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Abstract

Governments extensively use price support instruments to the energy industry combined with direct support for cultivating perennial crops to promote conversion of solid biomass to energy, in order to meet the goals of energy independence and mitigation of the greenhouse effect. In this paper, focusing on less fertile land classes in Poland, biomass supply is determined for a range of hypothetical prices and policy scenarios using bottom-up sector modelling. Risk-neutral and risk-averse farm-based models are run for examining willow and miscanthus adoption by Polish farmers at the municipal level.

Keywords: Willow, Miscanthus, Mathematical Programming, Utility Function, Biomass Supply, Spatial allocation

JEL classification: C6, Q16, Q41

1 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 sources (RES) have the priority to the grid and operators are obliged to purchase their energy 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, which 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 this case to determine the minimal tariff level so that co-firing activity would be triggered and reach the desired targets for renewable energy penetration into the market 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, numerous other agents are also involved in the chain, namely farmers that produce solid biomass. Thus there is an additional question concerning the availability of biomass, which is crucial for the industry to answer before investing in technology. The accurate estimation of the price-quantity relationship (supply response function) is also useful to public agencies in order to design efficient policies and more specifically the level of feed-in tariff levels.

Following an engineering approach, some studies evaluate the policy instruments for encouraging biomass supply by means of mathematical programming (MP) and utilize cost-minimising models that consist of (i) constant costs for biomass input; (ii) increasing transport costs calculated geometrically based on the assumption of evenly distributed resource; and (iii) a detailed technical description of co-firing (Kangas et al., 2009). Bottom up approaches also using MP, nevertheless consistent to the agricultural economics viewpoint, focus on farm-based sector models. These models attempt to estimate the marginal cost of the resource. High variability of biomass marginal cost reported in the literature is due to the land heterogeneity (Martinet, 2013) and the small size of decision making units (farms). Relevant literature includes the evaluation of energy crops for biofuel supply in France (Sourie and Rozakis, 2001; Kazakçi et al., 2007), perennial crop supply in Greece and the impact of the Common Agricultural Policy (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 et al., 2010).

Agricultural economists appreciate the reluctance of farmers to adopt and install perennial plantations for energy purposes (e.g. Nilsson et al., 2007; Sherrington et al., 2008; Yudego and González-Olabarria, 2010) and so include in the analysis other motives than mere profit seeking, e.g. risk considerations. Risk-averse farmers' rationality has recently been introduced in MP models regarding perennial energy crops (Boqueho and Jacquet, 2010; Ridier, 2012). These models have been implemented in a limited number of farms giving interesting results and valuable insights on the adoption of energy plantations by farmers in France.

Since the nature of the product (wood or stem, which is less vulnerable than grain) and the many years of research have contributed to a solid knowledge and assure low yield variability, a crucial issue for the take-off of energy crops is to ensure price expectations that exhibit less volatility than those for conventional crops. Indeed, 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 a key factor to enhance the adoption of energy crops. In the United States, multi-region, multi-period mixed integer MP models have been constructed to evaluate different contractual arrangements, namely land-lease versus farmer-contract alternatives (Epplin et al., 2007).

In a recent comprehensive survey for Poland it was 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 (Iglinski et al., 2011). Nevertheless, beginning from the power station of "Ostroleca" in 1997, most of the big electro-thermal power plants mix biomass with coal. Straw, as agricultural residue, can cover a large part of biomass demand, although coverage percentage varies depending on plant location and competition from neighbouring units (Rozakis et al., 2013). In addition, straw-like agricultural residues should not exceed a certain percentage of total biomass used in co-firing. Therefore there is room for woody biomass from the wood industry or dedicated plantations, which is somewhat preferable and usually valued at a higher rate than straw.

Planting of perennial energy crops began in 2005 in Poland and was initially supported by the national budget. Areas cultivated with perennial plantations have decreased (about 1060 km^2 in 2007 against approximately 450 km^2 in 2009) as in the following years only moderate European funding was available (Szymańska and Chodkowska-Miszczuk, 2011). However, Poland is committed to achieve European targets of biomass use by 2020, so policy measures complementary to the existing ones should be devised. In this study we aim to evaluate the expansion potential of two perennial energy plantations in Poland, namely miscanthus and willow, within a plausible range of feed-in tariffs, at the same time scrutinizing different support schemes, taking into account competition from conventional crops and the economic context within which arable farms operate. For this purpose, we built a multi-annual optimisation model that accommodates discounted cash flows, and integrates representations of revenue variability over time for both energy and conventional crops. The competing conventional crops that we consider are rye and triticale. Alike in Boqueho and Jacquet (2010), we assume that farmers maximise utility, so that risk-averse attitude and policies coping with risk and liquidity constraints can be taken into account. By means of parametric optimisation we then estimate biomass supply at the LAU-2 (formerly NUTS-5) region level[1] under three policy scenarios: (i) business as usual, or base-case scenario; (ii) an installation subsidy scenario; and (iii) a scenario involving a low rate loan to the producers.

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[1] The NUTS (Nomenclature of Units for Territorial Statistics) classification system is a geocode standard for referencing the subdivisions of countries in the European Union for statistical purposes and currently consists of three levels (NUTS-1, -2 and -3). The LAU classification is an extension to the NUTS system and includes two reference levels, where the lowest (LAU-2) consists of municipalities or equivalent units. The LAU-2 units were called NUTS-5 until the adoption of Regulation (EC) No 1059/2003.

The paper is organised as follows: next section presents the modelling methodology, the basic multi-year model structure and its extension to decision making under uncertainty. Section 3 presents the case study and describes the spatial and economic data of all crops considered in the analysis. Results and discussion are presented in section 4. Conclusions and ideas for further research complete the paper.

