AUA Working Paper Series No. 2012-2
December 2012

Economic and spatial modelling for estimating supply of perennial crops' biomass in Poland

P. Mathiou, S. Rozakis[†]
Department of Agricultural Economics and Development
Agricultural University of Athens, Greece

R. Pudelko, A. Faber
Dept. of Agrometeorology and Applied Informatics
Institute of Soil Science and Plant Cultivation, Poland

[†]**Corresponding author, rozakis@aua.gr**

This series contains preliminary manuscripts which are note (yet) published in professional journals

Agricultural University of Athens ·
Department of Agricultural Economics
& Rural Development · http://www.aoa.aua.gr

Economic and spatial modelling for estimating supply of perennial crops' biomass in Poland

P. Mathiou, S. Rozakis
Department of Agricultural Economics and Development
Agricultural University of Athens, Greece

R. Pudelko, A. Faber
Dept. of Agrometeorology and Applied Informatics
Institute of Soil Science and Plant Cultivation, Poland

Abstract

Among measures to promote renewable energy the electricity feed-in tariff scheme is extensively used in many countries to meet the goals set by governments related to energy independence and mitigation of greenhouse effect. In this paper, an agricultural supply spatial model is run to estimate biomass plantations adoption by Polish farmers at the municipal level. Detailed spatial and agronomic information is used limiting potential areas to the less fertile land, focusing on certain land classes where research undertaken by IUNG has provided reliable estimates for willow and miscanthus cultivation needs and production yields. Decisions on multi-year land use for dedicated energy plantations replacing conventional annual crops such as rye and triticale are driven by discounted cash flow analysis. An appropriate mathematical model is built in order to estimate biomass for energy supply for a range of hypothetical prices offered by coal fueled power plants. Parametric optimization results are shown in supply curve form in order to determine efficient price levels. Results are illustrated also in terms of crop acreages as well as spatial distribution at the national level in NUTS5 resolution.

Keywords: Willow, Miscanthus, Cost analysis, Mathematical programming, Biomass Supply, Feed-in tariffs, Spatial analysis

INTRODUCTION

The scheme prevailing in Europe to overcome the problem of competitiveness and take-off of biomass carriers includes investment subsidies, tradable permit certificates and the so-called feed-in laws. Feed-in laws create demand otherwise not justified by costs and market prices prevailing in the competitive energy sector. Renewable energy (RES) has the priority to the grid, and operators are obliged to purchase it at a tariff price that is determined by the regulators. Such legislation is currently common in Europe and lately countries like Finland, the Netherlands, Ireland and the UK included co-firing in this scheme that may result in increased profitability of existing fossil power plants (Lintunen and Kangas, 2010). The key issue for policy makers is to design cost-effective measures, in other words determine the minimal tariff level so that co-firing activity would be triggered and reach the desired targets at the least cost for the electricity consumer (Clancy et al., 2012). In contrast to other RES such as photovoltaics where the agents involved are the regulatory authority and the industry, in the case of biomass resource beside these two, numerous agents are involved in the chain, namely farmers that produce solid biomass. Thus there is an additional question concerning the availability of biomass that is crucial for industry to answer before investing in technology. The accurate estimation of the relationship price-quantity is also useful to public agencies in order to design efficient policies and more specifically the level of feed-in tarrifs levels.

Following an engineering approach some studies evaluate the policy instruments by means of mathematical programming (MP) to build cost-minimising models that consist in (a) constant costs for biomass input, (b) increasing transport costs calculated geometrically based on the assumption of evenly scattered resource and (c) a detailed technical description of co-firing (Kangas et al., 2009). Bottom up approaches also based on MP models, on the other hand, consistent to the agricultural economics viewpoint, focus farm based sector models. These models attempt to estimate the marginal cost of the resource that, because of heterogeneity and small size of decision making units (farms), shows high variability. The typical model structure is based upon statements about the short-run physical restrictions to production (resource availability limits), decision rules (profit seeking behaviour) and the economic environment within which the farmer operates (imports or quotas, tariffs on certain levels, competitive or monopolistic price formation or guaranteed prices, etc). Implicit response functions for output (supply curves) or input (demand curves) variables can be numerically determined by means of parametric optimisation under variations of market or policy parameters (Kutcher and Norton, 1979). Relevant literature includes the evaluation of energy crop for biofuel supply in France (Sourie and Rozakis, 2001, Kazakci et al., 2007), perennial crop supply in Greece and the impact of the CAP 2003 reform (Lychnaras and Rozakis, 2006) as well as a growing body of literature focusing on miscanthus and short rotation coppice (Styles et al., 2008, Sherrington and Moran, 2010, Bauen et al., 2010, van der Hilst F. et al., 2010). Furthermore, agricultural economists appreciate the reluctance of farmers to adopt and install perennial plantations for energy purposes (i.e. Nilsson, 2007, Sherrington et al. 2008, Yudego and González-Olabarria, 2010) so that they include in the analysis other motives than mere profit seeking e.r. risk considerations.

In order to estimate biomass supply and at what extent demand can be satisfied, we proceed first to assess the cost of the perennial crops under scrutiny. Then a model is used to estimate biomass supply from perennial crops in Poland focusing on the country level while the unit of analysis is the municipalities or NUTS5 region (NUTS5 system: Nomenclature of Territorial Units for Statistics, FADN: Farm Accountancy Data Network). For this purpose we built a multi-annual optimisation model that accommodates discounted cash flows, taking into account site specific yields of traditional as well as dedicated perennial energy plantations. Price and cost parameters prevailing in Polish arable farms complete the database.

Site specific supply curves determined observe dominance of willow plantations over miscanthus substituting for rye and triticale with considerable regional variations of the degree of adoption of biomass-to-energy cultivation.

The paper is organised as follows: next section presents the case study and describes spatial and economic data. Then the modelling methodology and decision making under certainty are analysed. Results and discussion on the limits of the analysis are presented in section 3. Conclusions and ideas for further research complete the paper.

Bioenergy from dedicated perennial plantation in Poland

Combustion of solid biomass is well expanded in Poland both in individual and in thermal plants. In a recent comprehensive survey for bioenergy in Poland (Iglinski et al, 2011), it is estimated that out of 250 municipal and industrial electro-thermal power stations, only a fraction has been converted to accommodate the co-firing of biomass. Nevertheless beginning from the power station of “Ostroleca” in 1997, most of the big electro-thermal power plants mix biomass with coal. Demand for biomass for co-firing in currently coal-fueled power plants is planned to increase in the near future as it is profitable at the average offered price of 6 euro per GJ (Faber et al., 2011). There is, however, a differentiation depending on biomass type, since straw-like agricultural residues cannot exceed a certain percentage of total biomass used in co-firing. Therefore woody biomass is somewhat preferable and thus valued at a higher rate.

Two perennial energy crops, willow and miscanthus will be evaluated as candidates for biomass suppliers to energy carriers at the NUTS5 level, that is the 2,171 regions comprising Polish territory. In an attempt to undertake realistic estimations and to avoid major competition with food crops, low fertility land classes have been selected for the analysis. According to the national classification system for Polish territory, arable soils are classified into 13 categories (complexes) and grass lands into 3 categories. Each complex consists of a group of different soils with similar agricultural features: character and properties of soil, climatic conditions prevailing, state of the terrain relief and hydrological background and moisture relationships. For instance, complex 1 is excellent for growing wheat while for the cultivation of energy plantations complexes 5, 6 and 8, 9 as well as the grassland complex 2x and 3z are the most suitable. In this study we focus on complex 5 that is moderately suitable and complex 6 that is considered weak for rye, barley and potatoes. Spatial statistics illustrate that acreages of this sort, are available in all 2,171 NUTS5 regions (NUTS2 aggregates appear in Table 1).

