AgBioForum, 21(2): 135-152. ©2018 AgBioForum.

Evaluation of Agricultural Reactivation on Abandoned Lands in Poland

Stelios Rozakis
Technical University of Crete, Greece
Institute of Soil Science and Plant Cultivation (IUNG-PIB), Poland

Robert Borek
Institute of Soil Science and Plant Cultivation (IUNG-PIB), Poland
European Agroforestry Federation, Montpellier, France

Cultivation of abandoned land can moderate indirect land use change induced by increased food and non-food demand by bio-based sectors. Using spatial analysis, we considered potential area of abandoned lands in Poland, using parcels identification system. The results are used to assess the relative profitability of SRC willow plantations and triticale cropping in medium quality soils. Taking into account uncertainty in prices, yields, maturation period, and seedling survival rate, stochastic budgeting is used to evaluate differential utility. There is no evidence that either agricultural activity is financially sustainable in small parcels. Willow plantations are preferred by risk-averse farmers for parcel sizes higher that 2 ha mainly because of fixed price contracts. Projections at the country level indicate that perennial plantations may reach approximately 20% of abandoned arable area, or 80,000 hectares. Further analysis, taking into account management schemes, demand, and spatial allocation of parcels, is necessary to determine the business potential of the two activities.

Key words: abandoned land, SRC willow, Poland, stochastic budgeting, utility function.

Introduction

Since 1992, bioenergy is among the means available to European Union (EU) countries to meet greenhouse gas reduction targets. In the first period of MacSharry reform, cultivation of biomass for energy production is allowed on land set aside from food production on large farms. The percentage of obligatory set-aside reached 15%, causing an increase in machinery depreciation costs due to excess idle machinery. Cultivation of biomass dedicated to energy has helped stabilize the profitability of farms in the EU15 and allowed the development of first-generation biofuel supply chains based on mature technology, after sufficient biomass raw material supply had been secured. In the following years the set-aside obligation was relaxed and finally abolished, replaced by fuel consumption mandates. As a result, recent biofuel production has typically taken place on cropland which could have been used for food or feed production. Assuming constant or increasing food and fodder demand, the deficit of supply will be at least partly made up by production from previously idle land such as grasslands and forests, most often in developing countries. This process is known as indirect land use change (ILUC). Indirect land use change can offset the greenhouse gas savings that result from increased biofuel production, because grasslands and forests converted to agriculture typically release high quantities of CO_2 into the atmosphere.

Recently new rules came into force—specifically the Renewable Energy Directive (EU, 2015) and the Fuel Quality Directive (EU, 2018)—amending previous biofuels legislation, with the goal of reducing the risk of indirect land use change and preparing for the transition to advanced biofuels. Additionally, the Sustainability Directive (EU, 2009) promotes renewable energy as well as the introduction of accompanying measures to encourage increased productivity on land already used for crops, the use of degraded land, and the adoption of sustainability requirements. To this end, the European Commission (EC) considered the inclusion of a factor for indirect land-use changes in their calculation of greenhouse gas emissions, in addition to the allocation of additional incentives to improve biofuel sustainability and minimize the impacts of ILUC.

According to Miyake, Mizgajski, Bargiel, Wowra, and Schebek (2016) the use of "underutilized agricultural land," including "abandoned agricultural land," is one of the most efficient solutions to minimize the effects of ILUC. Agricultural land abandonment in Central and Eastern Europe is largely associated with dysfunctional agricultural and land reforms and political and institutional issues following political regime shifts. In Poland, farming on poor soils, in small holdings or those located in less developed regions became, for various reasons after the transition of the 1990s, unprofitable. Abandoned fields where a succession of natural vegetation appeared became more prevalent in the landscape. Despite Polish accession to the European Union and the implementation of the direct payments support scheme, 1.3 million ha of arable land, 281,000 ha of pastures, and 39,000 ha of orchards still remain uncultivated (Pudełko, Kozak, Jędrejek, Gałczyńska, & Pomianek, 2018), amounting at 14.6% of agricultural area and 5.18% of the country's area. High quality land is only marginally affected by the problem of land abandonment, whereas in case of medium-good quality land (Class III, 250,000 ha) and medium quality land (Class IV, 690,000 ha), the problem is visible across the country. Conversion of these areas to agricultural food production could have great importance for ensuring national food security. The largest portion of abandoned land belongs to low quality soil classes that have a large potential for biomass cultivation for energy or industrial purposes (Pudełko et al., 2012). However, in the low-quality land case, the authors refer only to technical potential; the economic potential remains to be evaluated after taking into account low yields, land amendment, etc.

In this paper we focus on medium soil quality land classes, assessing both food and fodder crops against non-food energy production. The former can enhance food security, as additional land will be reset into production, whereas the latter can provide biomass to energy, saving GHG since only direct land use change is accounted for. However, the intensive management required to ensure profitability of land converted to production implies controversial environmental effects. Nevertheless, the above two options are not necessarily mutually exclusive; a multifunctional exploitation of land is also possible. As a matter of fact, agroforestry, a land-use management system with significant potential to restore land productivity, may conserve biodiversity, increase the resilience of agro-ecosystems, contribute to food security and nutrition (Hillbrand, Borelli, Conigliaro, & Olivier, 2017), and also produce biomass for industrial purposes. The potential of agroforestry for landscape restoration can make a significant contribution to more sustainable land use in Europe in terms of bioeconomy policy, particularly in order to mitigate climate change and improve farms' resilience to changing conditions. Integrated food and non-food production on the same land will contribute to dual objectives of producing more and better quality food for improved food security and producing alternative sources of energy to substitute for fossil fuel-intensive industrial products (Ghaley & Porter, 2014) in accordance with the European Bioeconomy Strategy.

On land with low opportunity cost for food production, such as medium-low quality and marginal land, agroforestry is an alternative to land abandonment and/or afforestation, providing different ecological benefits, diversifying land use, relaxing competition with food crops, and diversifying farmer incomes (Borek, 2016, 2017). One of the agroforestry options utilized on marginal lands is an alley cropping system including short rotation coppice (SRC) tree species—black locust, poplar, and willow (Abolina & Luzadis, 2015; Ghezehei, Shifflett, Hazel, & Guthrie Nichols, 2015; Quinkenstein et al., 2009).

From an economic viewpoint, the mutually exclusive comparison of alternative investments is pointed out as a shortcoming of economic risk analyses on the adoption of SRC. They propose considering alternative crops as a portfolio "whereby diversification effects are expected due to the different ecology, products and markets" (Hauk, Gandorfer, Wittkopf, Muller, & Knoke, 2017, p. 142). Focusing on the economic dimension, low or negative correlation of gross margins of SRC versus annual crops justifies the introduction of SRC into the crop mix, increasing the profitability and decreasing the risk of the portfolio. Evidence is provided by a case study in south Germany that diversification of crop rotations with SRC plantings, positive external agronomic and biodiversity effects notwithstanding, lies on the gross margin—risk efficient frontier. This observation holds even after taking the irreversibility element into account, in the case of extreme market shift resulting in increased profitability of annual crops.