2 Materials and Methods

2.1 Problem formulation - NPV Approach

We aim to estimate biomass supply of the selected energy crops at the LAU-2 level throughout Poland. In other words, we try to capture how farmers' crop mix decisions respond to different policy measures. 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. MP models may fill this gap since they constitute an approach consistent with microeconomic theory, which is the maximisation of an economic result (e.g. profit) under an appropriate set of constraints. Such models have been widely suggested to agricultural economists, especially in case of substantial policy changes (Hazell and Norton, 1986). The typical farm model structure is thus based upon statements about the short-run physical restrictions to production (resource availability limits), decision rules (profit seeking behaviour) and institutional constraints (imports or quotas, tariffs on certain levels, competitive or monopolistic price formation or guaranteed prices, etc.).

Since the model should be able to compare the economic viability of innovative energy plantations against that of traditional annual crops, a multi-annual model is specified to accommodate different cash flow profiles. A number of considerations are taken into account in order to adequately express the impact of time on the actions to be taken and their respective consequences. The main reason the time aspect should not be ignored is the absence of stability that accompanies any long-term plan. Dynamic elements 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 competing enterprises that last for a number of years—thus interlacing time with consumption—while at the same time optimizing an economic result that should also be adjusted over time.

In this article dynamics are taken into account by calculating the net present value (*NPV*) of the net profit margins for energy plantations and conventional crops. A linear programming model can then allocate the optimal proportion of land—that maximises total *NPV*—between competing enterprises, over a period of *T* years:

$$\max \ NPV = \sum_{t} \left[\left(\frac{1}{1+d} \right)^{t-1} \sum_{j} M_{jt} X_{jt} \right] + \sum_{t} \sum_{j} Z_{jt} X_{jt} \tag{1}$$

subject to

$$\sum_{j} \sum_{e} \sum_{t} X_{jt} R_{nje} \leq B_{n} \tag{2}$$

Index j denotes activities, t denotes the years of the crop plan ($t = 1, 2, \ldots, T$) and e the years that elapse. X_{jt} is the decision variable and represents the acreage cultivated with crop j in year t. Parameters M_{jt} and Z_{jt} represent the gross margin and the terminal value respectively of crop j cultivated in year t, d is the discount rate, R_{nje} is the requirement for resource n from crop j when it is e years old and B_{n} denotes the availability of the *n*-th resource.

Objective function (1) calculates the maximum attainable *NPV* when the optimal farm plan is in place for each decision making unit, whereas (2) represents a resource availability constraint. The first part of the objective function 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 *T*-year limit. Specifically, the annual gross margin (M_{jt}) 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 energy plantations, their terminal value (Z_{jt}) is incorporated. This value is calculated as the *NPV* of gross margins attained beyond the given time frame.

In the previously described model, farmers choose among food crops and non-food crops so as to maximise *NPV*. Variables take their values in a limited feasible area defined by the set of constraints. 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, 1982). Parametric optimisation in the present article is implemented by applying incremental increases in the price of energy. With this procedure one can obtain different biomass prices for every energy crop, depending on its heating value. For every energy price level, the model returns the corresponding optimal acreages allocated to perennial crop plantations in each decision making unit. Total energy (q_d) against energy price (p_d) can then be illustrated in the form of a relation $p_d = J(q_d)$, which represents an (inverse) energy supply curve. By using a single supply model for each decision unit, it is possible to take into account the spatial economic heterogeneity of biomass production and finally to aggregate individual responses in order to obtain raw material supply for industry.

2.2 Alternative objective functions under uncertainty

Parametric optimisation to generate supply curves can be implemented using any objective functional form in linear or nonlinear programming models. A common type of a nonlinear farm programming model is one which includes an objective function that explicitly represents production decisions under risk. In effect, many studies in social sciences have observed that farmers are indeed risk-averse since even short-term decisions, i.e. annual cultivations, are subject to uncertainty concerning yields and prices. Especially in the case of conventional crops, recent information such as yield deviations from the mean, price volatility in the short and the long term as well as high and low price peaks, is available to farmers (a decade past experience is assumed for everyone in the profession, even for young farmers).

Expected utility (E-U) theory represents the axiomatic approach to modelling decision making under risk. It assumes that individuals assign discrete or continuous probability distributions to uncertain prospects and respond to this risk by maximising the expected utility $E[U(\cdot)]$ of the wealth W that these prospects generate. Risk-averse behaviour in E-U theory implies utility functions with specific characteristics, i.e. they need to be concave so that higher revenues result in higher utility (non-satiation, $U'(W) > 0$), although at a decreasing rate (decreasing marginal utility, $U''(W) < 0$). Since economists are interested in ordering preferences and not in the absolute value of the utility measure, any function that satisfies these requirements can be considered suitable for modelling choice under risk.

Two well known utility functional forms are the exponential and logarithmic utility functions. An exponential utility function may be formulated as $U = A - \exp(-rW)$, where parameter A shows the upper utility limit and r stands for the absolute risk aversion coefficient which is constant, in other words the degree of risk aversion is invariant to wealth. In contrast, the logarithmic function $U = \ln(W)$ exhibits the more plausible property of a decreasing risk aversion coefficient ($r = 1/W$), which implies that a decision maker becomes less risk-averse as wealth increases. On the other hand, the exponential utility function can accommodate negative cash flows, whereas in the case of logarithmic utility some kind of transformation is necessary in order to respect the positivity requirement.