Table 1. Aggregates at the NUTS2 level for selected areas of complexes 5 and 6 in ha

Voivodeship NUTS-2	Total arable area	Complex 5	Complex 6	% C5 of arable land	% C6 of arable land
Dolnośląskie	1778195	25191	19151	1.42%	1.08%
Kujawsko-pomorskie	1714271	65171	37532	3.80%	2.19%
Lódzkie	1709745	42720	66080	2.50%	3.86%
Lubelskie	2414985	54291	46412	2.25%	1.92%
Lubuskie	1335455	16578	20823	1.24%	1.56%
Małopolskie	1344943	5477	5027	0.41%	0.37%
Mazowieckie	3344506	77755	106412	2.32%	3.18%
Opolskie	866624	22691	9185	2.62%	1.06%
Podkarpackie	1686822	11257	19368	0.67%	1.15%
Podlaskie	1926361	30717	46119	1.59%	2.39%
Pomorskie	1720140	36006	35080	2.09%	2.04%
Śląskie	854298	8987	16355	1.05%	1.91%
Świętokrzyskie	1103679	10801	23778	0.98%	2.15%
Warmińsko-mazurskie	2360709	39106	49799	1.66%	2.11%
Wielkopolskie	2833763	82390	85025	2.91%	3.00%
Zachodniopomorskie	2153661	50611	36895	2.35%	1.71%
Country total	29148157	579750	623043	1.99%	2.14%

- Complex 5: light soils, medium depth, acidic quality, susceptibility to droughts, relatively poor nutrient content and low water holding ability
- Complex 6: poor structure, ranging from heavy to light, often excessively wet, without ruling out the possibility of dry areas.

Miscanthus and willow are chosen because of their low-input requirements, high level of biomass production and for being remarkably suitable for the Polish temperate climate (Borzęcka-Walker et al. 2008, 2011; Borzęcka-Walker 2010). Conventional crops, rye and triticale are the major competitors for land of similar agronomic and ecological attributes.

Total demand for biomass from major power plants is about 11 Mt, a figure that falls in the same order of magnitude compared with biomass technical potential in complexes 5 and 6. In fact for a modest yield of 9 tons per annum (weighted average for all energy plantations) assuming that all the area (1.2 million ha) is cultivated with energy crops, total production amounts to 11 Mt.

Agronomic assumptions for energy crops

Miscanthus is assumed to have a 20 year life cycle and willow has a 21 year life cycle. Establishment operations - such as soil preparation and planting - take place during the first year, while harvesting starts in the second and third year for miscanthus and willow, respectively. While miscanthus is harvested annually, willow was assumed to have a three year rotation length. An average yield of 10.6 t ha^{-1} of dry matter per harvest is assumed for miscanthus and 23.6 t ha^{-1} for willow.This statement holds for a hypothetical farm using average figures, regarding yields and expenses. Average yields for conventional and energy crops at the country level in complexes 5 and 6 appear in Table 2.

Table 2. Crop yields and Std. Deviation per harvest

	Rye	Triticale	Miscanthus		Willow	
	Complex 5 & 6	Complex 5 & 6	Complex 5	Complex 6	Complex 5	Complex 6
Average Yield	2.5	3.2	12.1	9.2	27.0	20.3
Std. Deviation	0.3	0.4	1.5	0.6	11.2	8.4

In the first harvest, both crops produce a fraction of their maximum yield, since they are assumed to reach full potential after the second harvest. Operations can be distinguished into three categories (Table 3), establishment operations, recurring and one-offs and decommissioning operations. It is assumed that fertilizers (various commercial N:P:K products) are applied to miscanthus plantations annually, but in the case of willow, nutrients and plant protection are applied only during the years after harvest. Finally, decommissioning process includes three operations: grubbing, deep ploughing and the application of herbicides.

Table 3. Operations and time of occurence

Miscanthus		Willow	
Category	Year	Category	Year
Establishment			
Liming	1	*Liming*	1
Light tillage	1	*Light tillage*	1
Winter ploughing	1	*Winter ploughing*	1
Harrowing	1	*Harrowing*	1
Fertilizer - Herbicide	1	*Fertilizer - Herbicide*	1
Planting	1	*Planting*	1
		Plant protection	1
Recurring Operations and One-offs			
Fertiliser application	2 to 20	*Fertilizer application*	4,7,10,13,16,19
Herbicide application	2	*Hoeing*	1
Cut back	1	*Plant protection*	4,7,10,13,16,19
Harvesting	2 to 20	*Cut back*	1
		Harvesting	3,6,9,12,15,18,21
Decommission			
Grubbing	21	*Grubbing*	21
Deep ploughing	21	*Deep ploughing*	21
Herbicide application	21	*Herbicide application*	21

Cost estimation and revenue streams for energy crops

In the process of estimating the economic viability of perennial energy crops as against conventional crops, the Net Present Value approach was adopted. The nature of agricultural production, especially in the case of the multi-annual plants in question, called for a realistic cash flow estimate that can take into account the irregularity of some agronomic activities, their corresponding expenses and thus the time value of money that accompanies them. Discounting cash flows ensure that bulk expenses or revenues during the early years are more important than the ones occurring later in time. The calculations are established for reference year 2011 and the future costs and revenue streams are discounted at a rate of 6%.

Table 4. Machinery used in energy crop plantation

Own machinery	Rented machinery	Rate of rent (PLN h^{-1})
Plougher	Liming machine	227
Harrower	Planter	123
Spreader	Trailer	92
Sprayer	6-roe hoe	101
	Cutter	123
	Miscanthus Harvester	302
	Willow Harvester	1117
	Grubber	106

The production cost of each energy crop is estimated by operation, made up by machinery, input and labour costs (hypotheses, values and assumptions are detailed in Mathiou, 2011). It was assumed that some pieces of machinery are owned due to previous conventional crop enterprises, while other specialised machinery were rented, with the operator cost incorporated in the rent rate (Table 4). In the case of willow, where a dedicated harvester is used, rent is more costly than that of miscanthus, harvested with a conventional straw machine. It should be noted that the cost of harvest is considered relative to the amount of yield; thus it is considerably lower during the first harvest. Labour cost amounts to 7 PLN h^{-1}. With regard to materials (fertilizers, herbicides, seedlings, cuttings, fuel), the prices were estimated using 2011 as the reference year (Table 5). The total annual cost includes brokerage and transportation expenses – with an average distance of 30 km between farm and power plant (Krasuska and Rosenqvist, 2011). In the case of miscanthus, we assumed that it is firstly delivered to a local storage; therefore roofed storage costs were added. The estimation does not include depreciation, land cost and taxes.