As a first step for the economic evaluation of agroforestry systems in Poland, we evaluate, in this present research work, the potential for adoption of perennial plantations on abandoned lands with medium quality soils. For this purpose, it is necessary to analyze profitability and associated risk relative to the opportunity cost farmers bear from the best alternative, in this case a food crop. Agricultural economists appreciate the reluctance of farmers to adopt and install perennial plantations for energy purposes (e.g., Mola-Yudego & González-Olabarria, 2010; Musshoff, 2012; Nilsson, McCormick, Ganko, & Sinnisov, 2007) and so include in the analysis other motives than mere profit seeking, such as risk considerations (Hauk et al., 2017; Skevas, Swinton, Tanner, Sanford, & Thelen, 2016). In this study we evaluate the economic potential of willow energy plantations compared to triticale in Poland, within current policy support schemes. For this purpose, we built a multi-annual optimization model that accommodates discounted cash flows and integrates representations of revenue variability over time. Following Boqueho & Jacquet (2010), we assume that farmers maximize expected utility, so that risk aversion and policies coping with risk and liquidity constraints can be taken into account. The stochastic capital budgeting approach is used for the evaluation of land use change in an uncertain environment (Regier, Dalton, & Williams, 2013).

The next section details the research methods used. In the third section, data and materials are presented, namely spatial information on abandoned parcels of agricultural land, triticale and SRC willow statistics, and characteristics in Polish conditions, as well as assumptions and parameters for calculation of net cash flows in an illustrative case. Results of the stochastic budgeting model are presented in section four. Issues for further research examining alternative options are discussed in section five, and concluding comments complete the paper.

Methods

Conceptual Framework

Stochastic dominance and stochastic efficiency with regard to a function (SERF) are the techniques employed to determine whether perennial plantations present an economic advantage for farmers versus conventional cereal crops in recovering marginal land for agriculture. Rational crop production choices are justified when selecting a crop mix that optimizes the farmer's utility. Utility can take different functional forms measured in monetary units or in theoretical units like utils or any other unit. No matter what the form, it has to include the value of net returns across a range of possible states of nature (i) taking into account the decision maker's risk preferences. In the case of growing bioenergy crops, the individual farmer makes crop production choices based on discounted cash flows over the time horizon (T) for the crop investment. Because crop prices and yields are stochastic, each NPV is a random draw, representing state i from the continuous probability distribution of alternative discounted investment net return values. The ranking of biomass investment projects against annual crops will depend on the farmer's risk preference. In case of risk neutrality, maximizing utility is equivalent to maximizing the expected net present value,

$$E[NPV] = \sum_{i=1}^{n} freq_i \times PAYOFF_i \qquad (1)$$

In the most common case where the decision maker is not indifferent to risk, an expected utility theory approach to decision making under risk is suggested in the literature (Hardaker, Huirne, Anderson, & Lien, 2015). Although empirical evidence for decreasing absolute risk aversion (DARA) prevails in the agricultural economics literature (Petsakos & Rozakis, 2015), there are arguments for selecting constant absolute risk aversion (CARA) coefficients (Boqueho & Jacquet, 2010), the convenient mathematical properties of the CARA functional form notwithstanding. In this exercise CARA is selected, as Skevas et al. (2016) point out, when using agronomic experimental data, it is an appropriate utility function because there is no need to account for heterogeneity in decision maker wealth levels. Risk preference may be embodied in a CARA function, so that the risk aversion coefficient (RAC) can vary over a range from risk neutral to highly risk averse.

Crop gross margin risk, according to Skevas et al. (2016) can be decomposed into three yield quantity factors and one price element factor: (i) survival risk, (ii) maturation risk, (iii) yield fluctuation risk in mature crops, and (iv) price risk. Survival and maturation risk are more important in the case of perennial plantations, whereas the yield fluctuation risk element dominates in the case of annual crops. Regarding price uncertainty, agricultural prices vary due to changes in markets in time and space. Nevertheless, cereal prices are more sensitive than prices of perennial energy crops, which are often regulated by contracts and incentive policies to the upstream industry.

Comparative breakeven budgeting for predicting adoption of new crops is appealing since it builds in the opportunity cost of foregoing new income from the best benchmark alternative crop. The most widely grown or more suitable in terms of a potential field crop in the studied area can be treated as the benchmark crop and the basis for comparison. In case of uncertainty a stochastic capital budgeting model is required, as it enables introduction of any source of yield risk plus price risk by means of simulation of probability distributions of NPVs for each crop in competition. It also allows for calculation of the monetary value of the certainty equivalent (CE) of each NPV distribution for a range of decision makers with given risk preferences. The steps involved in building the stochastic investment analysis model are detailed below, as described by Skevas et al. (2016): (i) statistical estimation of the equations for the three forms of biomass yield risk using appropriate functional forms, (ii) retention of coefficient standard errors to simulate random coefficient models, (iii) fitting of parameters to appropriate probability distributions for additive random errors, (iv) collection of suitable random price data, (v) synthesis of these components into a stochastic simulation of NPV distributions by crop, and (vi) analysis of results as certainty equivalents for risk neutral and risk averse decision makers. In case of discrete values, Steps ii-iv are concatenated to the estimation of the decision tree payoffs.

Risk Averse Case: Stochastic Capital Budgeting

Comparison of the alternative bioenergy crop NPV cumulative distributions for decision makers who may be risk averse is performed using stochastic dominance criteria. These criteria rank investment prospects by comparing the empirical distributions of investment returns, without requiring explicit knowledge of individual risk preferences. Common stochastic dominance criteria are first-degree (FSD) and second-degree stochastic dominance (SSD). FSD requires only the assumption that the decision maker prefers higher returns to lower returns, and covers all risk preferences. SSD requires the added assumption that the decision maker is risk averse, so it omits risk-preferring individuals. Both approaches involve pairwise comparison of the cumulative distribution functions (CDF) of NPVs from alternative investment options. When FSD and SSD cannot identify preferred alternatives, an approach with more restrictive assumptions but stronger discriminating power, stochastic efficiency with respect to a function (SERF) is suggested by Hardaker et al. (2015). Under the assumption that a decision maker's risk preferences are known (as CARA with assumed coefficients, in this case), the certainty equivalent value can be calculated as the monetary value that would leave the decision maker indifferent between receiving it instead of the entire CDF from the risky investment. In mathematical terms, when preferences are represented by expected utility, the certainty equivalent of a lottery (risky investment) is the solution of the equation $U(CE) = E[U(X)]$, that indicates the lowest threshold price accepted by the owner of the particular lottery. If the individual is risk averse, a price lower than the expected value of the lottery would be accepted; in other words, the certainty equivalent of the lottery would be lower than its expected value. This difference is called risk premium, defined as the amount that the individual is willing to forego in order to get rid of the risk associated with the lottery. *Ceteris paribus*, the higher the risk aversion the lower the CE. SERF ranks a set of risky alternatives in terms of CEs. Among different mathematical specifications, we use the negative exponential constant absolute risk aversion (CARA), thus the utility function is formulated as

$$e^{-RAC \times PAYOFF_i} \tag{2}$$

The CE represents the amount of money a decision maker would require to be indifferent between receiving that amount for certain and receiving a potential result from the risky investment.

$$CE(NPV) = -ln\left(\sum_{i}^{n} freq_i \times e^{-RAC \times PAYOFF_i}\right) / RAC \tag{3}$$

Case Study

Spatial Data for Unutilized Land

Pudelko et al. (2018) have determined the abandoned unutilized arable land parcels at the country level. As expected, the highest percentage of abandoned land falls within soils Classes V and VI, which, due to their natural conditions, in many cases may be converted to other types of land use without serious consequences for agriculture. Nevertheless it is estimated that more than 440,000 ha of arable land on soils of Class IV and some 170,000 ha on soils of Class III are unutilized. In case of Class IV there is an additional 240,000 ha of unutilized grasslands and pastures. One would expect that the best and very good quality soils (Classes I and II) would constitute a negligible share of abandoned land. Therefore, it is surprising that on Class II soils there are 20,000 ha of unutilized arable land. Considering the quality of soil, the percentage of abandoned land for this valuation class should be close to zero, as it is in case of valuation Class I (Table A1 in the Appendix). On soils of valuation Class VIz (the worst quality subclass of VI), as well as areas covered with trees and shrubbery (Lzr), the percentage of unutilized area is insignificant. In the first case, Class VIz represents a small area in comparison to other classes, which translates into actually unutilized areas. Likewise in the second case, where it should be noted that this land use class does not formally represent the situation when trees and bushes appear as a result of natural succession on abandoned land. Detailed distribution by soil classes and activity can be found in Pudelko et al. (2018).

