008). Depending on the modelled agricultural systems' characteristics, the choice of modelling tools remains a matter of debate. While PMP models are particularly used when specific information of the production process is scarcely available, LP models are mostly compatible with a precise representation of complex technical and multi-scale agricultural systems (Baranger et al. 2008). Additionally, the superiority of PMP models to deliver optimal solution identical to observation is counter-balanced by the easiness of LP models to provide detailed post information on primal and dual variables in different contexts (Louhichi et al. 2013)

Wide range of MP models have been used to evaluate the effectiveness of CAP measures, thereby assessing changes in land use, input and economic performance of farms in consequence of the structural reforms, and to examine policy instruments and propose alternatives. In the context of greening (2014 - 2020), most of IA have been delivered for regional or country cases (Mahy et al. 2015, Solazzo et al. 2015). For instance, Solazzo and Pierangeli (2016) developed a regional PMP model in which the whole set of greening commitments and sanctions were implemented, to estimate the behaviour of Northern Italian individual farms in terms of land use and income. Using an LP model, Czekaj et al. (2013) analysed the impacts of different scenarios related to greening payments on Polish farm revenues and production.

Nevertheless, few studies provided a comprehensive farm-level analysis at wider scale, i.e. European level, using mainly PMP models. While Louhichi et al. (2017) integrated crop diversification measures at individual farm level in IFM-CAP model, Gocht et al. (2017) used a sectoral CAPRI model, in which European farms were aggregated into representative farm types within regions. This approach is mainly used to capture the heterogeneity of EU farms in terms of farming systems, economic size and policy impacts (Louhichi et al. 2017, Espinosa et al. 2016). Accordingly, farm-level models cover a large part of crop and animal activities, thereby reflecting the behaviour of several farm types using different agricultural practices.

Likewise, AROPAj model is an optimisation technical-economic tool of the European agricultural supply, describing numerous farming activities ranging from land allocation, crop production, to animal husbandry. Individual farmers are well represented as they are clustered into farm groups (FG) based on their technico-economic orientation, their economic size and their altitude class within regions. In the most recent version of the model (V_5-AROPAj), in which the main micro-economic data are acquired from FADN-2012, 1 993 FG were created for 136 European FADN regions, from a part of 83 000 individual FADN sampled farms (excluding those of FADN farm type 2 and 3), representing 129.3 million hectares (Mha).

Furthermore, the AROPAj model has been extensively used to assess the interactions between agricultural activities and the environment through evaluating agro-environmental policies (Bourgeois et al. 2014, Jayet and Petsakos 2013), climate change adaptation and mitigation (Leclère et al. 2013, De Cara and Jayet 2011, Durandeau et al. 2010, De Cara et al. 2005), and cellulosic bioenergy supply (Ben Fradj et al. 2016, Ben Fradj and Jayet 2018). Although the model was initially designed to evaluate the impacts of the CAP reforms in the EU (Galko and Jayet 2011), the greening measures have not been assessed yet. That becomes possible by the present version, in which a new module considering crop diversification options is integrated.

In addition, despite the large number of greening IA analyses, to our knowledge, none of them, went beyond merely assessing the economic and/or environmental impacts of greening measures and lacking a cost analysis when one or two command of crop diversification options, i.e. number and/or area's threshold of eligible crops, change. By means of the upgraded version of AROPAj, we then aim at assisting policy makers to make informed choices regarding the number and mix of eligible crops that may be efficiently cultivated, by adding relevant variable as a command of the optimisation problem. To be consistent with the EU strategies, for instance the updated bioeconomy strategy, we suggest the integration of alternative bioenergy crops such as willow, to allow farmers to increase their sustainability, ecology and biodiversity performance. As a first attempt, we limit the study scope to one Member State (MS), which is Poland, to better capture and validate the economic and land use allocation. This latter are spatially analysed, basing on a high resolution spatialization module developed to locate the different FG (Cantelaube et al. 2012, Chakir 2009).

The paper is organised as follows. Section 2 introduces the modelling framework and tool, i.e AROPAj model, used to assess the impacts of crop diversification measures. Section 3 describes the application of AROPAj to the Polish case as well as the methodology used to integrate an energy fast-growing plantation, i.e. willow. Section 3 presents and discusses results regarding farm income and land use allocation. Finally, Section 4 presents our conclusions and perspectives.

2 Modelling tool for assessment of crop diversification options: AROPAj - an European agricultural supply model

2.1 Model description

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 detailed in manual from Jayet et al. (2017). The structure is mainly accommodates the technico-economic farm profile designed according to the a microeconomic approach (Arfini 2012). It consists of independent, mixed integer and LP models, each of which describes a typical farming system of an individual representative farm called FG. Dealing with an optimisation problem, each FG 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:

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

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

where x_k and g_k are respectively the (nx1) vector of activities and the (1xn) vector of gross margins for the k^{th} FG. 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 FG 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 which are added in the form of sub-matrices referring to the objective, right hand side (RHS) compounds, activities, constraints, and matrix elements.

2.2 CAP reforms modelled in AROPAj

AROPAj was used to assess the impacts of the successive CAP reforms ranging from the 1992 MacSharry, to the 2003 Luxembourg agreement. As for 2013 reform related to crop diversification, measures have been recently integrated to assess farmers' choices regarding environmentally-friendly production schemes. The 2013 CAP reform supports evolution towards the environment through green direct payments introduced in the agenda of CAP. Greening measures, usually referred as greening of CAP, come as an answer to contemporary environmental issues related to agricultural production, and payments are proposed as incentives benefiting farmers in counterpart of environmentally friendly choices. More precisely, the CAP moves to support agricultural activities not only in terms of produced quantities but also in terms of more sustainable and showed environmental concerns.

In order to press the farmers to qualify for an increasing part of subsidy, the CAP is reshaped so that they have to adopt certain practices or to conform to certain conditions leading to crop diversification. Through controlling the number of crops cultivated in the farm as well as crop land sharing, the main aim of this measure is to reduce pesticide, fertiliser and water use as well as the environmental damage resulting from the excessive use of land. It also enhances biodiversity while improving soil organic matter, water quality and it can reduce soil erosion and the effects of climate change.