In this study we compare alternative projects—biomass and food crops—by means of three different criteria: the expected net present value, $E[NPV]$; the expected utility of net present value, $E[U(NPV)]$; and the expected discounted sum of the utilities of the cash flow streams $E[NPU]$. When assuming a risk-free environment, i.e. no price or yield volatility, the NPV criterion is used, where the discount factor translates the time value of money. Conversely, in case of explicit uncertainty in future costs and benefits, the decision maker is either assumed risk-neutral, maximising the expected net present value (linear objective function) or risk-averse, maximising expected utility (a nonlinear objective function). The utility function takes into account farmers' aversion to risk and assists them to select the best alternative by assigning utility to *NPV*s and calculating $E[U(NPV)]$. An even more invasive approach is that of the third criterion, where utility is assigned directly to the cash flow and then its net present value is calculated as in equation (3), which is also nonlinear with respect to the decision variable X_{jt} (index *j* denotes activities or crops).

$$E\left[NPU\right]=\sum_{t}\left[\left(\frac{1}{1+d}\right)^{t-1}U\left(\sum_{j}M_{jt}\,X_{jt}\right)\right]+\sum_{t}U\left(\sum_{j}Z_{jt}\,X_{jt}\right) \qquad (3)$$

3 Case study: estimation of biomass supply from perennial energy crops in Poland

3.1 Bioenergy from dedicated perennial plantations in Poland

In this exercise, willow and miscanthus are evaluated as candidates for biomass suppliers to energy carriers at the LAU-2 level, that is, the 2171 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). Each complex consists of a group of different soils with similar agricultural features: character and properties of soil, prevailing climatic conditions, 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 are the most suitable. In this study we focus on complex 5 which is moderately suitable and complex 6 which is considered weak for rye, barley and potatoes. Spatial statistics illustrate that acreages of this sort are available in all 2171 LAU-2 regions (NUTS-2 aggregates appear in Table 1)[2].

[INSERT TABLE 1 ABOUT HERE]

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[2] The current NUTS classification for Poland lists 6 regions at NUTS-1 level, 16 voivodeships at NUTS-2 and 66 sub-regions at NUTS-3 level.

- 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 climate (Borzęcka-Walker, 2010; Borzęcka-Walker et al., 2008, 2011; Janczak et al., 2013). Conventional crops, rye and triticale are the major competitors for land of similar agronomic and ecological attributes. In Poland, total demand for biomass from major power plants is about 11 million tons (Mt), a figure that falls in the same order of magnitude with the technical potential of perennial energy crops (Pudelko et al., 2012). Regarding complexes 5 and 6 only, for a modest yield of 9 t/ha per annum for miscanthus and willow[3] and assuming that all the area (1.2 million ha) is cultivated with the aforementioned energy crops, total production amounts to 11 Mt.

As explained in section 2, the decision problem that we formulate in order to examine the adoption of miscanthus and willow by Polish farmers corresponds to a multi-annual constrained optimisation model. We have considered complexes 5 and 6 in all rural LAU-2 regions as individual decision making land units (DMU). Due to their large number (two soil complexes for 2171 LAU-2 regions = 4342 DMU in total) the model is compiled in GAMS. The only resource constraint considered in the model is that of land availability, which is assumed fixed over time for all decision (land) units. Information for land availability was obtained from the Wielkopolska Chamber of Agriculture. The model initially maximises expected *NPV* by using all the associated cash flows, then it maximises expected utility of *NPV* and finally expected net present utility (the formula given by equation 3). Unlike other studies that evaluate the adoption of energy plantations by farmers and assume exponential utility for its numerical tractability (e.g. Boqueho and Jacquet, 2010), we opt for the logarithmic utility function because the assumption that the risk aversion coefficient is (i) invariant to wealth and (ii) numerically equal for all Polish farmers is difficult to

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[3] The yield potentials of miscanthus and willow are presented in section 3.2.

justify. In order to avoid negative wealth values that will cause problems in the calculation of the $E[NPU]$ index, cash flows have been increased by the absolute value of the largest negative cash flow item (establishment cost in year 0 that is farm specific) plus one.

3.2 Agronomic assumptions and estimation of production costs

Operations for energy crops can be distinguished into three categories, namely establishment operations, recurring and one-offs and decommissioning operations (Table 2). 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 products are applied only during the years after harvest. Finally, the decommissioning process includes three operations: grubbing, deep ploughing and the application of herbicides.

[INSERT TABLE 2 ABOUT HERE]

The annual operations for 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.

Miscanthus is assumed to have a 20-year life cycle and willow 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 year for miscanthus and in the third year for willow. Miscanthus is harvested annually, whereas willow is assumed to have a three year rotation length. Both crops are assumed to reach full potential after the second harvest, and thus they produce only a fraction of their maximum yield in the first harvest. Under these assumptions, yield potentials for the energy plantations and the cereals under consideration were estimated from a spatial database provided by the Institute of Soil Science and Crop Cultivation, as well as the Wielkopolska Chamber of Agriculture, which contained detailed information on complexes 5 and 6 in all 2171 LAU-2 land units nationwide. Average yields for conventional and energy crops per soil complex appear in Table 3. The average yields amounts to 12.1 t/ha of dry matter per harvest for miscanthus and 27 t/ha for willow in complex 5 and 9.6 t/ha of dry matter per harvest for miscanthus and 20.3 t/ha for willow in complex 6. Since willow is harvested once every three years, the previous value corresponds to an annual equivalent biomass yield of about 9 and 7 t/ha in complexes 5 and 6. The average yields for rye and triticale are 2.5 t/ha and 3.2 t/ha.