After aggregate results of the aforementioned study, one observes that soil Classes IIIb, IVa and IVb correspond approximately to total areas of 80,000, 160,000, and 150,000 hectares respectively. The amount of avail-

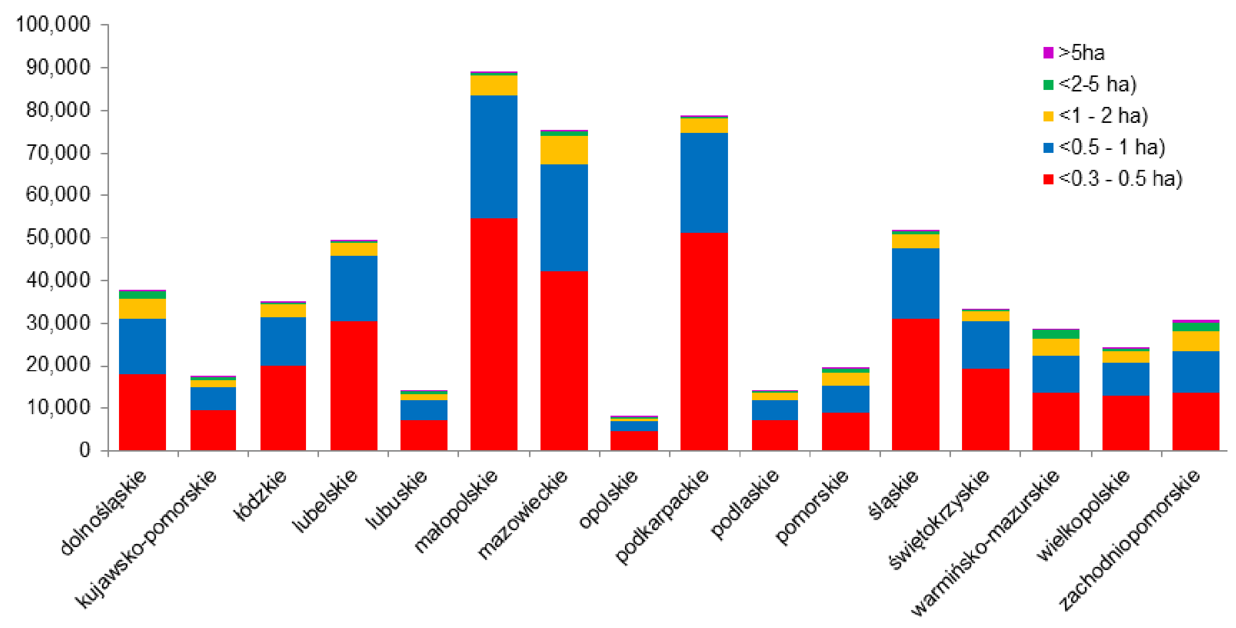

Figure 1. Abandoned land parcel size concentration and corresponding area in Poland.
Source: Pudelko et al. (2018)

able land of this sort is significant, varying between 0.3 and 80 ha per parcel. Nevertheless, the average size reveals that the majority of these parcels are small holdings. In Figure 1 we can observe concentration of size classes in Polish provinces (Absolute numbers and regional indices in the Appendix Table A2).

Conventional Crops: Triticale

In Poland, cereal cultivation area has slightly decreased in the last 20 years whereas harvested volume has increased. Triticale cultivation has expanded at the expense of rye that ranked second after wheat in terms of cultivated area and harvested volumes (ARR, 2013). Since 2009 triticale has covered a substantial share of the local market. According to Triticale-Infos, in 2008 less than 10% of harvested triticale was sold into the market; the main quantity was self-consumed on farm. However, experts predict planted area will increase in the future, so forming a regional market will be crucial in parts of the EU. Most of the triticale sold goes into export markets at better prices than rye. Considering overproduction of rye in Europe, it can be expected that triticale production will continue to grow and displace rye. Prices of triticale are highly volatile as they are aligned with wheat and other cereals. Table 1 presents average monthly triticale price data over the period 2009 to 2013. Column 2 shows the number of months the average price was at each level and Column 3 contains the cumulative percentages.

Table 1. Frequency and cumulative distribution of monthly triticale prices (2009-2013).

Value EUR	Frequency	Cumulative %
400	9	4.09%
500	35	20.00%
600	4	21.82%
700	17	29.55%
800	55	54.55%
900	99	99.55%
1000	1	100.00%

According to Arseniuk and Oleksiak (2004; Table 1) there is a positive relationship between triticale plantation size and yield, ranging from 3.41 to 4.21 t/ha for fields areas from 0.5 ha to 5 ha, respectively. Data were collected during the period 1995-2000 from more than 1000 fields in Poland. It has to be noted that yields in commercial production are less than half of those achieved in trial conditions (Arseniuk & Oleksiak, 2004, Figure 3). Trial grain yields are also available by soil class as shown in Table 2.

The sources for regional diversification analysis of triticale production were statistical GUS (central statistical office in Poland) data from 2006-2007, accessed according to the province, as presented in Jaśkiewicz

Table 2. Grain yields in t/ha of winter triticale (mean of cultivars) by soil valuation class.

Soil valuation class	Class II	Class IIIa	Class IIIb	Class IVa	Class IVb
Grain yield	8.82	8.41	8.05	7.48	6.73

Source: Noworolnik and Jaśkiewicz (2018)

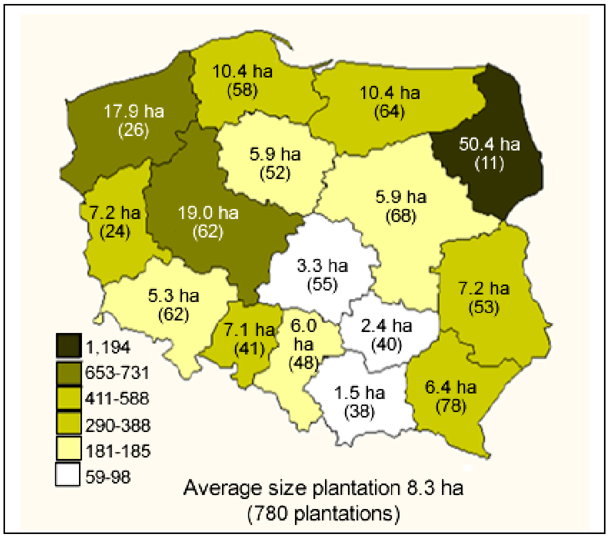

Figure 2. Average size of SRC willow plantations in Poland.
Source: Grzybek and Hryniewicz (2010)