Table 5. List of inputs and price in 2011

Miscanthus			Willow		
Name	Type	Price (PLN/unit)	Name	Type	Price (PLN/unit)
Ammonium sulphate	Fertilizer	1.2	Glyphosate 360 SL	Herbicide	18.25
Polifoska 6	Fertilizer	1.7	Polifoska 4	Fertiliser	1.37
Chwastox turbo 360	Herbicide	24.5	Dual gold 960 EC	Herbicide	90.37
Roundup	Herbicide	21.8	Fusilade forte	Herbicide	106.42
Lindua	Herbicide	346.6	Zoocyd actar	Pesticide	541.80
Ca/Mg	Lime	0.1	Cuprate fungicide	Fungicide	33.08
Seedlings	Propagation		Ammonium nitrate	Fertiliser	0.95
			Ca/Mg	Lime	0.05
			Cuttings	Propagation	

Costs are classified into six categories in terms of annual costs for rye and triticale and annual equivalent costs for perennial crops appearing in the upper part of Table 6. In order to calculate revenue streams, we assumed a biomass market price of 6 €GJ^{-1} offered by the industry at the plant gate; a Lower Heating Value of 17 GJ t^{-1} was assumed for miscanthus and 19 GJ t^{-1} for willow.These values translate into 71 (multiplied also by 70% to take into account straw type biomass devaluation for power plants) and 114 € t^{-1} , for miscanthus and willow respectively. The difference reflects the preference for woody biomass due to better behaviour in boilers and higher calorific value. At the moment, there is no provision made for governmental support, in the form of subsidies or direct payments, therefore no such income was included in the calculation.

Table 6. Cost and revenue estimates, in euro per hectare

	Rye	Triticale	Miscanthus	Willow	Miscanthus Scenario 1	Willow Scenario 1
Establishment	351.0	340.8	350.2	62.0	23.4%	9.8%
Operations	55.6	116.1	169.4	125.2	0.3%	6.3%
Harvesting	138.9	158.5	171.3	211.3	10.0%	25.0%
Transport	23.5	23.5	371.7	212.5	5.0%	5.0%
Decommission	0.0	0.0	5.2	3.6	0.0%	0.0%
Miscellaneous	0.0	0.0	40.4	50.1	15.0%	15.0%
TOTAL COST	568.9	639.0	1108.3	664.7	984.1	579.8
Yield per harvest	2.5	3.2	10.6	23.6	10.6	23.6
Price	147.5	156.8	71.4	114.0	71.4	114.0
Main Product	370.2	497.6	705.1	834.7	705.1	834.7
By product	41.0	11.7	0.0	0.0	0.0	0.0
TOTAL REVENUE before subsidies	411.2	509.3	705.1	834.7	705.1	834.7
NET REVENUE before subsidies	-157.8	-129.6	-403.1	170.0	-279.0	255.0
Coupled subsidy	24.4	24.4	0.0	0.0	0.0	0.0
Direct subsidy	216.8	216.8	0.0	0.0	0.0	0.0
TOTAL REVENUE	652.4	750.5	705.1	834.7	705.1	834.7
NET REVENUE	83.4	111.5	-403.1	170.0	-279.0	255.0

The economics of conventional crops

An estimate of the production cost for wheat and barley, according to the Wielkopolska Chamber of Agriculture (2011), was used as the basis for the estimation of the economics of rye and triticale respectively. Soil preparation, sowing, maintenance, harvesting and all the associated machinery and labour were assumed alike to those used in miscanthus and willow production; the only difference being the type and dosage of certain variable inputs and the level of production. Any data missing was drawn and adjusted accordingly, from the Institute of Soil Science and Plant Cultivation (Matyka, 2008).

The annual operations for both rye and triticale were: liming, light tillage, harrowing, fertiliser application, seedbed preparation, sowing, harvesting and transportation of the product away from the field. It was assumed that 200 Kg of rye seed and 250 Kg of triticale seed were sown per hectare. In return, cereal grain was assumed to be the main product and straw (baled) was considered as a by-product.

The method of estimation and the economic assumptions (prices, rent, labour wage) used for the two energy crops, were also applied to rye and triticale. With the exception of some specialised machinery being rented i.e. combine harvester, straw-bailing machine, while the rest was assumed farm property.

With regard to revenue generation, it was assumed that rye produces a yield of 2.5 t ha^{-1} and triticale a yield of 3.2 t ha^{-1}. A market price of 605PLN t^{-1}(148€ t^{-1}) was attributed to rye grain and 643 PLN t^{-1}(157€ t^{-1}) to triticale grain; straw was assumed to sell at 120 PLN t^{-1}(29€ t^{-1}). Because straw prices present significant increases lately, sensitivity analysis will be performed. In contrast to energy crops, both rye and triticale are subsidised under EU policy. A direct payment of 889 PLN (217€) and a seed subsidy of 100 PLN (24€) per hectare apply currently (GCA, 2011)[1].

Net revenues and future scenarios

In Table 6 annual equivalent costs of perennial crops are presented together with the annual costs and revenues of conventional crops, currently cultivated in the areas of interest. The left part of the table (four columns) show that conventional crops result in modest but positive net revenues. However, if we deduct subsidies, annual crops give negative net revenues (losses of 158 and 130 euro per hectare, for rye and triticale respectively). One can see that these crops especially in the areas of study, are very sensitive to price and yield fluctuations. Farmers would presumably candidate for planting perennial energy crops if conditions were favourable. At the time being miscanthus realises a loss of 403 euro per ha, due to modest yields and high costs, specifically its very high establishment cost. Willow is in the most favourable position out of the four crops, generating a profit of 170 euro per ha even before subsidies, due to its

[1] Average annual exchange rate for 2011 is 1€ = 4.012 zl

relatively low cost as well as its high assumed price and yield level. As previously mentioned willow biomass is about 30% more valuable for the industry than that of miscanthus, due to higher heating value and better behaviour in boilers. Harvested willow biomass is more often referred to as annual averages, so the value that we use corresponds to almost 8 t ha^{-1} during the cruising period.

The development of energy crops in countries where they have been cultivated for the past couple of decades, can be resumed through the so-called ‘learning curve’; a well known term used by social scientists who study innovative technologies to illustrate decreasing costs that reflects organisational and technical progress. In the agricultural sector and especially in the case of perennial crops prospective improvements occur for two basic reasons. Firstly, large scale cultivation results in better management of production thank to experience acquired by farmers and more efficient coordination of activities, development of supporting industries (machinery etc.) and lower transport and brokerage costs. Secondly, in the long term, scientific research improves the efficiency of biological processes. On this track Krasuska and Rosenqvist (2011) distinguished two scenarios for perennial energy crop cultivation in Poland, namely “large scale cultivation with current technologies” (for a total area larger than 100 Kha) and a second scenario that combines “scale effects with technology improvement”. We used their assumptions to decrease expenses by cost item for the first case (scenario 1) and recalculated net revenues for both crops. Percentage reductions by cost category appear in the last two columns of Table 6. Overall costs are reduced by 13% for willow and 11% for miscanthus on a annual equivalent cost basis. This results in higher net revenues than in the base case but still negative albeit higher in the case of miscanthus. It is possible to make energy cropping profitable if the public authorities support establishment by direct subsidies or low interest rate loans and develop a secure market environment for farmers, such as fixed prices for a number of years. A long-term and consistent policy will reap the benefits of scenario 2, according to which, higher yields may ensure net revenues before subsidies for the growers. This is true especially for miscanthus, where an increase of yield by about 60% can make the activity break even. This yield improvement is close to the predicted range for Poland, where perennial crops are sparsely cultivated at the time being, giving 40% and 60% of expected increase in future yields for willow and miscanthus respectively.

However there is significant variation in land suitability for all crops and also there are various farm sizes and structures since the data set concerns the entire country. Thus it is reasonable to assume that some cost items could be lower in areas where the farm size is bigger with less fragmented properties. We have exploited relevant information of the data set, especially concerning yield variability and heterogeneous suitability of soils in order to estimate biomass-to-energy supply at the country level for complexes 5 and 6. In order to simulate the behaviour of the heterogeneous decision making units as well as to take into consideration the multiannual setting with respect to different policy measures, mathematical programming is required as it enhances the analysis complexity and exploits available information at a fairly fine level (time periods, land units, etc.).