The CAP crop diversification options were designed as to account for three cases excluding the one from the other and making the farm eligible for additional green payments:

1. the threshold in defining what is a small farm with arable land area less than 10 ha;
2. the threshold referring to medium farms with arable land ranging between 10 and 30 ha and committed to cultivate at least two different crops and main crop area should not exceed 75% of arable land;
3. bigger farms with more than 30 ha and at least three crops have to be cultivated and the area of two main crops should not exceed 95% of arable land.

In addition, there is no condition in terms of arable land coverage in two cases: 1) the total area devoted to fallow, temporary meadow and legume is over 75% of arable land; 2) the total area devoted to grasslands (permanent and temporary meadow) and rice is greater than 75% of the utilised agricultural area (UAA).

2.3 Crop diversification mockup

In many mathematical programming models conceived for optimising farming system's decisions, given the total amount of UAA, crop areas (or shares of land dedicated to series of crops) refer to standard decision variables (so-called activities), unlike the number of crops by itself. Rendering this number a decision variable in addition to a series of threshold conditions (e.g. limits for subsidy exclusion) requires the insertion of integer variables (usually restricted to binary variables). Here, we explain how a part of CAP greening options was stylised and implemented in the model Jayet et al. (2017), through adding series of parameters, real and binary variables and constraints.

A comprehensive CAP greening block is detailed in table 1 . We denote j by the crop, most of parameters are k-indexed, depending on FG. The block calls for:

Parameters:

- area limits: $sdmin(k)$, $sdmax(k)$ (share of land in [0,1]);
- subsidy related to crop diversification: $sudiv(k)$ (in €ha^{-1});
- numbers of crops delineating farm size categories: $ndivb$ and $ndivc$;

- minimum area dedicated to crops accounting for the real number of crops: $thrss(k)$ (in ha).

Variables:

- crop areas (pre-existing variable): $xtk(j,k)$ (in ha);
- number of farms in the farm group: $zf(k)$;
- binary variables of 1-value when $xtk(j,k)$ is strictly positive: $itk(j,k)$;
- number of crops cultivated in the MP solution, of value greater than $thrss(k)$: $nttjk(k)$;
- total amount of land accounting for agricultural activities: $xarab(k)$ (in ha);
- total amount of land accounting for a one-size category: $xdiv(b)$, $xdivc(k)$, $xdivd(k)$ eligible for green support and $xdive(k)$ when the farm opts out the green payment (in ha);
- binary variables related to diversification limits: $idivb(k)$, $idivc(k)$, $idivd(k)$, $idive(k)$.

Constraints:

- sub-block dedicated to n-constraints designed for the CAP greening: $eld(n,k)$, e.g. $eld(13,k)$: $xdivb(k) \leqslant sdmin(k)$; $eld(13,k)$: $xdivb(k) \leqslant sdmin(k)$;
- specific constraints related to crops accounting for the number of crops: $ild(j,k,n)$, e.g.$ild(j,k,2)$: $xtk(j,k) \geqslant thrss(k)\, zf(k)$.

Table 1: The AROPAj block for CAP greening option. The first line refers to labels of MP variables. The left column refers to labels of constraints. The cell contents refer to values, predefined or defined by parameters, or zero values by default. The k-index refers to a farm group and the j-index refers to a crop.

	xtk(j,k)	xdivb(k)	xdivc(k)	xdivd(k)	xdive(k)	xarab(k)	idivc(k)	idivd(k)	idivb(k)	idive	itk(j,k)	nttjk(k)	zf(k)		RHS
obj		sudiv(k)	sudiv(k)	sudiv(k)										=	
eld(1,k)	-1					1								<	
	j eligible														
eld(2,k)		1	1	1	1	-1								<	
eld(13,k)		1											-sdmin(k)	<	
eld(3,k)			1										-sdmax(k)	<	
eld(4,k)			-1					-99999	-99999	-99999			sdmin(k)	<	
eld(10,k)				-1			-99999		-99999	-99999			sdmax(k)	<	
eld(5,k)			1				-99999							<	
eld(6,k)				1				-99999						<	
eld(11,k)		1							-99999					<	
eld(12,k)					1					-99999				<	
eld(9,k)							1	1	1	1				<	1
eld(7,k)											-1	1		<	
eld(8,k)											0.999999	-1		<	
eld(14,k)							ndivb					-1		<	
eld(15,k)								ndivc				-1		<	
ild(j,k,1)	1										-99999			<	
ild(j,k,2)	-1										thrss(k)			<	

One of the most important features of AROPAj model is its capacity to generate spatial outcomes at a fine geographical scale, which can be aggregated at regional level.

2.4 Localisation of AROPAj FG and activities

To spatially locate FG and activities, Cantelaube et al. (2012) integrated a spatial distribution module, thereby expanding the micro-economic data by physical information on climate (Monitoring Agriculture from Remote Sensing project database), soils (JRC), land cover (CorineLandCover), land use (LUCAS) and terrain elevation (digital elevation model). The spatialisation module consists on downscaling model results at fine-resolution scale for each crop activity within a region. For this purpose, three steps are required:

1. Estimation of crop location by intersecting maps on physical data at a grid cell level (1km x 1km);
2. Calculation and refining crop location probabilities based on cross entropy method Chakir (2009);
3. Estimation of FG location by assigning them presence probabilities in each grid cell.

A description of the modelling process ranging from data collection to spatialisation is presented in Figure 1.