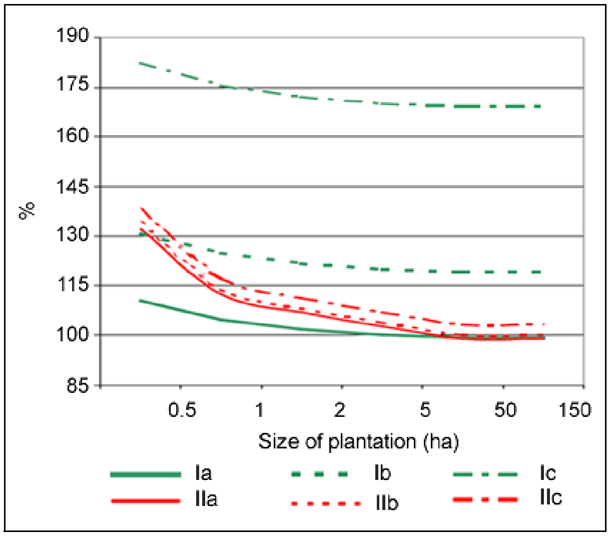

Figure 3. Production cost of SRC willow production for energy purposes.
Source: Pawlak (2010)

(2009). Applying multivariate analysis, the author studied the factors influencing the regional diversification of triticale production and yields in Poland. Triticale cultivation is concentrated mainly in Wielkopolska and Kujawy regions and in central and eastern parts of the country. Production intensity and agronomic practices are the main factors influencing triticale yield. As shown in Figure 1 (Noworolnik & Jaśkiewicz, 2018), there is significant regional variation. Regional averages for yields of production vary between 75% and 119% of nationwide average yield.

Short Rotation Willow

One of the priorities for the Polish policy for reducing greenhouse gas emissions from agricultural sources is increasing the area of agricultural land devoted to annual and perennial bioenergy crop production. The crops that are often most considered for this purpose are *Miscanthus* and willow. In a comprehensive survey in Poland, it was estimated that out of 250 municipal and industrial electro-thermal power stations, only a few have been converted to accommodate the co-firing of biomass (Iglinski, Iglinska, Kujawski, Buczkowski, & Cichosz, 2011). Nevertheless, most of the big electro-thermal power plants mix biomass with coal. Straw, as an agricultural residue, can cover a large part of biomass demand, although the percentage varies depending on plant location and competition from neighboring units (Rozakis, Kremmydas, Pudełko, Borzęcka-Walker, & Faber, 2013). In addition, straw-like agricultural residues should not exceed 20% of total biomass used in co-firing (Wieck-Hansen, Overgaard, & Larsen, 2000) whereas the maximum ratio of biomass when it comes to wood lines up to 50% (Ko & Lautala, 2018). Therefore, there is room for woody biomass from the wood industry or dedicated plantations, which is somewhat preferable and usually valued higher than straw. However, recent changes in the Polish Renewable Energy Sources (RES) law (lower value certificate of origin, energy auctions, obligation to purchase agricultural biomass at a distance of no more than 300 km from the energy producer) may cause significant changes on the biomass market. In brief, energy producers will be even more interested in buying biomass at the lowest prices. The unit cost of biomass for dedicated boilers is reported at 17 Polish zloty (PLN) per gigajoule (GJ) by Świerzewski & Gładysz (2017), based on its chemical energy. The cost of biomass production in traditional plantations cannot be significantly reduced (Stolarski, Olba-Zięty, Rosenqvist, & Krzyżaniak, 2017). Thus the profitability of biomass production on these plantations is not competitive relative to typical agricultural crops, which limits the growth of plantation areas and biomass supply.

Planting of perennial energy crops began in 2005 in Poland and was initially supported by the national budget. In subsequent years only moderate European funding was available, so the area cultivated with perennial plantations has decreased from about 1060 km^2 in 2007 to approximately 450 km^2 in 2009 (Szymańska & Chodkowska-Miszczuk, 2011). Extensive research has been conducted since then, as disseminated by recent publications on pilot plantations in Poland (Stolarski, Krzyżaniak, Tworkowski, Szczukowski, & Niksa, 2016) that update previous studies (Borzecka-Walker et al., 2013; Krasuska & Rosenqvist, 2012) with statistics and experimental results as well (Stolarski, Szczukowski, Tworkowski, Krzyżaniak, & Załuski, 2017). Presently, there is no specific governmental support for establishing and maintaining short rotation coppice (SRC) plantations, although SRC is listed as eligible for basic farm payments. Ecological focus areas (EFAs; CAP 2014-2020), on the other hand, allow production of willow, birch, and black poplar and its hybrids, harvested over rotation cycles of not more than 8 years for willow and poplar and 10 years for birch. In the case of willow, the use of NPK fertilizer is allowed at an application rate not greater than 20:20:40 kg ha^{-1} year^{-1} in the establishment year; in the year following the harvest the use of chemical plant protection products is prohibited (Borek, 2015).

The average size of willow plantations in Polish provinces varies from 1.5 to over 50 ha (Grzybek & Hryniewicz, 2010). Plantations in the North and West regions of Poland vary from 10 to 50 ha, whereas those in the South and East range from 1.5 to 7.2 ha, reflecting significant heterogeneity in parcel size (Figure 2). One observes that willow dominates perennial energy plantings, amounting to over 60% of total area planted (Grzybek & Hryniewicz, 2010, Appendix Table A3). An economic evaluation by Pawlak (2010) demonstrates that the effect of plantation size on costs is significant. As one observes in Figure 3, parcels less than 5ha experience an increase in production costs of 10-30% as compared to the benchmark 50 ha parcel. Field size also has an effect on yield, just as in triticale plantation, with 15% reduction in expected yields on small parcels (1.6 ha) compared to large ones (70ha; Grzybek & Hryniewicz, 2010, details in the Appendix Table A4). Yield values provided by Muzalewski (2010) are used as a reference, modified for plantation size and regional average yields from pilot plantations. The effect of willow planting density on the survival rate and yield of two varieties and three clones in ten successive one-year harvest cycles has been studied in an experiment conducted in 2004-2013 in northern Poland. The final survival rate was close to 85% with a planting density of 12,000 ha^{-1} and 24,000 ha^{-1}, drastically decreasing by half at the highest planting density. An increase in planting density up to 24,000 ha^{-1} resulted in greater yield, with no further increase at higher densities (Stolarski, Szczukowski, et al., 2017).