Modelling methodology

The aim is to estimate biomass supply of the selected energy crops at the NUTS5 level throughout Poland. In other words, we aspire taking into consideration farmers' response, regarding crop mix decisions, to policy measures such as fixed prices for biomass, direct support or loans with subsidized interest rate and so on.

In order to get reliable estimates useful for policy analysis, appropriate model building is recommended. 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 elasticities. Moreover econometric estimates are valid only for the observed range of variation of relative prices and other variables. Mathematical models may fill this gap and derive response functions for output, incomes, employment and other variables implicitly by means of parametric optimization (Kutcher and Norton, 1979). Especially in case of substantial policy changes, mathematical programming models have been widely suggested to agricultural economists (Hazell & Norton, 1986). Furthermore the model should be able to to compare the economic viability of innovative energy crops (miscanthus, willow that on top are multiannual) against that of traditional annual crops (rye, triticale). A multi-annual model is specified to accommodate different cash flow profiles such as annual versus perennial crops. The decision problem was treated as a constrained optimisation model, under certainty; due to the large number of decision making units (2x2,171 NUTS5=4,342) the model is compiled in GAMS software tool (McCarl et al., 2012) and solved in order to maximize NPV.

A number of considerations were taken into account, as to adequately express the impact of time on the actions to be taken and their respective consequences. The main reason why the time aspect shouldn't be ignored is the absence of stability that accompanies any long-term plan. Dynamic elements that change over time include financial and budgeting factors varying from one year to another, exhaustible resource availability depending on the consumption in previous years, exogenous parameters such as price and yield that are not constant and current decisions that affect future productivity. In short, when facing problems containing multiple year dynamic elements, the aim is to optimally allocate resources between antagonizing enterprises that last for a number of years - thus interlacing time with consumption - while at the same time optimizing some kind of economic result - that should also be adjusted over time.

Problem formulation – NPV Approach

The annual net margins of biomass and conventional crops are used in a linear programming model, in order to calculate the NPV of each activity. This model allocates the optimal proportion of land – that maximizes total NPV -between the competing enterprises, for each of the 2,171 Polish regions, over a period of twenty-one years. The model was solved for each land unit (NUTS5 areas), to assess the likely uptake of perennial energy crops at various levels of biomass prices.

(1) $$MaxN = \sum_{l} \left\{ \sum_{t} \left[a \sum_{j} \left(X_{ljt} M_{ljt} \right) \right] + \sum_{t} \sum_{j} X_{ljt} T_{ljt} \right\} \quad \text{Where} \quad a = (1+r)^{-t}$$

Subject to

(2) $$\sum_{j} \left(\sum_{e} \sum_{t} R_{lje} X_{ljt} \right) \leq B_{l}$$

and $X_{ljt} \geq 0$

Indices *N, net present value of total gross margin*

l, land units, l={1, … 2171}

j, activities, j={rye, trit, misc, wil}

t, years of the crop plan, t={1, … T}

e, years that elapse, e={1, … 21}

parameters M_{ljt}, *gross margin of crop j, cultivated in year t, in land unit l*

T_{ljt}, *terminal value of crop j, cultivated in year t, in land unit l*

r, the discount rate

R_{lje} , *resource requirement of crop j, when it's e years old, in land unit l*

B_{l}, *resource availability of land unit l*

Variables *X_{ljt}, acreage of land unit l, cultivated with crop j, in year t*

The objective function (1) calculates the maximum NPV attainable, when the optimal farm plan is in place for each decision making unit. The decision variables represent the acreage of land in each land unit, which should be ideally allocated to each crop at the start of every year. The first part of the equation provides the discounted value of annual gross margins that derive from activities within the lifespan of the plan, while the second part adds the residual value of activities that extent beyond the 21-year limit.

Specifically, the annual gross margin (M_{ljt}) is calculated as the difference between total revenue and cost, where the former includes all sources of income i.e. main product revenue, by-product revenue and subsidies (when applicable). Because of the perennial nature of two out of four activities, their terminal value (T_{ljt}) is incorporated. This value was calculated as the NPV of gross margins attained only from the activities that generate income beyond the given time frame.

The remaining block of equations represents a resource availability constraint. To that effect, equation (2) limits the amount of acreage cultivated each year to the available land in each land unit, by using both time expressions e and t.

It is postulated that farmers choose among food crops and non-food crops so as to maximize the agricultural income of their farm. Thus, each producer maximizes gross margin (*M*). Variables *X* take their values in a limited feasible area defined by a system of institutional, technical and agronomic factors. Parametric optimization consists of iterative solutions of the model, by increasing the value of energy crop price. When increasing the price of energy, one obtains the corresponding prices for different kinds of biomass depending on heating values and consequently for the energy crops in question, and after optimization increasing acreages cultivated by perennial crop plantations. Total biomass against corresponding biomass energy price can be illustrated in the relation $p_d=J(q_d)$ that is a (inverse) supply curve of the resource. Thanks to supply models, it is possible to take into account heterogeneity and finally to aggregate individual farm responses in order to obtain raw material supply for industry. This approach also leads to an estimate of the agricultural producers' surplus, which is an item of the cost-benefit balance of bio fuels. These results underline the interdependence between arable crops as well as cross-price dependencies. Non-food crop production is distributed in an optimal way among the various farms, so that reduction in the objective function value, i.e. the total value of production, becomes maximal.

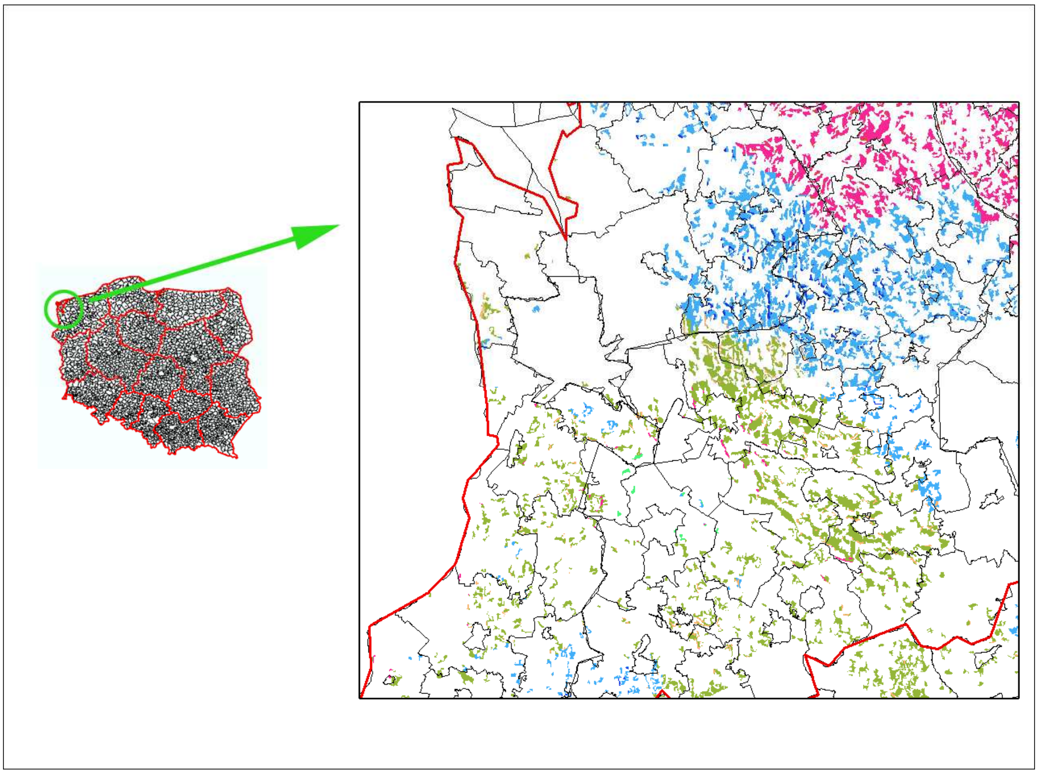

Figure 1. Complex 5 land units in selected NUTS-5 areas.