[INSERT TABLE 3 ABOUT HERE]

Annual costs for rye and triticale and annual equivalent costs for energy plantations are classified into six (operations) categories, in general the same throughout land units, although some items are size dependent as is explained later in the text. Each category is composed of machinery, input and labour costs. It is assumed that some pieces of machinery are owned due to previous conventional crop enterprises, while other specialised machinery are rented, with the operator cost incorporated in the rental rate. In the case of willow, where a dedicated harvester is used, rent is more costly than that of miscanthus, which is harvested with a conventional straw machine. It should be noted that the cost of harvest is considered relative to the amount of yield and thus it is considerably lower during the first harvest. The cost of materials (fertilizers, herbicides, seedlings, cuttings, fuel), was estimated using recorded prices for 2011.The total annual cost also includes brokerage and transportation expenses—with an average distance of 30 km between farm and power plant (Krasuska and Rosenqvist , 2012). In the case of miscanthus, we assumed that harvested biomass is firstly delivered to a local storage facility; therefore roofed storage costs were added. The estimation of total costs does not include depreciation, land rents and taxes. Details on the assumptions regarding cost estimations, machinery operating costs and rental rates, as well as material input costs are provided by Mathiou (2011) and Mathiou et al. (2012).

An estimate of the production cost for wheat and barley from the Wielkopolska Chamber of Agriculture is 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 are assumed alike to those used in miscanthus and willow production, the only difference being the type and dosage of certain variable inputs. Any data missing are drawn and adjusted accordingly using information provided by the Institute of Soil Science and Plant Cultivation (Matyka, 2008). The method of estimation and the economic assumptions (prices, rent, labour wage) used for the two energy crops, are also applied to rye and triticale. With the exception of some specialised machinery being rented (combine harvester, straw-bailing machine), the rest is assumed farm property. A summary of costs for all crops under consideration is given in the upper part of Table 4 (the first four columns).

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 reflect 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, thanks to the experience acquired by farmers and the more efficient coordination of activities, the development of supporting industries (machinery etc.) and lower transport and brokerage costs. This statement is verified in a recent study comparing three farms cultivating willow in 140, 80 and 10 hectares in Lodzkie voivodship (Janczak et al., 2013). Both in terms of establishment costs and harvested yields, the large willow plantation performs significantly better than the medium and the small plantation. Establishment costs are approximately 1200, 1375 and 1525 euro/ha (in 2012 prices) and yields amount to 33, 30 and 20 t/ha per harvest respectively. Secondly, in the long term, scientific research improves the efficiency of biological processes. On this track Krasuska and Rosenqvist (2012) distinguish two scenarios for perennial energy crop cultivation in Poland, namely "large scale cultivation with current technologies" (for a total area larger than 100 thousand ha) and a second scenario that combines "scale effects with technology improvement". We use their suggestions to decrease expenses per cost category for the first of the two scenarios, assuming that it is representative of the current state in 2013. Percentage reductions by cost category appear in the last two columns of Table 4. Overall costs are reduced by 13% for willow and 11% for miscanthus on an annual equivalent cost basis.

3.3 Estimation of revenue streams and definition of policy scenarios

With regard to revenue generation, a market price of 147.5 euro/t was attributed to rye grain and 156.8 euro/t to triticale grain; straw was assumed to sell at 29 euro/t. In contrast to energy crops, both rye and triticale are subsidized under European Union policy. A direct payment of 216.8 euro/ha and a seed subsidy of 24.4 euro/ha apply currently. Revenue streams for miscanthus and willow are generated as part of the parametric optimisation process. More specifically, our energy price range is based on current prices offered to biomass producers by various power plants, which are, in turn, based on the average and variability of the price of coal. When biomass chips substitute for coal dust, assuming biomass energy value of 24 GJ/t and coal dust market price of 113 euro/GJ (Owoc and Walczyk, 2013), energy is priced at 4.71 euro/GJ for wood chips (113:24 = 4.71). On the other hand, Faber et al. (2012) report prices offered by large power plants at about 6 euro/GJ. Given these two indicative values, parametric optimisation was performed for energy prices in the closed interval [3.5 – 6.0] euro/GJ. Assuming a Lower Heating Value of 17 GJ/t for miscanthus and 19 GJ/t for willow, the energy price range translates into a biomass price range of [41.65 - 71.4] euro/t for miscanthus (multiplied also by 70% to take into account straw type biomass devaluation for power plants) and [66.5 - 114] euro/t for willow. The price difference reflects the preference for woody biomass due to better behaviour in boilers and higher calorific value.

The nature of agricultural production, especially in the case of the multi-annual plants in question, calls for a realistic cash flow estimate that can take into account the irregularity of some farm 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%.

For generating stochastic revenue streams for all crops considered in this exercise, we defined three different “states of nature” with equal chances of occurrence. In the case of the energy crops the states of nature take the form of {-10%, 0, +10%} deviations from the estimated biomass yield and in the case of the conventional crops of {-20%, 0, +20%} deviations from the assumed grain price.

At the moment there is no provision made for governmental support in the form of subsidies or direct payments, therefore no such income was considered. However, in order to explore the effects of policy implementation and financial support on the decision to adopt energy crops, three policy scenarios were established, namely the base-case scenario where there is no financial support whatsoever (business as usual scenario, denoted S1), a scenario where farmers are awarded a 50% establishment grant (denoted S2) as well as the case of taking out a low-rate loan (3% rate which is 50% lower than current rate) covering all establishment expenses and repaying it over a period of ten years (denoted S3). An establishment grant equal to half the expenses of the first year corresponds to 531 euro/ha, whereas the present value of the gain from the subsidized loan corresponds to the amount of 146 euro/ha.