Willow is among the few perennial crops that have been planted commercially to a significant extent in the EU. It is thus familiar to many farmers, with extensive pilot plantations observed in all Polish provinces. Advantages reported include winter harvests that do not overlap with other labor-intensive agricultural operations, low operating expenses after the initial establishment investment, and higher productivity in Northern Europe (Mola-Yudego, 2010). Productivity for willow cultivation is usually modeled based on information from trials that overestimate yields and do not offer good regional coverage. Based on commercial plantations in five Nordic countries (including Poland), Mola-Yudego (2010) attempted to estimate willow yields based on climatic and agronomic parameters. As a matter of fact the productivity of oats is used as the agro-climatic index, the main independent variable in Equation 5. In this exercise, oats yield is estimated based on its high correlation with triticale yield using 25 year time series data from Poland, as specified in Equation 4. Triticale yield data are readily available since triticale makes up to 14% of cereal production throughout Poland (Jaśkiewicz, 2009). Then willow yield can be estimated by combining management data with the local productivity of oats, as specified in Equation 5 (Mola-Yudego & Aronsson, 2008).

$$y_{oats} = (b_0 + 10000 \cdot b_1 \cdot y_{oats} / 10000) \tag{4}$$

where $b_0 = -4459.7$ and $b_1 = 0.92475$

$$y_{willow,l} = b_0 + b_1 \cdot yield_{OATS,l} \cdot PLA_{lkj} + GRO_c \cdot PLA_{lkj} + b_2 \cdot EXP_{lkj} \tag{5}$$

Triticale yields have been adapted for this exercise combining three factors: geographical location, size of plantation, and soil class, as detailed in the previous section. Beginning with triticale yields, Equation 4 derives the yield of oats, with regional averages shown in Table 4. Finally, willow yield is calculated by applying Equa-

Table 3. Parameter estimates for Equation 5.

Parameter	Estimate
b_0	2.213
b_1	0.075
b_2	-0.204
GRO_{50}^{*}	-0.129
GRO_{25}	-0.039
EXP	1.5
PLA	30

** Categorical parameter related to grower performance and management experience*

Source: Mola-Yudego & Aronsson (2008)

Table 4. Regional average yields (t/ha) of oats, triticale, and (annualized) yield of SRC willow.

Province	Triticale	Oats	Willow
Dolnośląskie	4.24	3.47	8.56
Kujawsko-Pomorskie	4.60	3.81	9.30
Łódzkie	4.00	3.25	8.06
Lubelskie	3.00	2.33	5.98
Lubuskie	3.64	2.92	7.31
Małopolskie	3.44	2.74	6.89
Mazowieckie	3.52	2.81	7.06
Opolskie	4.76	3.96	9.64
Podkarpackie	3.32	2.62	6.64
Podlaskie	3.76	3.03	7.56
Pomorskie	4.24	3.47	8.56
śląskie	3.72	2.99	7.47
świętokrzyskie	3.24	2.55	6.47
Warmińsko-Mazurskie	4.08	3.33	8.22
Wielkopolskie	4.64	3.84	9.39
Zachodniopomorskie	4.20	3.44	8.47

Source: Authors' calculations

tion 5, using parameter values as shown in Table 3 along with yield of oats as the benchmark.

Results

Profitability of Examined Alternatives and Stochastic Dominance

Payoffs (gross annual profit in PLN per ha) for different states of nature have been calculated for willow and triticale in parcel sizes reported based on assumptions and data detailed in the previous section. Dolnośląskie province is selected for this illustrative example as a region with above average performance among Polish provinces. Combinations of prices and yields used are presented in Table 5; the payoff functions are shown below.

Table 5. Stochastic price, yield, and survival scenarios for triticale and willow.

Variable	Modal value	Probability
Triticale price, PLN/T	350	0.0409
	450	0.1591
	550	0.0182
	650	0.0773
	750	0.2500
	850	0.4500
	950	0.0045
Triticale yield, T/ha	3.392	1/3
	4.240	1/3
	5.088	1/3
Willow survival rate	10% below mean	1/3
	5% below mean	1/3
	Mean	1/3
Willow yield	Min: 15% below mean Max: 15% above mean	10 random values assuming uniform distribution

Stochastic price (mode_price (PLN/T) | prob_price) = {350, 450, 550, 650, 750, 850, 950| 0.0409, 0.1591, 0.0182, 0.0773, 0.25, 0.45, 0.0045}

Stochastic yield (mode_yield (T/ha) | prob_yield) = {3.392, 4.24, 5.088| 1/3, 1/3, 1/3}

PAYOFF_triticale (# price_scen (7) x # yield_scen (3) = total number of scenaria (21)) = stoch_price * stoch_yield * index (yield, parcel_size) – average_cost (input parameters assumed and corresponding payoff illustrative results for the 21 scenarios in the Appendix Table A5)

Stochastic survival rate (mode | prob) = {-10%*mean_yield, -5%*mean_yield, mean_yield| 1/3, 1/3, 1/3}

Stochastic yield (mode_yield (T/ha) | uniform distribution) = N ~ (mean_yield, max: 15%*mean_yield, min -15%*mean_yield)

PAYOFF_willow (# survival_scen (3) x # yield_scen (10) = total number of scenaria (30)) = Annual equivalent NPV (yield, price, variable costs)

The corresponding Cumulative Density Functions were formulated as shown in Figure 4 by means of ad

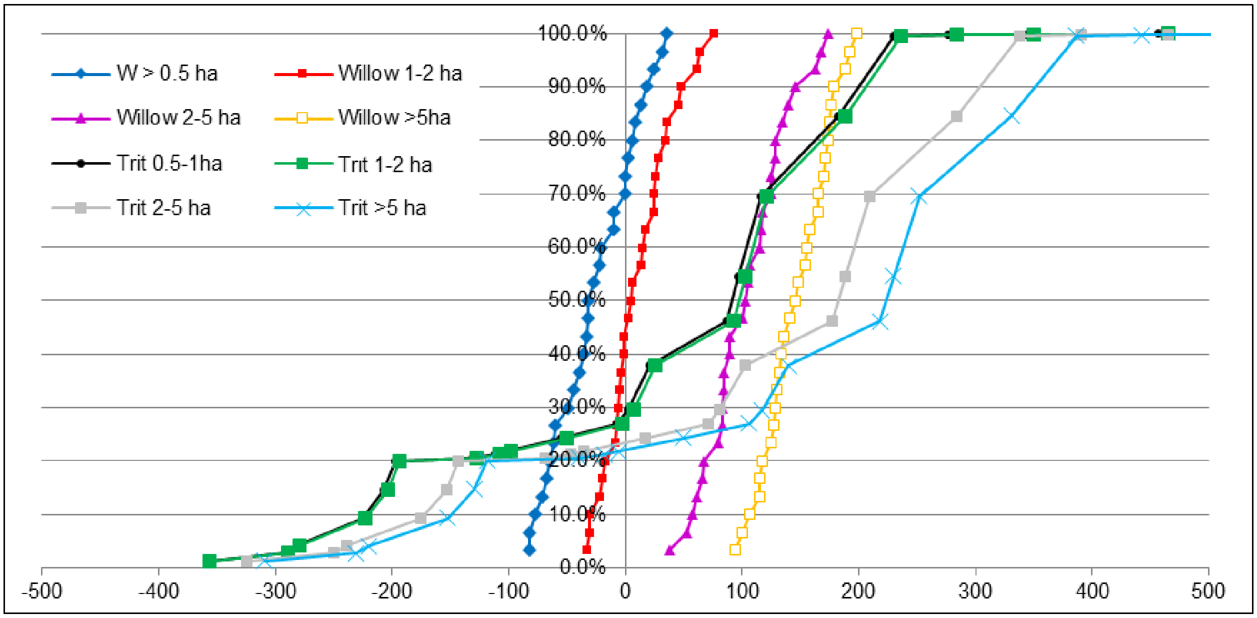

Figure 4. Frequency distribution of annual payoff of triticale in Dolnośląskie province.

hoc spreadsheet calculations. Stochastic dominance can compare two or more mutually exclusive alternatives, assuming that the payoff distribution is representative of the population to which each alternative belongs. Results in Figure 4 reveal that payoffs do not justify FSD (no alternative with consistently higher returns), since the lower tails of each parcel size class for willow and triticale cross in the neighborhood of a cumulative probability of 0.30, implying that no dominant alternative can be identified. We can observe that a pairwise comparison of willow versus triticale descriptive statistics for the same parcel size results in consistently higher average payoff for triticale, along with higher standard deviations since the range of minimal to maximal values is much higher for triticale (Table 6). This is explained by the strong assumption for energy crops of fixed contractual prices. Thus, they are exposed only to survival risk and yield variability, whereas triticale suffers from high price variability as well.