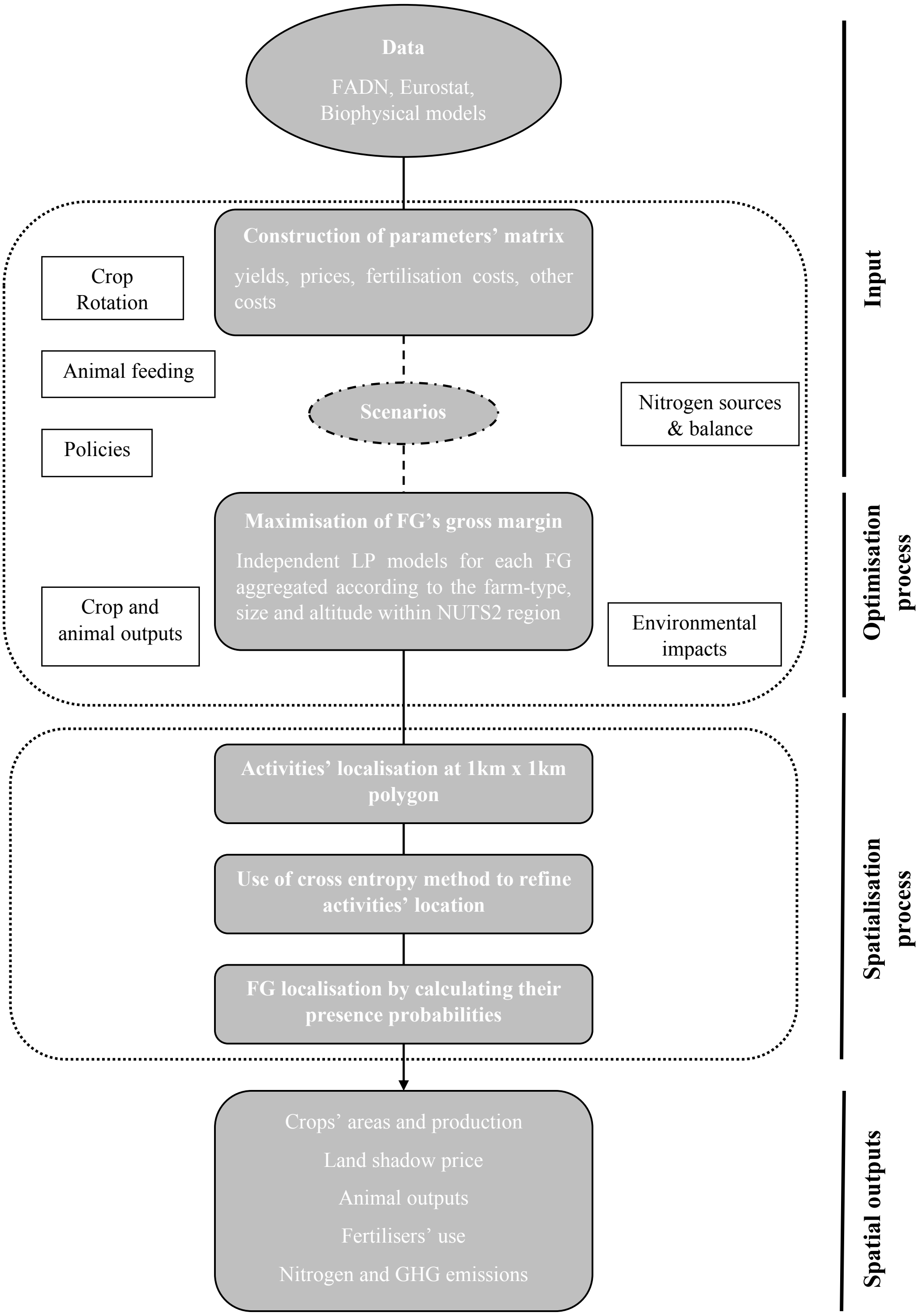

Figure 1: Schematic representation of AROPAj modelling processes ranging from data collection and treatment, scenarios' construction, optimisation, to outputs' spatialisation

3 Implementation of crop diversification measures in Poland

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. Since the implementation of the CAP, the agricultural sector has become one of the main pillars of economy, employing 10.5% of the work force (EC 2017). The sector 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 viability of agricultural sector is though 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. 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. As it is the case of other MS, 30% of greening direct payments are committed to foster the crop diversification, the maintenance of permanent grasslands and the conversion of 5% of Arable Land (ArL) into Ecological Focus Areas (EFA).

In AROPAj model, individual Polish farmers are well represented as they are clustered into FG 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 (apart from farm type 2 and 3). Horticulture and permanent fruit crops, e.g. vineyards and olives, are not included into AROPAj crop production activities.

If we are to test the consistency of some AROPAj results, Table 2 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 2: 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

3.1 Integration of dedicated energy crops in the Polish context

In AROPAj model, and given the modelled UAA, each FG may opts for one of the three farm categories eligible for the green payment or may opt out of this payment. The clustering of FADN-surveyed farms into FG as well as the number of crops cultivated by each FG depends on pre-existing crops referring to data sourced from sampled farms belonging to FADN surveys. This clustering implies that the potential number of crops in a FG is greater (and usually much greater) than the number of crops in each of the sampled farms accounting for the FG. Activating the CAP greening option is driven by an increase in number of eligible crops. The potential number of crops can be enlarged by considering new crops such as short rotation trees. Here we opt for willow as a candidate, with the aim to explore the impacts of CAP greening when varying the number crop limit and the specific payment benefiting areas planted with willow.

The interest for energy fast-growing plantations, e.g. willow short rotation coppice (SRC), has increased with the introduction of greening payments, which is enabling an expansion of crop diversification (Bartolini et al. 2015). According to Monteleone et al. (2018), the insertion of energy crops foster the transition towards a multifunctional agriculture reconciling farming economics with ecology. Being eligible to EFA, growing willow allows farmers to acquire additional revenue. Nevertheless, the crop has to be cultivated sustainably with respecting the environment and natural resources constraints, to mitigate climate change, to conserve biodiversity, and to fulfil the requirements for the development of a bio-based economy.

In Poland, willow sector has the most well developed biomass network. Grown on more than 8 000 ha in 2010, the crop represents a high potential for bio-based energy and materials. Being harvested in SRC system (every

3-5 up to 25-30 years), its yield records are relatively high depending on management practices (Stolarski et al. 2019). SRC delivers a large variety of ecosystem services in terms of Carbon storage and biodiversity (Emmerling and Pude 2017). Moreover, Schmidt-Walter and Lamersdorf (2012) showed that well-managed willow SRC on low-lying drinking water catchment areas can prevent nitrate and leads to a moderate impact on groundwater, but this depends on management measures.