4 Results

4.1 A preliminary skirmish on economic results

Before using the farm programming model to evaluate the potential supply of biomass at different energy price levels, we examined the profitability of all four crops by calculating their annual equivalent revenues using the previously stated cereal prices and their weighted average yield values. Results reported in Table 4 (lower part of the first four columns) reveal that conventional crops produce modest but positive net revenues. However, if we deduct subsidies, annual crops give negative net revenues (losses of approximately 160 and 125 euro/ha, for rye and triticale respectively). Farmers would presumably opt for planting perennial energy crops if conditions were favourable. For the energy crops we assumed an average energy market price of 6 euro/GJ, which, following the calculations described in section 3.3, corresponds to a biomass price of 71.4 euro/t and 114 euro/t for miscanthus and willow respectively. Miscanthus realises a loss of about 400 euro/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/ha due to its 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 lower maintenance requirements in boilers.

[INSERT TABLE 4 ABOUT HERE]

The future scenario that we consider results in higher net revenues, but still negative in the case of miscanthus. It is possible to make energy cropping profitable if 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 may ensure positive net revenues before subsidies for the growers, especially when combined with the higher yields predicted in the second future scenario by Krasuska and Rosenqvist (2012). 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.

In order to demonstrate the policy effect, we estimate all decision criteria ($E[NPV]$, $E[U(NPV)]$ and $E[NPU]$) for the three policy scenarios (S1, S2 and S3) using the cost and yield data appearing in Table 4 to calculate revenue streams for a 21-year period for an energy price of 5.5 euro/GJ[4]. Table 5 summarizes the alternatives.

[INSERT TABLE 5 ABOUT HERE]

It is obvious from Table 5 that miscanthus cultivation under current technology conditions is not competitive at all, whereas willow is chosen over both conventional crops for prices above 5.5 euro/GJ. At this price level the farmer should be indifferent between willow and triticale according to both the $E[NPV]$ and $E[U(NPV)]$ criteria, since they result in practically equal values. Regarding the $E[NPU]$ criterion, triticale is clearly preferred, achieving 0.524 utils (units measuring utility) compared to 0.389 for willow. This difference derives from concavity of the utility function, which

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[4] This specific price was selected because it returns approximately equal *NPV* values for triticale and willow are under the S1 scenario.

penalizes small positive or negative cash flows; in contrast to conventional crops, perennial plantations contain at least one big negative cash flow in the year of establishing the plantation. Thus, in the case of the establishment grant scenario (S2), that truncates the salient negative establishment cost of the initial years, and also in the 10-year low rate loan scenario (S3), expected *NPV* for willow increases by 40% and 11%, respectively. When the expected utility of *NPV* or the expected *NPU* are considered, utility increases in both scenarios S2 and S3, outranking triticale.

4.2 Cultivated area and biomass supply

4.2.1 The case of no policy support

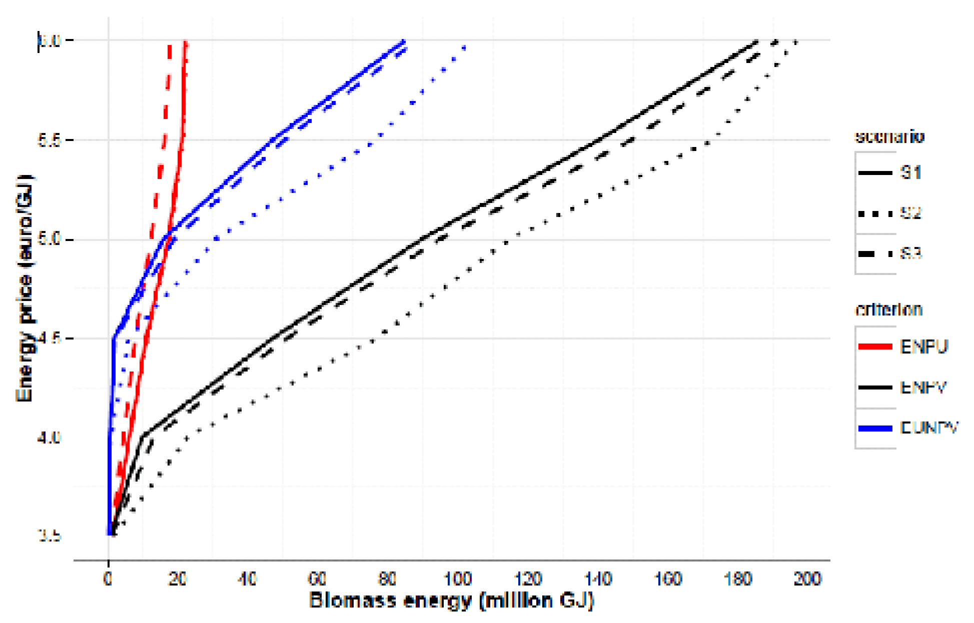
Under no policy intervention (base policy scenario S1), the optimal crop plan derived from the linear objective function (expected *NPV*) reveals that miscanthus is not economically viable within the applied price range (3.5 to 6.0 euro/GJ) when average yield values are considered. In all cases, willow plantations dominate and increase substantially in size, exceeding 1 million hectares at energy prices higher than 6 euro/GJ. Meanwhile, triticale stands as the main competitor with a maximum of 1.2 million ha for low energy prices, progressively decreasing to 93 thousand ha as the price of energy attains its highest level. A study (Baum et al., 2013) on the potential for agricultural biomass to energy in Poland confirms that willow from special plantations is the most suitable biomass for the high-capacity power industry. However Majewska-Sawka (2009) reports that willow plantations occupy an area only 10-12 thousand hectares. Available data for Podkarpackie voivodship more recent report approximately 130 thousand tons (Owoc and Walczyk, 2013) corresponding approximately to maximum 15 thousand hectares, that is about 40% of land belonging to complexes 5 and 6, whereas the model's optimal solution (risk-neutral farmers) at the 6 euro/GJ price level suggests almost 92% coverage by willow. In the same region, Sliz-Szkliniarz (2013) estimates that excluding protected land, and considering restrictions due to water scarcity and soil erosion, "an area of 428,818 ha (corresponding to 41% of the total arable land available in the region) is free of any of the aforementioned restrictions and would be suitable for cultivating energy crops ". As a matter of fact, one observes that areas planted by willow for energy purposes are rather limited compared to the theoretically available land, taking into account that feed-in tariff levels effectively offered by Polish co-firing power plants amounting up to 6 euro/GJ.