Table 6. Annual payoff descriptive statistics by parcel size class (€/ha).

Willow annual equivalent benefit (15 years)	**<0.5-1 ha)**	**<1-2 ha)**	**<2-5 ha)**	**>5 ha**
Mean	-26.3	11.0	104.1	147.0
stDev	35.2	29.0	34.8	28.5
Min	-82.4	-33.8	37.9	94.5
Max	35.7	76.0	173.6	198.3
Triticale annual gross profit	**<0.5-1 ha)**	**<1-2 ha)**	**<2-5 ha)**	**>5 ha**
Stdev	47.9	52.9	133.1	171.7
Mean	161.2	162.4	198.5	224.8
Min	-358.4	-356.4	-324.7	-309.5
Max	456.8	464.9	593.8	655.9

Stochastic Efficiency with Respect to a Function, Certainty Equivalent, and RAC Hypothesis

In order to implement the stochastic efficiency with respect to a function (SERF) method in search of a more restrictive result, we calculated utilities corresponding to the finite set of values of each CDF applying Formula 1 and 2. The certainty equivalent estimated by Formula 3 is used to order alternatives within a range of risk aversion coefficients. SERF has already been applied to estimate risk premiums for biomass-to-energy prices needed to convince Polish farmers to change from food to energy production (Faber et al., 2012). To assure a level of profitability similar to traditional agricultural enterprises, median prices of 3.0-4.2 € GJ^{-1} are necessary. In practice, such prices, corresponding to crop prices of 59-80 € t^{-1}, are not attractive for farmers. Therefore, calculated stochastic risk premiums varied between 2.5 and 5.1 € GJ^{-1} depending on the predominant type of production on a farm and the energy crop.

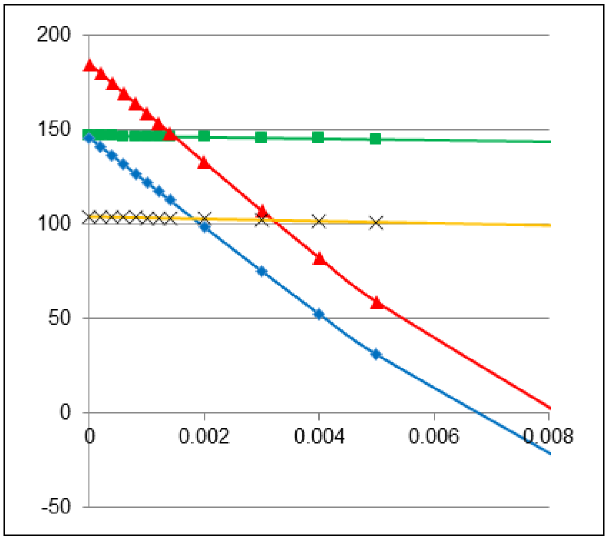

Figure 5. Illustration of SERF for simultaneous comparison of CE (vertical axis) over risk aversion levels (horizontal axis).

** yellow and blue lines plot CE of willow and triticale respectively in parcels 2-5 ha*

*** green and red lines plot CE of willow and triticale respectively in parcels >5 ha*

The total median prices, including risk premiums, needed to attain profitability fall in the range of 5.7-6.4 € GJ^{-1}. This was close to the biomass price offered by the energy sector in Poland, 6 € GJ^{-1} at the time of this study. These prices, in combination with areas suitable for energy crops, were used to estimate the economic potential of biomass, which amounted to 0.45 million ha of agricultural land. This accounted for 28% of technical biomass production potential with the capacity to produce 4.3 million tons of biomass.

At the current time the energy price is set at 4.05 € GJ^{-1} for biomass dedicated boilers. The lower biomass price is compensated by the eligibility of plantations for the decoupled area payment from the CAP that, along with a presumed contractual arrangement for fixed biomass price at the farm gate, significantly moderates price risk. Willow plantation is evaluated against annual cropping to cultivate currently abandoned land. Certainty equivalent values are calculated using the SERF method; the alternative resulting in the higher CE is assumed to be preferable for resuming farming activity on abandoned land.

Based on the classification of degrees of risk aversion mentioned by Hardaker, Richardson, Lien, and Schumann (2004), relative risk aversion with respect to wealth varies between 0.5 (hardly risk averse) to 4 (extremely risk averse). Multiplying the intersection points (0.0014 to 0.002 in Figure 5 for parcels greater than 5 and between 2 and 5 ha, respectively) by the wealth (in this case the annualized present values of net cash flows, 147-171 € ha^{-1} in Table 6) produces values of the relative risk aversion coefficient from 0.2 to 0.342 (calculated as ra(x)* net worth). However, in this case study, for values beyond 0.008 the differential between the certainty equivalents of willow and triticale is notably high, so there is no need to extend to higher values as in Table A5 for triticale in Dolnośląskie province.

As one observes in Figure 5, the CE curve for all alternatives decreases as the decision maker becomes more risk averse. In both parcel size classes, CE curves cross at a very low RAC value, close to 0.002, a level denoting risk-neutral agents. Below this level, the certainty equivalent of triticale is higher than that of willow. For the most likely case when RAC values are higher than 0.003 (also called Breakeven Risk Root), the differentials are positive in both size classes (2-5 ha and >5 ha) and follow an increasing trend with willow CE clearly dominating. For smaller size classes willow plantations do not seem profitable, so these curves are not included in the graph (this information is illustrated in tabular form in Appendix Table A6). Risk premium, calculated as the differential between CE curves, indicates the amount paid to the farmers to plant the second alternative instead of the dominating one. In this case, the risk premium to establish perennial plantations for risk neutral or quasi-neutral farmers varies between 40 and 20 € ha^{-1}. Beyond the breakeven risk root, an increasing risk premium has to be paid to risk-averse farmers to cultivate triticale; this may reach 70 € ha^{-1} or more for RAC beyond 0.006.

Concluding Comments and Issues for Further Research: The Agro-forestry Option

Stylized stochastic budgeting analysis results provide evidence that establishing perennial plantations of willow in unutilized or abandoned fields larger than two ha can be economically feasible in Poland for virtually all farmers, including hardly risk neutral farmers. This finding, if projected to the population of parcels larger than two ha, can give an estimation of the economic potential for biomass for non-food purposes. In fact, the economic potential is lower than the technical potential and higher than the business potential. Translating this finding into numbers, about 2.5% of the unutilized/abandoned parcels observed by Pudelko et al. (2018), representing about 20% of the area of soil Class III and

IV and amounting up to approximately 80,000 ha, hold economic potential for bioenergy. The agricultural reactivation of these lands by biomass production can create economic opportunities for rural regions. This number is not negligible, as it would supply several biomass-to-energy plants. However, in order to assess the business potential a detailed spatial analysis of supply chains needs to be undertaken.