Case study: Parameter setting and optimal solution

Technical and economic coefficients are estimated from the relevant data provided by the Institute of Soil Science and Crop Cultivation, as well as the Wielkopolska Chamber of Agriculture and they are assumed fixed for all land units. Annual crop cultivated areas and yields and perennial crop productivity as well as resource endowments are fed into the model drawn from spatial database containing detailed information on complexes 5 and 6 in all 2171 NUTS 5 land units nationwide (percentage of selected complexes in overall arable land is highly variable among NUTS 5 as shown in figure 1). The model maximizes NPV by using all the associated cash flows, as elaborated in previous sections. There are several types of output produced, the optimal land allocation between the four crops of interest and the annual production of biomass at the municipal, the regional and the national level, to name a few.

The level of biomass supply, in an average year, ranges between 12.5 and 201.9 PJ. Specifically at the lowest price levels of 15.5 to 20.5 PLN GJ^{-1}, biomass production covers between 6 and 48% of the estimated power station capacity of 202.4 PJ for processing biomass as input. A more satisfactory proportion (exceeding 60%) is achieved at the price of 21.5 PLN GJ^{-1}. It should be noted that supply originates solely from willow that dominates miscanthus, due to its higher (average) calorific value of 19 GJ $t^{-1}$and lower annual cost per hectare.

The level of biomass supply follows an upward trend, as the biomass price rises to the level of 28.5 PLN GJ^{-1} and remains fixed from the price of 29.5 PLN GJ^{-1} onwards. The minimum supply is 12.5 PJ, achieved at the lowest limit of the price range (15.5 PLN GJ^{-1}), accounting for 6.2%of the estimated power plant capacity (202.4 PJ). Supply peaks when price is set at 29.5 PLN GJ^{-1}, reaching 201.9 PJ. Moreover, at the asking price of 24.5PLN GJ^{-1} the optimal output would be 182.8 PJ, reaching 90% of capacity. Although capacity is never fully satisfied, supply is edging closer - shy of approximately 2.8 PJ - when price is set relatively low, at 26.5 PLN GJ^{-1}(Graph 1).

In the process of discerning the economic viability of miscanthus without the excess influence of willow, the latter was excluded from the crop plan. This resulted in 12.5 TJ produced at the price of 21.5 PLN GJ^{-1}, progressively increasing to the amount of 96.4 PJ (at 44.5 PLN GJ^{-1}); this figure corresponds to 47.6% of power station capacity. It should be stressed that at the price of 24.5 PLN GJ^{-1}, only 0.17% of capacity is satisfied (Graph 2).

Table 9. Areas cultivated by crop (in ha) against various biomass prices (in PLN/GJ)

Biomass Price	Acreage Cultivated in Year 1			
	Miscanthus	Willow	Rye	triticale
15.5	0	55,690	57,178	1,089,925
16.5	0	143,170	53,369	1,006,253
17.5	0	235,891	52,403	914,499
18.5	0	347,791	52,403	802,598
19.5	0	382,959	52,057	767,776
20.5	0	501,967	31,866	668,959
21.5	0	677,905	17,252	507,634
22.5	0	845,525	8,023	349,245
23.5	0	965,079	5,308	232,405
24.5	0	1,060,018	4,516	138,259
25.5	0	1,125,729	4,229	72,834
26.5	0	1,174,631	4,229	23,932
27.5	0	1,188,969	4,229	9,594
28.5	0	1,191,544	4,229	7,019
29.5	0	1,192,065	4,229	6,498
30.5	0	1,192,078	4,229	6,485
31.5	0	1,192,078	4,229	6,485
32.5	0	1,192,078	4,229	6,485
33.5	0	1,192,078	4,229	6,485
34.5	0	1,192,078	4,229	6,485

Biomass Price	Acreage Cultivated in Year 1			
	Miscanthus	Willow	Rye	Triticale
19.5	0	0	76,360	1,126,433
20.5	0	0	76,360	1,126,433
21.5	35	0	76,325	1,126,433
22.5	193	0	76,166	1,126,433
23.5	339	0	76,021	1,126,433
24.5	1,067	0	75,293	1,126,433
25.5	1,393	0	74,981	1,126,418
26.5	1,652	0	74,832	1,126,309
27.5	2,260	0	74,648	1,125,883
28.5	2,618	0	74,374	1,125,800
29.5	4,325	0	72,816	1,125,651
30.5	7,675	0	70,900	1,124,218
31.5	13,236	0	67,512	1,122,044
32.5	23,102	0	65,283	1,114,408
33.5	40,221	0	61,286	1,101,285
34.5	64,804	0	57,718	1,080,271
35.5	94,247	0	54,914	1,053,632
36.5	155,177	0	54,055	993,560
37.5	196,694	0	53,130	952,967
38.5	239,801	0	53,093	909,898
39.5	298,563	0	52,403	851,826
40.5	351,113	0	52,403	799,277
41.5	379,075	0	52,403	771,315
42.5	397,176	0	52,403	753,214
43.5	427,565	0	52,349	722,878
44.5	474,435	0	41,470	686,887

Cultivated area and Land coverage

According to the optimal crop plan, miscanthus is not economically viable within the applied price range. Due to its perennial nature, willow is planted in 4 out of 21 years but not at all price levels; whereas rye and triticale enter the crop mix annually. In all cases, willow plantations dominate and increase substantially in size, at a price higher than 21.5 PLN GJ^{-1}, nearing 1.2 million hectares. Meanwhile, triticale stands as the main competitor -when price is set low - with the maximum of 1.1 million ha, progressively decreasing to 6.4 thousand, as the biomass price rises. Rye supplements the crop mix, mainly at the lower price levels of 15.5 - 19.5 PLN GJ^{-1}, covering a maximum of 57.1 thousand ha during the first year as illustrated in Table 9.