In AROPAj model, a wide range of perennial dedicated activities were integrated, ranging from miscanthus, switch-grass, poplar, to willow. In this study, we consider only willow. As regards yields, we suggest to correlate data with that of a control plant, e.g oat. Willow yield is therefore estimated by combining management data with local productivity of oats as mentioned in Mola-Yudego and Aronsson (2008), through applying Eq.1 using parameter values as shown in Table 3 along with yield of oats as benchmark.

$$Y_{willow,l} \ = \ b_0 + b_1 yield_{oats,l} PLA_{lkj} + GRO_c PLA_{lkj} + b_2 EXP_{lkj} \tag{1}$$

Table 3: Parameter estimates for Eq.1 (Mola-Yudego and Aronsson 2008)

Parameter	Estimate	Parameter	Estimate	Parameter	Estimate
b0	2.213	b2	-0.204	EXP	1.5
b1	0.075	GRO50*	-0.129	PLA	30
b2	-0.204	GRO25	-0.039		

The estimated willow yields at FG level are in line with those provided in the frame of BioMagic[1] project. In this regard, Figure 2 shows the distribution of available data on 3-year rotation yields within the Polish soil complexes which belong to marginal land, and medium and weak quality grassland.

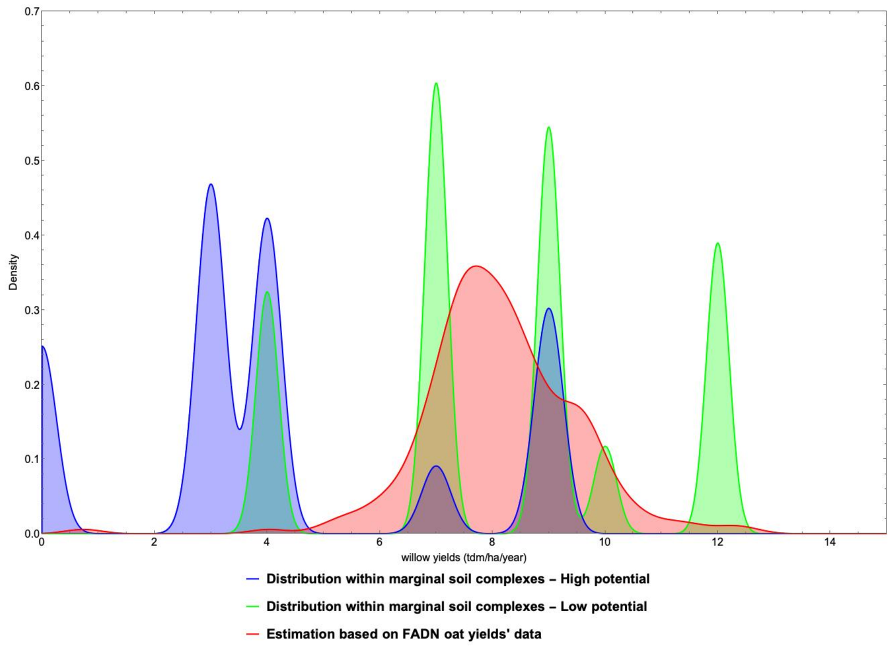

Figure 2: Distribution of willow yields as estimated by our approach and within marginal soil complexes considered as potential areas for willow plantation.

3.2 Simulation scenarios and assumptions

AROPAj is flexible enough so that many scenarios can be tested, by scanning different command variables and parameters. Increasing the number of eligible crops is one of the former options. In fact, since FG represent higher number of crop activities than those of FADN sampled farms, we suggested to increase the number of eligible crops than what is assigned by the model calibration. A simple counting of number of crop activities per FG was

[1]BIOproducts from lignocellulosic biomass derived from MArginal land to fill the Gap In Current national bioeconomy, is a national project funded by the National Center for Research and Development (NCBiR) under the program BIOSTRATEG

done in order to set the starting point of the scanning grid. From Figure 3 one can notice that the lowest number of activities is about 2 recorded in Mazowsze and Podlasie, and Malopolska and Pogorze, and the highest is 15 in Wielkopolska and Slask. The number of required crops, hereinafter referred to as *ndiv* was then varied from 2 to 16 crops.

To this was added a second scanning regarding one of willow parameters, i.e. subsidy. A wide range variation of willow subsidy amount was then proceeded, with the double aim of increasing the number of eligible crops and ensuring the multifunctionality of Polish agriculture. We proposed to scan the subsidy value from 0 to €250 ha^{-1} by increments of 10. In a first attempt, we set the parameters related to the crop's threshold area (*thrss*) and the maximum area limit (*sdmax*) to 1 ha and 95% of UAA, respectively. In addition, we considered that willow area is limited to 15% of UAA, its price is fixed at €77 tdm^{-1} and the annual costs are about €395 ha^{-1}. All these conditions were tested for two scenarios, i.e. low and high, representing low and high values of subsidy for crop diversification, i.e. €50 ha^{-1} and €100 ha^{-1}, respectively.

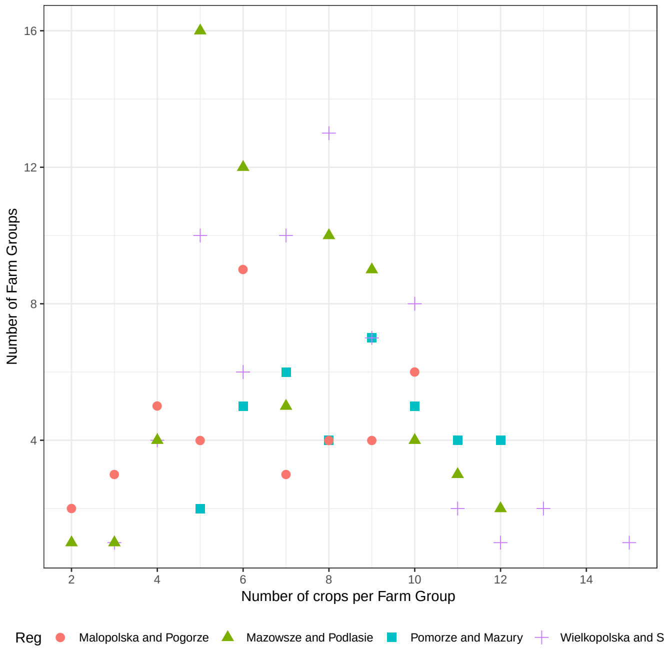

Figure 3: Distribution of the number of crop activities as calibrated for AROPAj FG according to the Polish FADN regions

4 Results and discussion

In this section, the impacts of different scenarios regarding the number of eligible crops (*ndiv*) and crop diversification subsidy (*sudiv*) on FG's economic outcome, i.e. gross margin, and land use change were declined according to the four Polish FADN regions. Two scenarios were compared with one another and assessed against a baseline situation, in which *ndiv* and willow subsidy are fixed at 0, for two levels of *sudiv* fixed at 50 and €100 ha^{-1}. Since crop production varies widely from one region to another, depending on soil quality and the farming system and economic size, the results regarding willow ara were spatialized at a fine geographical scale (FG level) to emphasize disparities between the different Polish regions.