Many factors make farmers reluctant to establish perennial plantations, as reported in the literature (Sherington et al., 2008), so actual biomass production is in fact much less than predicted by the optimum of the risk-neutral model formulation. This is affirmed by Faber et al. (2012), who used stochastic simulation after considering the contribution of the risk premium for energy crops in the current biomass price in Poland. They estimated that price has to go beyond 8 euro/GJ in order to cultivate more than 80% of land available in low fertility soils. An extensive body of literature in agricultural economics has demonstrated that alternative specifications of the objective function in farm models (which are nonlinear and incorporate risk and other criteria beyond profit seeking) may achieve a higher predictive capacity than LP ones (risk-neutrality hypothesis) and are fairly suitable for market- and policy analysis. Rozakis (2011) recalls the development of alternatives to the profit maximisation rationale in agriculture, focusing on their contribution to produce input- or output functions which are useful for environmental- and/or energy policy. There is evidence that response curves generated by nonlinear models can predict more accurately farmers' response to market- and policy parameters compared with classic profit maximising behaviour. The validity of this argument is clearly demonstrated in Table 6, which presents the aggregate land allocation in complexes 5 and 6 under all three decision criteria, ($E[NPV]$, $E[U(NPV)]$ and $E[NPU]$), where it can be observed that nonlinear objective function specifications lead to more diversified, and therefore more realistic, production plans with moderate energy crop penetration.

[INSERT TABLE 6 ABOUT HERE]

The level of energy produced from biomass, based on the expected NPV criterion, ranges between 0.8 and 190 PJ (petajoules). Specifically at the lowest price levels of 3.5 to 4 euro/GJ, biomass production corresponds to 5% of the estimated power station capacity for processing biomass as input (which equals almost 11 Mt). A more satisfactory proportion (exceeding 40%) is achieved at the price of 5 euro/GJ. It should be noted that, according to Table 6, supply originates solely from willow, which dominates miscanthus due to its higher (average) calorific value of 19 GJ/t and lower annual cost per hectare. Biomass energy derived by the utility maximising model (NLP) is 4 to 5 times less than the one derived by the LP, while the distance increases for higher energy prices (Figure 1). In terms of biomass supply, at the price level of 6 euro/GJ the LP model would supply approximately 90% of the total co-firing plants capacity, whereas the NLP models may supply between 5% (for the *E*[NPU] criterion) and 40% (for the *E*[*U*(*NPV*)] criterion).

Figure 1. Biomass energy supply for different utility functions and scenarios



For each point on the supply curve the model can convey to the system relevant information on the supply of individual land units so that the spatial distribution of the biomass production is illustrated. The maps in Figure 2 shows the acreage of energy plantations in the LAU-2 land units. The one on the left illustrates energy crop cultivation in complex 5, whereas the other on the right illustrates the corresponding results for complex 6. Willow yields are lower in complex 6, for this reason the area cultivated by willow is generally lower than in complex 5. Both maps are generated by the *NPV* maximisation model (risk-neutral farmers) based on results under the base-case S1 scenario (no support policy) and an energy price of 6 euro/GJ.

[INSERT FIGURE 2A ABOUT HERE] [INSERT FIGURE 2B ABOUT HERE]

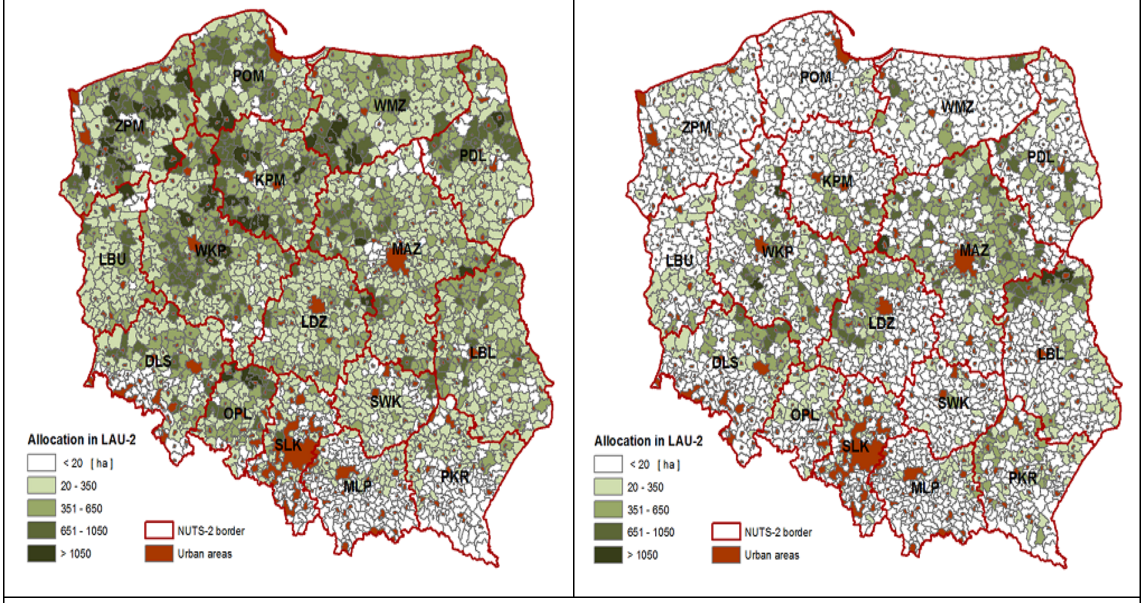


Figure 2. Spatial allocation of willow plantations at the energy price level of 6 euro/GJ for the base case (no subsidy) in complex 5 (a) and complex 6 (b) under the risk neutrality hypothesis (expected NPV criterion)