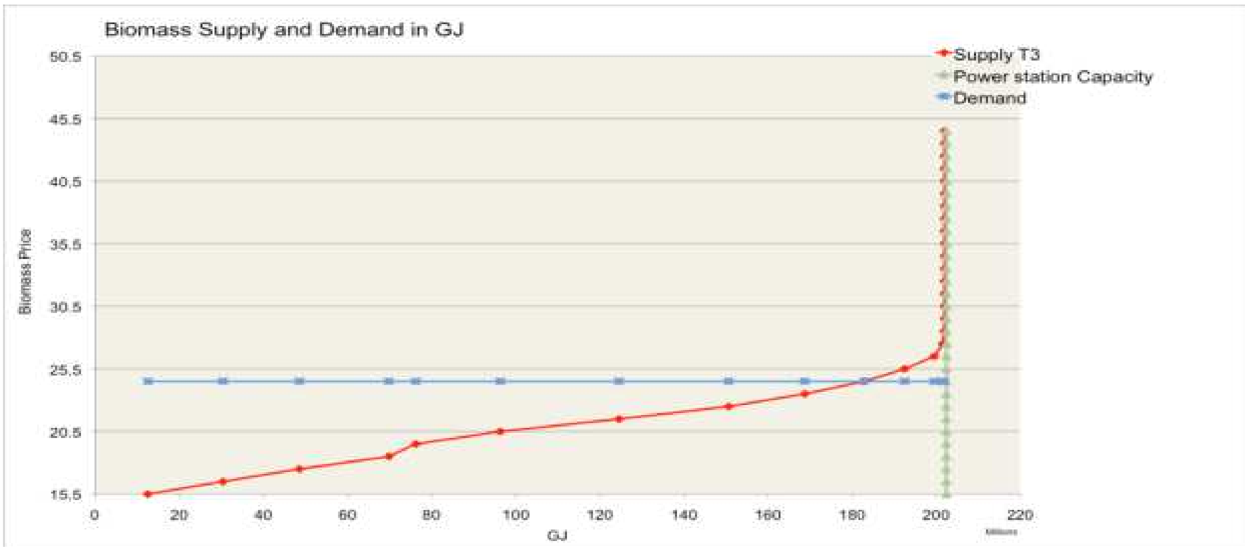

Figure 2. Biomass supply curve

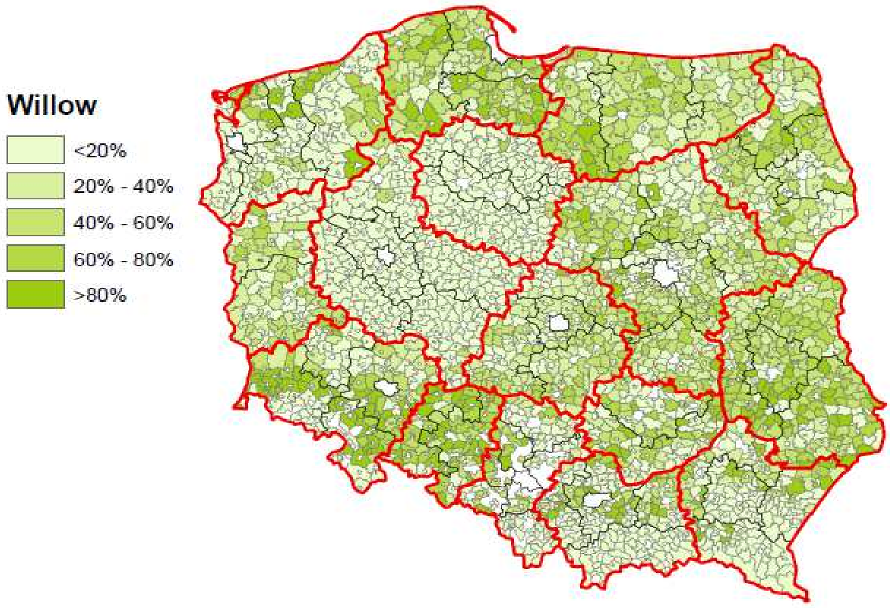

Figure 3. Biomass supply in NUTS5 at the 20 PLN/GJ price level.

For each point on the supply curve the model can convey to the system information so that the spatial distribution of the biomass production is illustrated Map in figure 3 shows the percentage of energy plantations over total arable land in the land units.

In terms of land coverage, all available land (1.2 million ha) is distributed between the three crops, at varying rates. Starting with a mere 5% (55.6 th. ha) of the available land at the price of 15.5PLN GJ^{-1}, willow ascends to 99% when biomass price reaches 27.5 PLN $GJ^{-1}$and to a respectable 88% at the asking price of 24.5 PLN GJ^{-1}. Conversely, triticale starts off covering almost 91% of the land and plummets to 11.5%, when biomass is sold at the market price. Similarly, rye follows a downward trend while price increases, alas displaying far more modest results - between 4.5 and 0.35% (graph in figure 4)

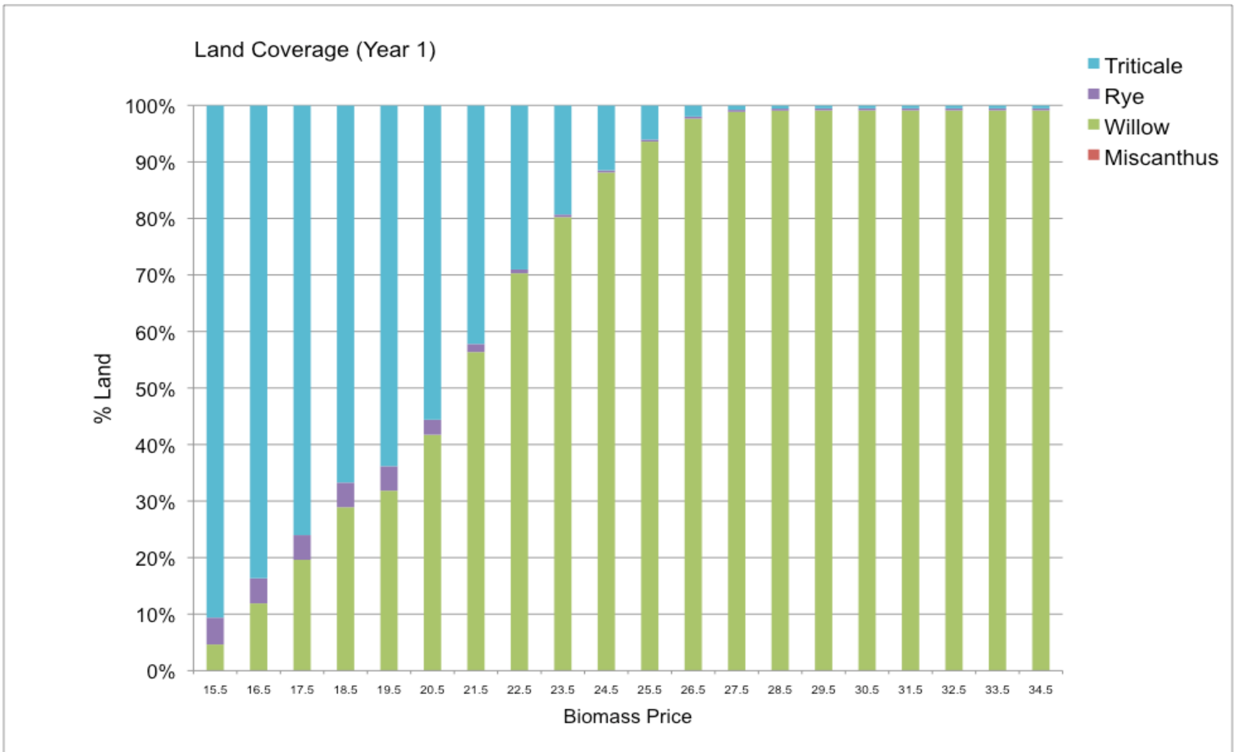

Figure 4. Crop percentage for various biomass prices

When excluding willow, miscanthus enters the optimal crop plan in the first year, at the relatively high price of 21.5 PLN GJ^{-1} (35 ha). It reaches a maximum of 474 th. hectares, at the highest applied price of 44.5 PLN GJ^{-1}. In the mean time, the asking price of 24.5 PLN GJ^{-1} results in 1,067 ha of land planted with miscanthus.