To understand and explain the results below, we first provide an overview of Polish agriculture as modelled by AROPAj. As showed in Table 4), Poland is known by an important agricultural activity characterised by an intensive crop management dominated by cereal farming up to 70% of UAA. Regarding animal husbandry, the greatest shares are recorded in Wielkopolska and Śląsk representing the highest livestock density per hectare of grasslands, and Mazowsze and Podlasie representing the highest area of grasslands.

4.1 Impact on farm income

From Figures 4 and 5, we notice that in most cases a support for crop diversification makes the farmer loosing profit, according to regions. The higher the number of imposed crops, the lower the profit. For *sudiv* equal to €100 ha^{-1}, the rates of loss range between 0.05 to 4 %, for *ndiv* lesser than 8 imposed crops, in Pomorze & Mazury and Małopolska and Pogórze. For the same number of eligible crops, the loss is up to 5-7% in Wielkopolska and Śląsk,

Table 4: Agricultural characteristics of Polish FADN regions - Results aggregated at regional level as estimated by V_5-AROPAj model calibrated on 2012-FADN data (Ben Fradj et al. 2018)

	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

Mazowsze and Podlasie, regions characterising by a high husbandry activities. Imposing a high number of crops or/and allocating a low subsidy level results in higher rates of loss. As a matter of fact, decreasing *sudiv* down to €50 ha^{-1} may lead to a decrease in income ranging from 4 to 12.5%.

Our results are somehow similar to those found in the literature, regardless the modelling tools and methodologies used for assessing the impacts of crop diversification options. For instance, Czekaj et al. (2013) based on an LP farm optimisation model FARM-OPTY to assess the effects of integrating greening scenarios with different direct payments in Poland. The authors found that although most of farmers complied with the crop diversification constraints, an appropriate diversification within simplified cropping systems had a negative impact on production, and consequently on farm revenues. The average decrease varies between 3.8 and 4%.

In all regions, a subsidy allocation to willow may slightly alleviate the loss of profit. However, assuming that FG adjust their cropping plan to integrate willow, for low number of required crops, increasing the subsidy level results in an insignificant impact on incomes. This finding is in line wtih Wąs et al. (2014) who used a farm optimisation model combined with a PMP technique to assess the impacts of greening reform on Polish farm types.

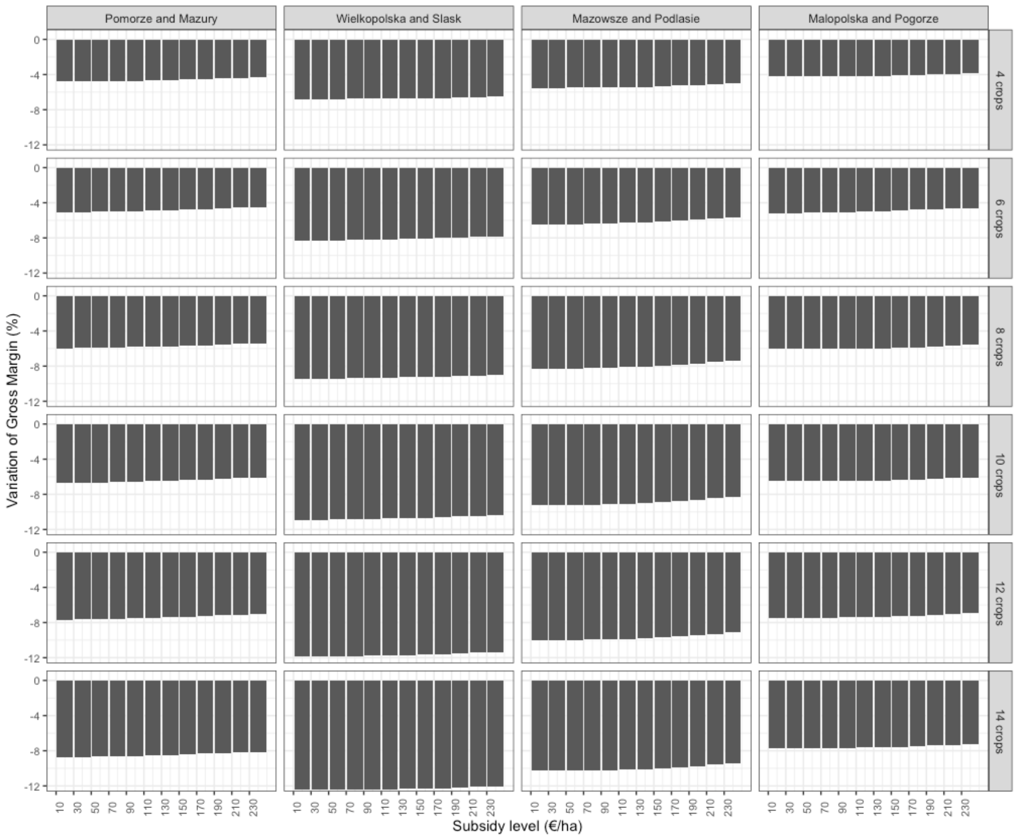

Figure 4: Average variation in gross margin per hectare in percent in Polish FADN regions for different *ndiv* levels and *sudiv* equal to €50 ha^{-1}