4.2.2 The role of policy implementation

In Figure 1 plots energy supply at the national level against the price range (3.5 - 6.0 euro/GJ) generated by the LP (maximisation of the expected *NPV*) and the NLP (maximisation of logarithmic utility) model for the scenarios giving incentives for planting perennial energy crops (S2: establishment grant, S3: subsidized loan). When expected utility is maximised, area to be cultivated by perennial plantations is significantly less than in the risk-neutral case. As a matter of fact farmers conform to economic rationality, including not only profit, but also taking into account risks and liquidity constraints. As shown in Figure 1 the establishment grant (scenario S2) affects biomass supply much more than does the subsidized loan (scenario S3). The establishment grant is proved to incite significant increase in land planted by willow. It is also the most costly measure since subsidy by means of grant (531 euro/ha) is higher than the subsidy avoided due to conventional crop replacement (rye and triticale receive a total of 241.2 euro/ha, consisting of direct plus seed subsidy—see Table 4).

Regarding scenario S3, the increase in the supply of energy within the price range 3.5-6.0 euro/GJ varies between 3 and 8% for the *E*[*NPV*] and *E*[*U*(*NPV*)], whereas supply in the case of *E*[*NPU*] is again almost perfectly inelastic (unresponsive to price increases), as is the case for the other two policy scenarios. The subsidized loan also results in a positive balance for every hectare of conventional crop replaced since the average annual gain from the loan amounts to 146 euro/ha (equivalent to unitary cost of subsidized loan). As a matter of fact, the subsidy avoided is higher than the cost of a low rate loan for perennial crops, and thus results in social surplus for every hectare converted from food to energy plantations. Indicatively for an energy price 6 euro/GJ, total subsidy for cereals is estimated at 86 M euro for *E*[*NPV*] and 19-40 M euro for *E*[*U*(*NPV*)] and *E*[*NPU*], whereas in the case of a subsidized loan there is an avoided overall subsidy (social gain) of 27.5 and 5-8 M euro respectively.

[INSERT FIGURE 3a ABOUT HERE] [INSERT FIGURE 3b ABOUT HERE]

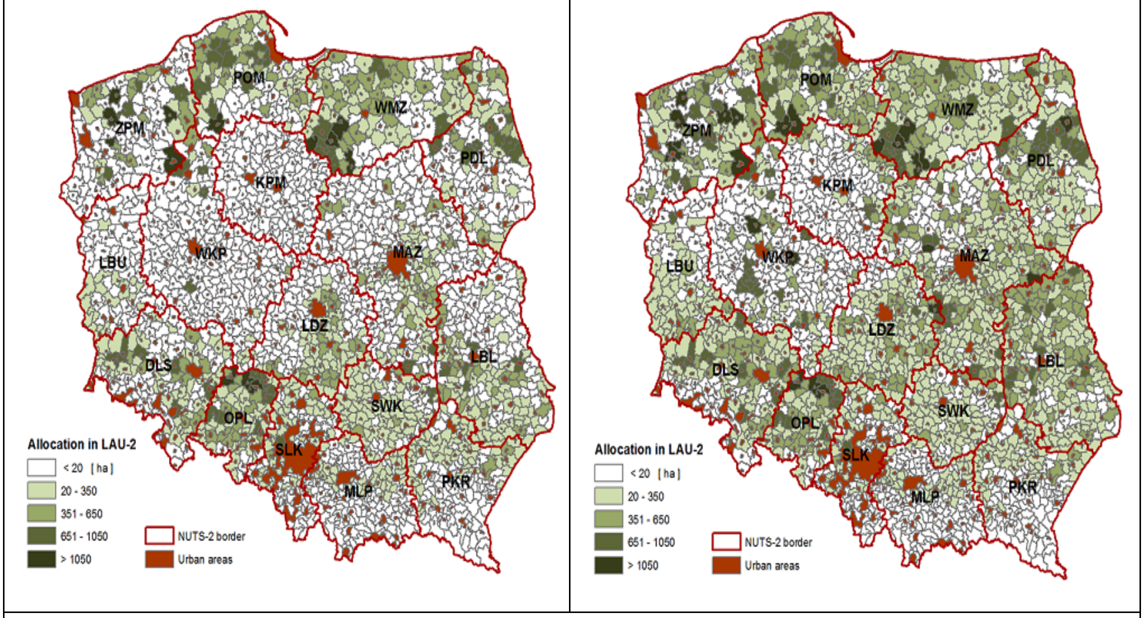


Figure 3. Spatial allocation of willow plantations in complexes 5 and 6 at the energy price level of 6 euro/GJ generated by the expected utility model (risk-averse farmer hypothesis) under no policy (a) and a grant of 50% establishment expenses (b).

Willow plantation areas shown in maps below are generated by the utility maximisation models (risk-averse farmers), and as previously observed they result in clearly lower surfaces cultivated by willow than those generated by the LP model for the same price level. Both maps in Figure 3 correspond to complex 5; the first one is generated under the base-case scenario, and, as previously, an energy price of 6 euro/GJ. When compared with the left map in Figure 2, one can observe that areas cultivated shrink since fewer LAU-2 (decision units) are involved in willow cultivation. In other words, less farmers would be willing to establish willow in their field. When scenario S2 (grant at 50% of the establishment expenses) enters into the analysis many more land units plant willow, although less than in the base-case scenario and the risk-neutral hypothesis.