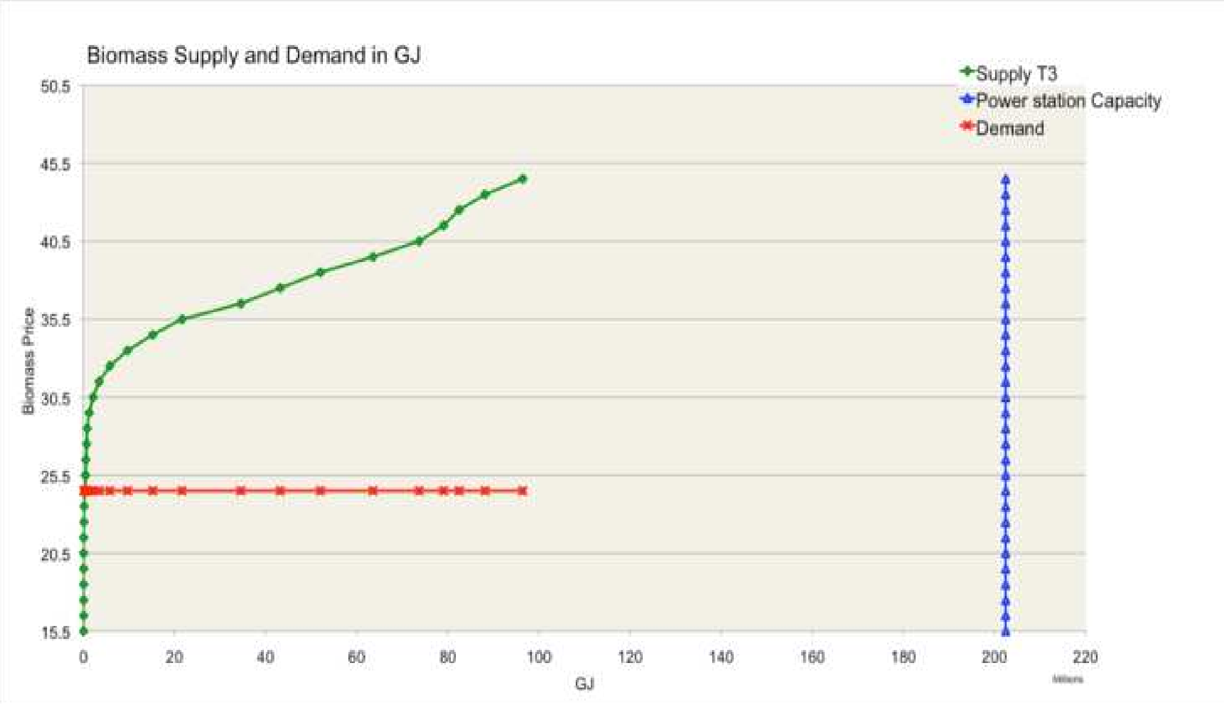

Figure 5. Biomass supply curve with miscanthus as only source of biomass.

Conventional crops are cultivated annually in far greater proportions than miscanthus. While both triticale and rye plantations diminish as biomass price becomes higher, the former constitutes a direct threat to miscanthus, starting at 1.1 million and reaching 686 th. ha. Rye on the other hand, overtakes willow as long as the price remains below 33.5 PLN GJ^{-1} (graph in figure 5).

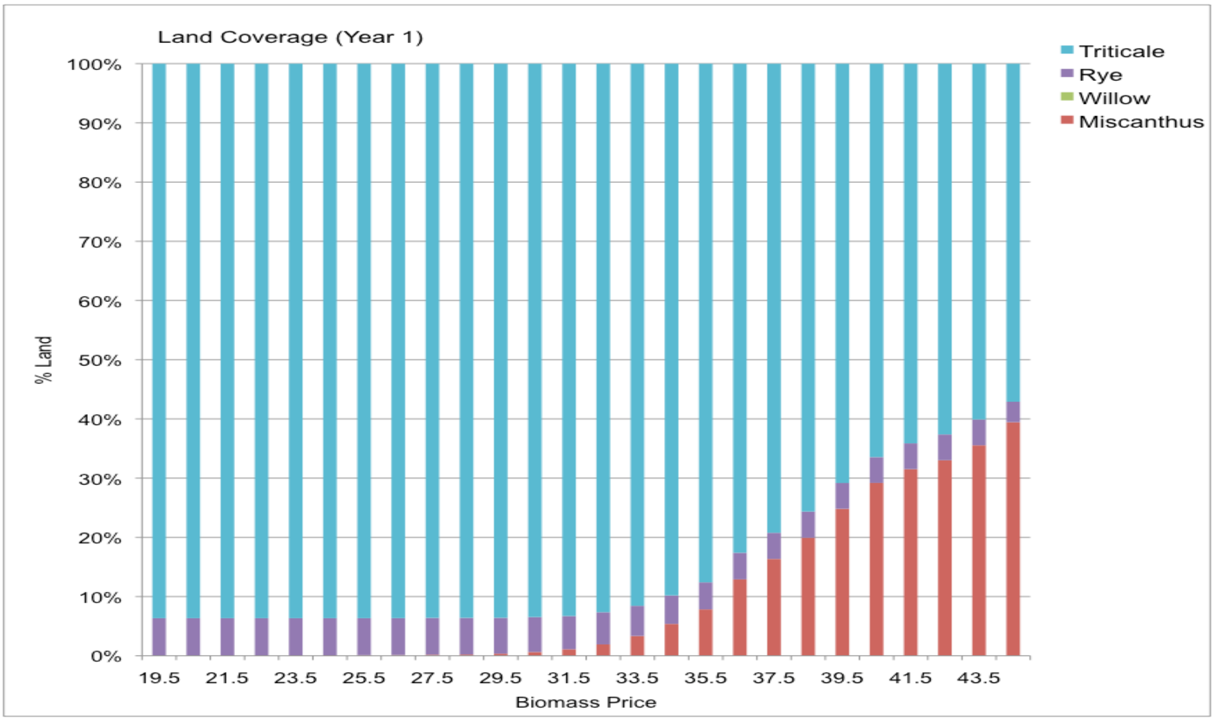

Figure 6. Crop percentage at various miscanthus prices

With regard to land coverage – as displayed in figure 6 - triticale dominates at all price levels. Especially at the market price of 24.5 PLN GJ^{-1}, miscanthus covers a meagre 0.1% of the available land, rye takes up 6.3% and the remainder is dedicated to triricale. Additionally, miscanthus peaks (39.4%) when biomass price is set at its highest, while triticale covers 57% of the land.

Conclusive comments and further research

Model results show that energy plantation may produce considerable quantities of biomass especially woody biomass from willow for current prices offered by coal-firing power plants. It is a first attempt to determine the supply curve, nevertheless a finer analysis would require more detailed and updated data at the farm level as well as introduction in the objective function of risk considerations of the farmers. As a matter of fact in Poland and other countries there is an increasing trend in both prices of wheat and rye, however after a peak in 2008 wheat prices plummeted by about 50%. If we transform the time series into frequency distribution, one can see that 7 out of 11 years prices were lower than the mean (124 € t^{-1}), the same has happened for 6 years in the case of wheat.