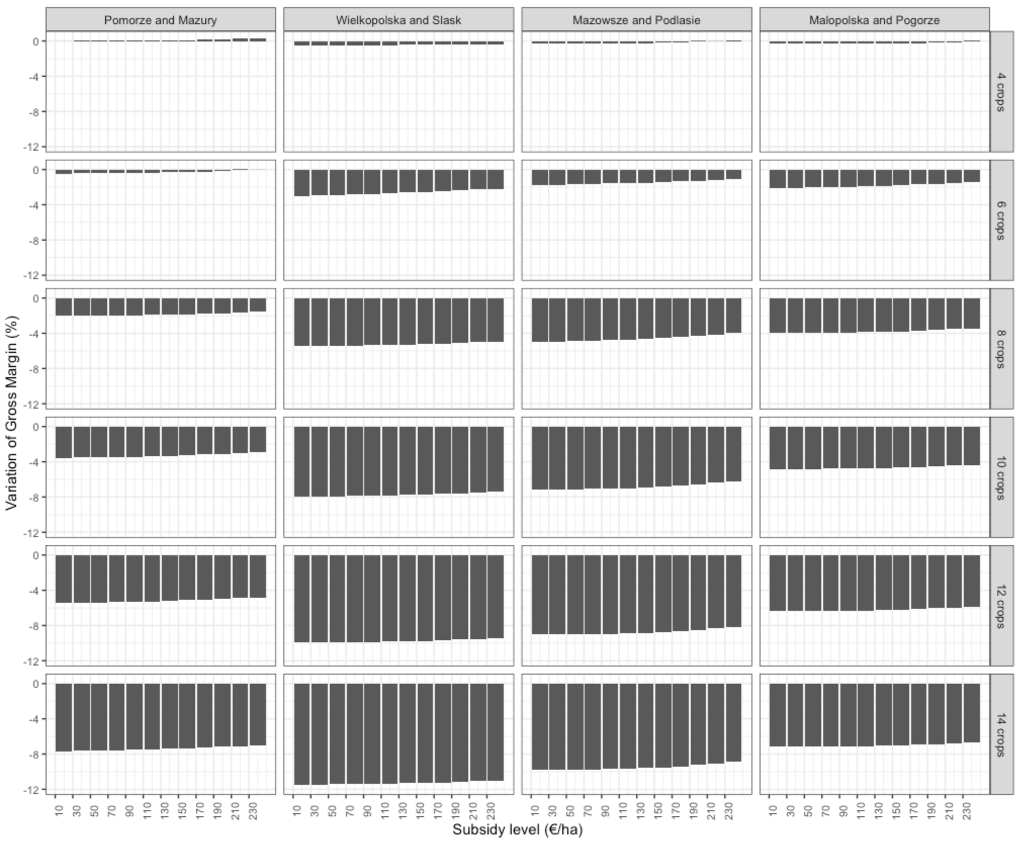

Figure 5: Average variation in gross margin per hectare in percent in Polish FADN regions for different *ndiv* levels and *sudiv* equal to €100 ha^{-1}

4.2 Impact on land use

In what follows, we consider that the agricultural land is shared between 4 land uses: cropland, grasslands including fodders and permanent meadows, fallow and willow. We then propose to examine changes in these areas caused by the crop diversification constraints and the insertion of willow according to regions and two *sudiv* levels. One can notice, from Figures 6 and 7, that increasing the number of required crops impacts FG's land use allocation differently, depending on the subsidy amount for diversifying the cropping system.

For instance, in the case of *sudiv* equal to €50 ha^{-1}, grasslands increase in all regions, except in Wielkopolska & Śląsk. In this region, an increase of grassland area is only recorded for an imposed high number of crops. Moreover, unlike Pomorze & Mazury and Wielkopolska & Śląsk, an increased number of crops decreases slightly the share of fallow. The same goes when *sudiv* equals €100 ha^{-1}, but with higher magnitudes. As regards willow, it is sligltly introduced in Pomorze & Mazury, Wielkopolska & Śląsk and Małopolska & Pogórze, more specifically when willow subsidy is around 110 and €130 ha^{-1} for both levels of *sudiv*. However, in Mazowsze & Podlasie, willow is introduced up to 5 000 ha, the regional average.

In the case of low *sudiv* level, for high crop diversification requirements, fallow and grassland areas increase specially in Pomorze and Mazury. They are more sensitive to scenarios with high number of required crops. The increase declines with a progressive amount of subsidy allocated to willow.

Figure 6: Average variation in land use allocation in percent of cropland, grasslands and fallow and in hectares of willow according to Polish FADN regions for different *ndiv* levels and *sudiv* equal to €50 ha^{-1}