The environmental implications, especially for biodiversity, are highly controversial. Based on four land use change scenarios developed for a rural region in northeast Poland, conversion to non-food biomass production seems to have a good potential to provide high-yielding biomass and income diversification to farmers (Miyake et al., 2016). Nevertheless, considering the requirements of intensive management for certain cultivation phases, the conversion of underutilized land to biomass plantations will somewhat degrade ecosystem services, including native biodiversity. A multifunctional land use system such as agroforestry or silvopastoral land use that incorporates biomass/timber woody vegetation into cropland or grassland, respectively, can have positive impacts concerning erosion, soil quality, improving the microclimate for annual crops, and increasing the health and disease resistance of grazing animals (Jose, 2009; Tsonkova, Böhm, Quinkenstein, & Freese, 2012). Financial payments targeting specific farming practices like biomass plantations, cultivation, and disregarding ecosystems resulting from traditional multifunctional agricultural landscapes are attractive only in a monetary sense for beneficiaries, as long as they are paid, and can never fully compensate for the direct benefits that people previously received from the environment (Fischer, Hartel, & Kuemmerle, 2012). Second, they distort land prices, artificially increasing the market value of marginal farmland, which in this case encourages production of a high-risk agricultural product than can only be sold long after the initial investment. Whilst the subsidies supply a satisfactory income return from the long-term investment and may delay land abandonment, they are unlikely in the long run to achieve their goal of halting and reversing this process, due to instability of market and climate factors (Merckx & Pereira, 2015). Furthermore, higher biodiversity and landscape complexity may provide a more stable supply of ecosystem services and greater adaptive capacity in the face of climate change (Bengtsson et al., 2003; Tscharnke, Klein, Kruess, Steffan-Dewenter, & Ties, 2005).

According to estimations by Miyake et al. (2015), environmental benefits can be gained only in scenarios where (i) open grazing areas (e.g., pastures) are used; (ii) native woody perennial bioenergy crops are planted; and (iii) the new plantations are under low management intensity. The results flagged the importance of careful planning and management strategies and the need for future bioenergy policy to provide more detailed prescriptions concerning land use planning and management if “underutilized agricultural lands” are to be used for future bioenergy crop production. The fourth factor, considered as key for maintaining efficient and resilient farming land use in the long term, is combination of food and non-food/energy production on the same land (Bogdanski, 2012). However, such systems should be established and maintained in compliance with environmental regulatory requirements and, where appropriate, adjusted to local habitats and landscape structure.

In this situation, an interesting alternative to typical biomass plantations can be agroforestry (AF). A recent study from EU-JRC compared the ecological benefits of eighteen of the EFA elements and found agroforestry highest in almost all countries surveyed. (Tzilivakis, Warner, Green, & Lewis, 2015). In the Ricardo-AEA study published recently (Martineau et al., 2016), a total of 22 mitigation actions were assessed in a meta-review of mainstreaming climate action in the Common Agricultural Policy (CAP). The study concluded that AF is among the mitigation actions having the greatest potential. All these aspects are key to recognizing the important role that AF can play as a technique for mitigation and adaptation of rural areas to climate change.

The introduction of trees in forest or agricultural lands as a way to promote the woody component of agroforestry was recently promoted by the European Union Rural Development (RD) programs (Measures 221, 222, and 223 and Sub-measures 8.1 and 8.2 in the CAP 2007-2013 and 2014-2020, respectively). The higher flexibility of agroforestry measures in CAP 2014-2020, linked to the definition (woody instead of tree) and the establishment of a five-year payment period after agroforestry establishment, helped to improve agroforestry adoption for a large number of Rural Development Programs. The loss of the Pillar I payment if agroforestry measures are implemented is a strong barrier to agroforestry adoption in Europe. In general, there is a 100 trees per hectare minimum limit to get the full CAP payment under the 2014-2020 CAP (Santiago-Freijanes et al., 2018).

In Poland, agroforestry is constrained by the lack of clear policy and program support at the national level, despite the wide range of forestry, agriculture, land, and economic policies in the country. The government did not implement Article 23 of the EU Rural Development Regulation, which supports the establishment and maintenance of AF areas. More information is needed on cost benefit analyses of planting different species and the consequences of scattered trees on the basic (i.e., CAP Pillar I) payments farmers receive. AF is not included in the measures for EFA within CAP Policy (EC, 2015). Country regulations do not include support for trees on agricultural land (e.g., environmental programs, favorable tax provisions). There is a lack of a clear definition and legal regulations relating to agroforestry. Absence of tree policies in Spatial Management Plans of communes and problems with complicated ownership characteristics of many land parcels in terms of inheritance also hamper implementation of AF systems (Borek & Gałczyńska, 2018). So far, no studies on SRC willow agroforestry have been conducted in the country, although implementation of low-input SRC strips on non-utilized agricultural land may result in social, economic, and ecological benefits (Dauber et al., 2012).

According to published research (Borzecka-Walker et al., 2012), the area dedicated to energy crops could cover up to 1.6 million ha (theoretical potential). This area may be considerably limited by climatic conditions, water limitation factors, and soil suitability. Furthermore, in recent years, the frequency of drought has been increasing; most climate change scenarios predict more precipitation during the winter as well as less precipitation during the summer. For these reasons, an evaluation into the impact of climate change on the potential productivity of SRC using climate change scenarios is essential for decision making proposes. The aim of the aforementioned study was to determine the potential yield in Poland for the current climate conditions and for climate change scenarios. The de-nitrification-decomposition (DNDC) model was used to perform calculations with a 99-year stochastic weather series characterized by temporal climate (1971-2000) to project scenarios describing climate conditions for 2030 and 2050. Simulations were conducted for the most typical soil types suitable for SRC production in Poland. The simulations for climate change scenarios for 2030 and 2050 showed a rather small but significant decrease in the yield level of SRC in Poland, as well as a significant change in potential carbon sequestration and reductions in nitrous oxide emission level (Borzecka-Walker et al., 2012). This information can be included in the stochastic budgeting model to extend the time horizon of the analysis.

An element targeting sustainable bioeconomy cannot be the subject of a single policy, but rather must be the object of a multi-policy landscape. Due to the complexity of the policy landscape in this matter and the variety of development paths in terms of bioeconomy and agroforestry integration, we focus only on analysis of policies linked to bioenergy production from SRC biomass crops, with particular attention paid to the economic environment of SRC willow biomass production. We examine these issues in the context of Polish agriculture and forestry, considering the Common Agricultural Policy and Renewable Energy Policy as well as most recent technical and agronomic information on willow cultivation in Polish conditions.

In further research we intend to benefit from accumulated knowledge to estimate the profitability of alternative agroforestry schemes in selected farms in Poland. Detailed pedoclimatic, land use, and economic information will be used to evaluate farming systems in order to quantify provisioning (marketable), supporting, and regulating ecosystem services.

References

Agencia Rynku Rolnego (ARR), Agricultural Markets Agency, Polish Ministry of Agriculture. (2013). November ISBN 978-83-64002-26-7.

Abolina E., & Luzadis V.A. (2015). Abandoned agricultural land and its potential for short rotation woody crops in Latvia. *Land Use Policy*, *49*, 435-445.

Arseniuk, E., & Oleksiak, T. (2004). Triticale in Poland. In M. Mergoum & H. Gomez-Macpherson (Eds.), *Triticale improvement and production* (pp. 131-134). Rome: Food and Agriculture Organization of the United Nations.