This kind of recent information (a decade past period is experienced by everyone in the profession even by young farmers) such as deviations from the mean, price volatility in the short and the long term as well as high and low price peaks, is observed by the farmers, it directly affects their revenues and frames their behavior regarding future decisions. Thus a crucial issue for the take-off of energy crops is the less volatile than conventional crops price expectations. With regard to yields many years of research, field and pilot experiments contributed to a solid know-how as well as the nature of the product (wood or stems instead of grains) that is less vulnerable assure low variability in yields. On the other hand policy implementation and promotion efforts for biomass energy in Europe have shown that contractual fixed prices for a relatively long period, for instance 10 years, may be the most efficient factor to enhance the adoption of energy crops. Multi-region, multi-period mixed integer mathematical programming models have been constructed to evaluate different contractual arrangements in the US namely land-lease versus farmer-contract alternatives (Epplin et al., 2007). However the analyst should risk attitude take into account in order to evaluate policy measures such as subsidy to installation or low rate loans to the producers. Mathematical programming models have recently been developed to test several incentives to encourage risk-averse farmers to plant trees incorporating technical, economic and financial criteria (Boqueho and Jacquet, 2010, Ridier, 2012). These models are implemented in a limited number of farms giving interesting results and valuable insights on the adoption by farmers of energy plantations in France. Further work is needed to apply such models at the national level including a large number of decision making units posing a number of technical and computational challenges in order to via parametric optimization to determine precisely the position of biomass supply curves.

References

Bauen, A.W., Dunnett, A.J., Richter, G.M., Dailey, A.G., Aylott, M., Casella, E., Taylor, G., 2010. Modelling supply and demand of bioenergy from short rotation coppice and Miscanthus in the UK, *Bioresource Technology*, 101 (21): 8132-8143

Berggren, M., Ljunggren, E., Johnsson, F., 2008. Biomass co-firing potentials for electricity generation in Poland-Matching supply and co-firing opportunities, *Biomass and Bioenergy*, 32 (9): 865-879.

Boqueho G., F. Jacquet, 2010. The adoption of switchgrass and miscanthus by farmers: Impact of liquidity constraints and risk preferences, *Energy Policy* 38: 2598-2607

Borzecka-Walker, M., Faber, A. and Borek, R. 2008. Evaluation of carbon sequestration in energetic crops (Miscanthus and coppice willow). Int. Agrophysics 22:185-190.

Borzecka-Walker, M. 2010. Nutrient content and uptake by miscanthus plants. Pol. J. Environ. Stud. 13(3):10.

Borzecka-Walker, M., Faber, A., Pudelko, R., Kozyra, J., Syp, A. and Borek, R. 2011. Life cycle assessment (LCA) of crops for energy production. J Food Agriculture Environment. 9 (3&4):698 -700.

Clancy, D., Breen, J.P., Thorne, F., Wallace, M., 2012. The influence of a Renewable Energy Feed in Tariff on the decision to produce biomass crops in Ireland, Energy Policy, 41: 412-421.

Epplin F.M., C.D. Clark, R.K.Roberts, and S. Hwang, 2007. Challenges to the development of a dedicated energy crop, American Journal of Agricultural Economics 89 (5): 1296-1302

Ericsson K., H. Rosenqvist, E. Ganko, M. Pisarek, L. Nilsson, 2006. An agro-economic analysis of willow cultivation in Poland, *Biomass and Bioenergy* 30: 16-27

Faber A., R. Pudełko, R. Borek, M. Borzecka-Walker, A. Syp, E. Krasuska, P. Mathiou, 2011, Economic potential of perennial energy crops in Poland, Agricultural Economics (forthcoming).

Greater Chamber Of Agriculture. Estimates of production costs 2011; in polish http://www.wir.org.pl/kalk/kalk.htm

Hansson, J., Berndes, G., Johnsson, F., Kjärstad, J., 2009. Co-firing biomass with coal for electricity generation-An assessment of the potential in EU27, *Energy Policy*, 37 (4): 1444-1455

van der Hilst F. et al., 2010. Potential, spatial distribution and economic performances of regional biomass chains: The North of the Netherlands as an example, *Agricultural Systems* 103: 403-417

Iglinski B., A. Iglinska, W. Kujawski, R. Buczkowski, M. Cichosz, 2011. Bioenergy in Poland, *Renewable and Sustainable Energy Reviews* 15: 2999-3007

Jasiulewicz M., 2010. Possibility of liquid biofuels, electric and heat energy production from biomass in polish agriculture, *Polish J. Of Environmental Studies* 19 (3): 479-483

Kangas H-L., J, Lintunen, J. Uusivuori, 2009. The co-firing problem of a power plant under policy regulations, *Energy Policy* 37: 1898-1904

Kazakçi A.O., S. Rozakis, D. Vanderpooten (2007) Energy crop supply in France : A min-max regret approach. *Journal of the Operations Research Society* 58(11): 1470-1479

Khanna, M., Önal, H., Dhungana, B., Wander, M., 2011. Economics of herbaceous bioenergy crops for electricity generation: Implications for greenhouse gas mitigation, *Biomass and Bioenergy*, 35 (4): 1474-1484.

Krasuska E., H. Rosenqvist, 2011. Economics of energy crops in Poland today and in the future, *Biomass and Bioenergy*, Available online 6 October 2011, 10.1016/j.biombioe.2011.09.011.

Kutcher G.P. and Norton, R.D., 1979. Operations research methods in agricultural policy analysis, *European Journal of Operational Research* 10: 333-345

Lintunen J., H-L. Kangas, 2010. The case of co-firing: The market level effects of subsidizing biomass co-combustion, *Energy Economics* 32: 694-701

Lumby, S., 2007. *Investment appraisal & financing decisions*, VNR Series in Accounting Finance.

Lychnaras V., S. Rozakis, 2006. Economic Analysis of Perennial Energy Crop Production in Greece under the light of the new C.A.P., *New MEDIT* 5(3): 29-37.

Mathiou, P., 2011. *Economic evaluation of perennial crop plantations in Poland*, Dissertation, Agricultural Economics Dept., Agricultural University of Athens, Greece

Matyka M. 2008. Cost-effectiveness and competitiveness of selected energy crops. Cultivation of energy crops and agricultural utilization of space, production in Poland. Studies and reports IUNG (in Polish)

McCarl B. , A. Meeraus, P. van der Eijl, M. Bussieck, S. Dirkse, P. Steacy, F. Nelissen. McCarl GAMS User Guide, http://www.gams.com/dd/docs/bigdocs (12/08/2012)

Nilsson H., K. McCormick, E. Ganko, & L. Sinnisov, 2007. Barriers to energy crops in Poland – from the farmers' perspective, Energy and Sustainability, *WIT Transactions on Ecology and the Environment* 105: 207-214

Ridier, A., 2012. Farm level supply of short rotation woody crops: Economic assessment in the long-term for household farming systems, Canadian J. Agricultural Economics 60: 357-375

Sherrington C., J. Bartley, D. Moran, 2008. Farm-level constraints on the domestic supply of perennial energy crops in the UK, *Energy Policy* 36: 2504-2512

Sherrington, C., Moran, D., 2010. Modelling farmer uptake of perennial energy crops in the UK, *Energy Policy* 38 (7): 3567-3578.

Simon D., W.E. Tyner, F. Jacquet, 2010. Economic analysis of the potential of cellulosic biomass available in France from agricultural residue and energy crops, *Bioenergy Resources* 3: 183-193

Sourie, J-C., and Rozakis, S., 2001. Bio-fuel production system in France: An Economic Analysis, *Biomass and Bio-energy* 20 (6): 483-489

Styles D., F. Thorne, M.B.Jones, 2008. Energy crops in Ireland: an economic comparison of willow and miscanthus with conventional farming systems, *Energy Policy* 35: 4335-4367

Yudego, B., González-Olabarria, J.R., 2010. Mapping the expansion and distribution of willow plantations for bioenergy in Sweden: Lessons to be learned about the spread of energy crops, *Biomass and Bioenergy*, 34 (4): 442-448.