5 Conclusive comments and further research

Detailed economic and agronomic information is used to assess cost of perennial energy crops in Poland. Namely, willow and miscanthus are studied in low fertility soils and compared to conventional crops such as rye and triticale. Willow is proved competitive for the state-of-the-art and current policy setting and price levels. Miscanthus may be competitive in the case of significant productivity improvement. A good approximation of biomass- and competitive crops cost conveys a clear idea of quantities offered by the farmer at given price levels. Spatial information is valuable to predict the reaction farms in different locations to price changes, helping policy makers to design more effective and targeted measures to support biomass for energy. Spatial information assists the agro-industry in estimating its inputs cost and subsequent profitability better. Aggregating supply curves at the regional level then aids in designing price-discrimination policies. We use mathematical programming for these purposes, where decision making units correspond to agricultural LAU-2 units countrywide. 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.

Parametric optimisation assists in rendering explicit response functions from alternative modelling structures. It is a first attempt to determine the supply curve of perennial energy crops at the national level in Poland focusing on spatially identified low fertility land, classifies as complexes 5 and 6. The introduction of farmers' risk considerations in the objective function significantly affects supply response, resulting in smaller area allocation to energy plantations compared to the risk-neutral case. Model results suggest that an establishment grant is the most influential measure pushing the supply curve outward, thus increasing biomass quantities supplied. A comparison of derived curves to those generated by classic LP reveals that utility based supply curves are closer to the observed acreages. Actual willow plantations produce somewhere between $E[U(NPV)]$ and $E[NPU]$ supply curves.

Nevertheless this evidence is based on fragmentary pieces of information and should be checked using extensive statistical- and survey data. Once the model is validated it can be used to assess various policy measures, including various levels of establishment grant, subsidized loans or combinations of these with feed-in tariffs. This modeling framework is also appropriate to consider imminent flat single farm payment rates that will change the relationship between conventional- and energy crop subsidy support. In this case extended use of farm statistics needs to be included in the model (i.e. Farm Accountancy Data Network—FADN statistics), so that the spatial representation of the current crop mix and operation expenses enables examination of agricultural policy scenarios and their influence in the production of biomass for energy.

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Table 1.Aggregates at the NUTS-2 level for selected areas of complexes 5 and 6

NUTS-2 region	Total arable area (ha)	Complex 5 (ha)	Complex 6 (ha)	% of arable land in Complex 5	% of arable land in Complex 5
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

Table 2.Farm operations for energy plantations and year of occurrence

Miscanthus		Willow	
Cost Category	Year	Cost 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			
Fertilizer	2 to 20	Fertilizer	4.7.10.13.16.19
Herbicide	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

Table 3. Crop yield averages and standard deviations per year (t/ha)

	Complex 5		Complex 6	
	Avg. yield	Std. deviation	Avg. yield	Std. deviation
Rye	2.5	0.3	2.5	0.3
Triticale	3.2	0.4	3.2	0.4
Miscanthus	12.1	1.5	9.2	0.6
Willow	27.0	11.2	20.3	8.4

Table 4.Annual average cost and revenue estimates (euro/ha)

	Rye	Triticale	Miscanthus	Willow	Scenario 1 Miscanthus	Scenario 1 Willow
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%	25%
Transport	23.5	23.5	371.7	212.5	5%	5%
Decommission	0.0	0.0	5.2	3.6	0%	0%
Miscelaneous	0.0	0.0	40.4	50.1	15%	15%
Total cost	569.0	638.9	1108.2	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 value	368.8	501.8	705.1	834.7	705.1	834.7
By-product value	41.0	11.7	0.0	0.0	0.0	0.0
Total revenue before subsidies	409.8	513.5	705.1	834.7	705.1	834.7
Net revenue before subsidies	-159.3	-125.4	-403.1	170.0	-279.0	254.9
Seed 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	82.0	115.8	-403.1	170.0	-279.0	254.9

* Yields correspond to national averages over soil complexes 5 and 6.

** Prices for miscanthus and willow correspond to an average energy price of 6 euro/GJ.

Table 5. Evaluation of alternative crop plans for a typical farm at the price of 5.5euro/GJ.

Project	Financing plan	$E(NPV)$	$E[U(NPV)]$	$E(NPU)$
Rye - 20 years	Subsidy & Direct payment	1014	0.304	0.396
Triticale - 20 years		1356	0.372	0.524
Miscanthus - 20 years	Business as usual (S1)	-5259	-7.438	-4.719
	50% Establishment Grant (S2)	-3183	-2.678	-1.750
	Loan 10 years (S3)	-4690	-5.719	-2.099
willow - 21 years	Business as usual (S1)	1343	0.388	0.389
	50% Establishment Grant (S2)	1874	0.505	0.682
	Loan 10 years (S3)	1489	0.422	0.573

Table 6.Areas to be cultivated by crop (in ha) against various energy pricesfor different decision criteriaunder the base case scenario (no policy support).

	Crops			
Price (euro/GJ)	Rye	Triticale	Willow	Miscanthus
E(*NPV*)				
3.5		1200162	2628	
4.0		1159740	43050	
4.5		971539	231251	
5.0		731261	471529	
5.5		410532	792258	
6.0		93818	1108972	
E[*U*(*NPV*)]				
3.5	601289	601288	205	
4.0	600043	599689	2104	
4.5	595534	598626	7039	
5.0	558830	569076	71864	
5.5	477587	487410	230974	
6.0	372230	387702	440889	
E(*NPU*)				
3.5	594400	594400	13251	
4.0	565095	565073	63673	
4.5	534834	534589	117315	70
5.0	486049	485974	203753	158
5.5	458147	458155	251881	499
6.0	456080	455904	257915	3057