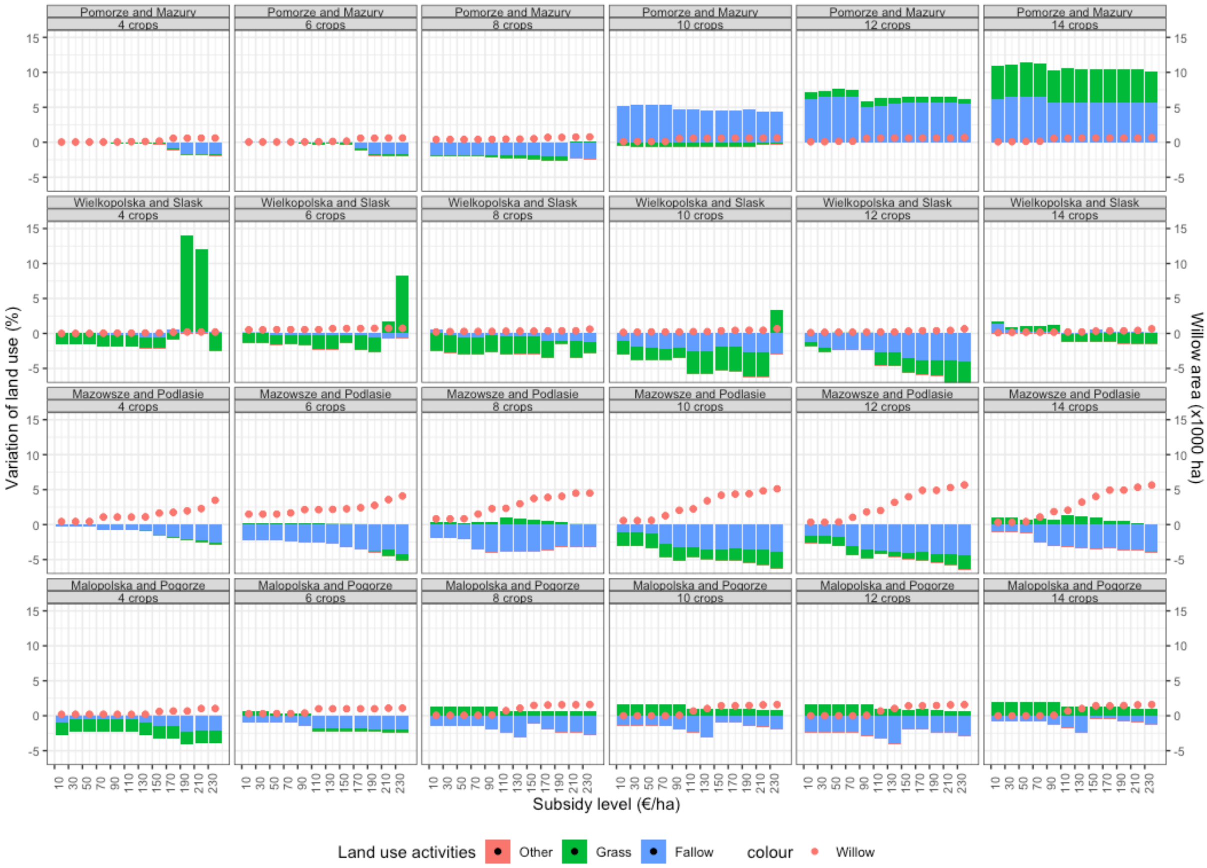

Figure 7: Average variation in land use allocation in percent of cropland, grassland and fallow, and in hectares of willow according to Polish FADN regions for different *ndiv* levels and *sudiv* equal to €100 ha^{-1}

Since FG are constrained by a fixed UAA, willow cultivation is at expense of existing activities, mainly fodders and fallow. Land allocated to food crops are also subject to decline, due to an expansion of willow and fodder production. Here, this effect is not well represented for aggregation reasons. Notice, as mentioned in Louhichi et al. (2017), the cultivation of main crops grown on important areas tends to decrease and areas of crops having low land share tend to increase.

In Figures 8, 9, 10, 11 showing the spatial distribution of willow presence, willow area is more sensitive to an increase in the amount of the subsidy allocated for it. As a matter of fact, for a subsidy level equal to €140 ha^{-1}, willow is grown up to 3% of UAA. This proportion increases up to 4% in some areas located in Mazowsze & Podlasie. For high levels of subsidy for planting willow, the area allocated to this latter varies between 1 and 5% of UAA, except in few locations where willow can be grown up to 10% of UAA, assumed limit to limit the competition with food and feed activities. If we are to superimpose our maps on that of soil complexes (Figure 12), we notice that willow may mainly be planted on complexes of marginal land, and medium and weak quality grassland.

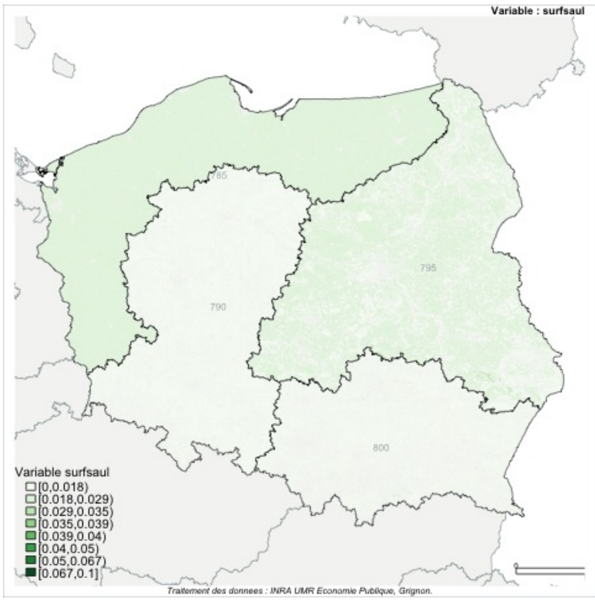

Figure 8: Spatial distribution of willow area for $ndiv = 7$**,** $sudiv =$ **€**50 **ha**$^{-1}$ **and willow subsidy equal to €**140 **ha**$^{-1}$

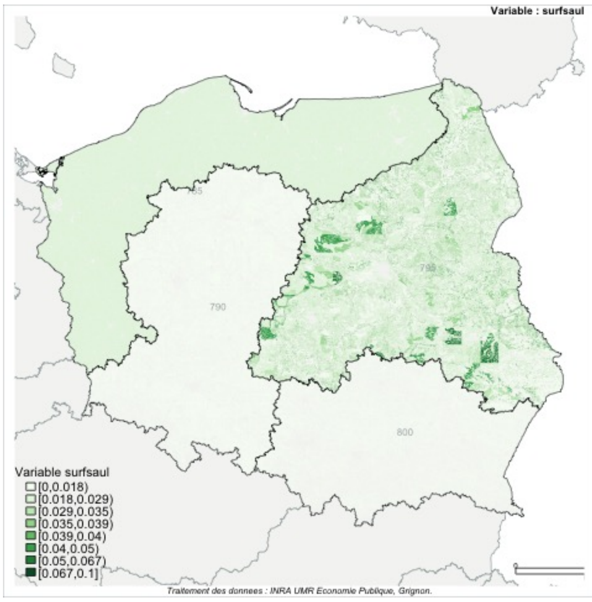

Figure 9: Spatial distribution of willow area for $ndiv = 7$**,** $sudiv =$ **€**100 **ha**$^{-1}$ **and willow subsidy equal to €**140 **ha**$^{-1}$

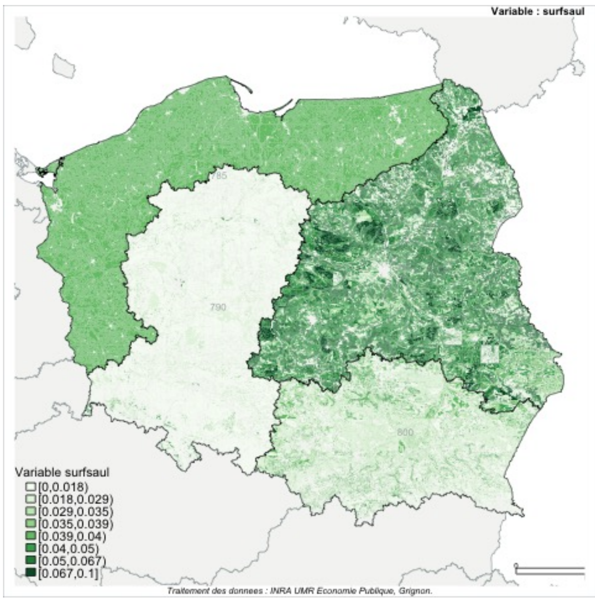

Figure 10: Spatial distribution of willow area for $ndiv = 7$**,** $sudiv =$ **€**50 **ha**$^{-1}$ **and willow subsidy equal to €**250 **ha**$^{-1}$

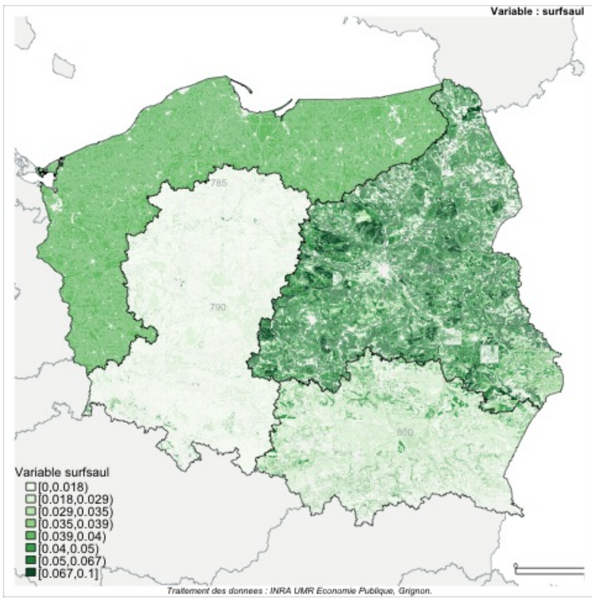

Figure 11: Spatial distribution of willow area for $ndiv = 7$**,** $sudiv =$ **€**100 **ha**$^{-1}$ **and willow subsidy equal to €**250 **ha**$^{-1}$

5 Conclusion and perspectives

Considering CAP crop diversification options, this study presents an upgraded version of AROPAj model, thereby helping the policy makers to make informed choices regarding the area, number, and mix of eligible crops that may be cultivated at a low cost.

Using this modelling tool, we pinpointed the impacts of crop diversification measure on FG's economic outcomes, i.e. gross margin, at Polish regional level. Although FGs represent higher number of crop activities than those of FADN sampled farms, this approach allowed us to assess the cost of crop diversification for farmers, obtained from simulations in which we set a larger number of eligible crops than what is assigned by the model calibration. To that end, the proposed method has been tested on a large part of FGs and the additional cost of increasing the number of required crops has been assessed.

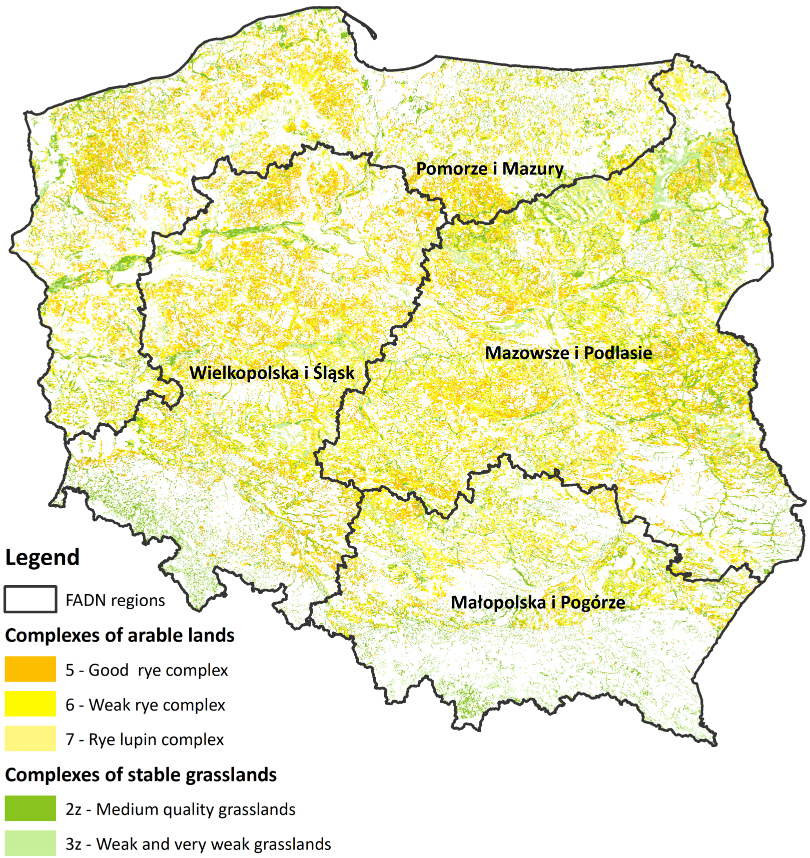

Figure 12: Spatial distribution of different Polish soil complexes considered as potential available areas for willow cultivation

As a first attempt, the model was run for Poland, offering large capacities to deliver economic and land use outcomes spatialised at a fine-resolution scale. In further work, agro-ecological and environmental indices will be taken into account to assess the sustainability and the friendliness-to-environment degree of Polish FG. In addition, for better targeted measures and understanding of farmers' behaviours, it is better to consider the diversity of farming systems (Weltin et al. 2017). The impact analysis of the aforementioned scenarios and assumptions can therefore be distinguished, depending not only on regions, but also on 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 options commands.

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