Bengtsson, J., Angelstam, P., Elmqvist, T., Emanuelsson, U., Folke, C., Ihse, M., et al. (2003). Reserves, resilience and dynamic landscapes. *Ambio*, *32*, 389-396.

Bogdanski, A. (2012). Integrated food—Energy systems for climate-smart agriculture. *Agriculture & Food Security*, *1*(9).

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

Borek, R. (2015). Agroforestry systems in Poland. A preliminary identification. *Papers on Global Change*, *22*, 37-51.

Borek, R. (2016). Agroforestry in Poland—The current state and policy perspectives. Paper presented at the *3rd European Agroforestry Conference*, Montpellier, France.

Borek, R. (2017). Agroforestry systems in Poland. The case study of silvopastoral systems as innovative and traditional knowledge-based way of farming in Poland on soils of low agricultural suitability. *Proceedings of Wooded rural landscapes in Central and Eastern Europe: Biodiversity, cultural legacy and conservation International Scientific Conference*, Rzeszów, Poland.

Borek, R., & Gałczyńska, M. (2018). Identifying bottlenecks and gateways for agroforestry development in Poland. Paper presented at the *4th European Agroforestry Conference—Agroforestry as a sustainable land use*, Nijmegen, the Netherlands.

Borzecka-Walker, M., Borek, R., Faber, A., Pudełko, R., Kozyra, J., Syp, A., & Matyka, M. (2013). Carbon and nitrogen balances in soil under SRC willow using the DNDC model. *Journal of Food, Agriculture and Environment*, *11*(3-4), 1920-1925.

Borzecka-Walker, M., Faber, A., Kozyra, J., Pudełko, R., Mizak, K., & Syp, A. (2012). Modelling the impact of climate change on miscanthus and willow for their potential productivity in Poland. *Journal of Food, Agriculture and Environment*, *10*(3-4), 1437-1440.

Dauber, J., Brown, C., Fernando, A.L., Finnan, J., Krasuska, E., Ponitka, J., et al. (2012). Bioenergy from "surplus" land: Environmental and socio-economic implications. *BioRisk*, *7*, 5-50.

European Commission. (2015). EFA layer guidance document on the establishment of the EFA-layer referred to in article 70(2) of Regulation (EU) 1306/2013.

European Union (EU) Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources.

EU Directive 2015/1513 of the European Parliament and of the Council, 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources.

EU Directive 2009/28 of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

Faber, A., Pudełko, R., Borek, R., Borzecka-Walker, M., Syp, A., Krasuska, E., & Mathiou, P. (2012). Economic potential of perennial energy crops in Poland. *Journal of Food, Agriculture and Environment*, *10*(3-4), 1178-1182.

Fischer, J., Hartel, T., & Kuemmerle, T. (2012). Conservation policy in traditional farming landscapes. *Conservation Letters*, *5*(3), 167-175.

Grzybek, A., & Hryniewicz, M. (2010). The production possibility of energy plants in Poland. In A. Grzybek (Ed.), *Modeling of biomass utilization for energy purpose*, *FOKUS Bioforsk*, *5*(6), 14-20.

Ghaley, B.B., & Porter, J.R. (2014). Determination of biomass accumulation in mixed belts of Salix, Corylus and Alnus species in combined food and energy production system. *Biomass & Bioenergy*, *63*, 86-91.

Ghezehei, S.B., Shifflett, S.D., Hazel, D.W., & Guthrie Nichols, E. (2015). SRWC bioenergy productivity and economic feasibility on marginal lands. *Journal of Environmental Management*, *160*, 57-66.

Hardaker, J.B., Huirne, R.B.M., Anderson, J.R., & Lien, G. (2015). *Coping with risk in agriculture: Applied decision analysis*. Wallingford, UK: CABI.

Hardaker, J.B., Richardson, J.W., Lien, G., & Schumann, K.D. (2004). Stochastic efficiency analysis with risk aversion bounds: A simplified approach. *Australian Journal of Agricultural and Resource Economics*, *48*(2), 253-270.

Hauk, S., Gandorfer, M., Wittkopf, S., Muller, U.K., & Knoke T. (2017). Ecological diversification is risk reducing and economically profitable—The case of biomass production with short rotation woody crops in south German land-use portfolios. *Biomass & Bioenergy*, *98*, 142-152.

Hillbrand, A., Borelli, S., Conigliaro, M., & Olivier, A. (2017). *Agroforestry for landscape restoration. Exploring the potential of agroforestry to enhance the sustainability and resilience of degraded landscapes*. Rome: Food and Agriculture Organization of the United Nations.

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

Jaśkiewicz, B. (2009). Regional diversification of triticale production in Poland. *Journal of Central European Agriculture*, *10*(2), 139-144.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforestry Systems*, *76*, 1-10.

Ko, S., & Lautala, P. (2018). Optimal level of woody biomass co-firing with coal power plant considering advanced feedstock logistics system. *Agriculture*, *8*(6), 74-95.

Krasuska, E., & Rosenqvist, H. (2012). Economics of energy crops in Poland today and in the future. *Biomass & Bioenergy*, *38*, 23-33.

Martineau, H., Wiltshire, J., Webb, J., Hart, K., Keenleyside, C., Baldock, D., Bell, H., & Watterson, J. (2016). *Effective performance of tools for climate action policy - meta-review of Common Agricultural Policy (CAP) mainstreaming*. Harwell, UK: Ricardo-AEA. Available on the World Wide Web: https://ec.europa.eu/clima/sites/clima/files/forests/lulucf/docs/cap_mainstreaming_en.pdf.

Merckx, T., & Pereira, H.M. (2015). Reshaping agri-environmental subsidies: From marginal farming to large-scale rewilding. *Basic and Applied Ecology*, *16*(2), 95-103.

Miyake, S., Smith, C., Peterson, A., McAlpine, C., Renouf, M., & Waters, D. (2015). Environmental implications of using 'underutilised agricultural land' for future bioenergy crop production. *Agricultural Systems*, *139*, 180-195.

Miyake, S., Mizgajski, J.T., Bargiel, D., Wowra, K., & Schebek, L. (2016). *Biodiversity and socio-economic implications of the use of abandoned agricultural land for future biomass production in central and Eastern Europe (CEE)*. European Biomass Conference and Exhibition Proceedings (24th EUBCE), pp. 1422-1430.

Mola-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 & Bioenergy*, *34*(4), 442-448.

Mola-Yudego, B. (2010). Regional potential yields of short rotation willow plantations on agricultural land in northern Europe. *Silva Fennica*, *44*(1), 63-76.

Mola-Yudego, B., & Aronsson, P. (2008). Yield models for commercial willow biomass plantations in Sweden. *Biomass & Bioenergy*, *32*, 829-837.

Musshoff, O. (2012). Growing short rotation coppice on agricultural land in Germany: A real options approach. *Biomass & Bioenergy*, *41*, 73-85.

Muzalewski, A. (2010). Costs and profitability of production of energy crops. In A. Grzybek (Ed.), *Modeling of biomass utilization for energy purpose*, *FOKUS Bioforsk*, *5*(6), 93-100.

Nilsson, H., McCormick, K., Ganko, E., & Sinnisov, L. (2007). Barriers to energy crops in Poland—From the farmers' perspective, energy and sustainability. *WIT Transactions on Ecology and the Environment*, *105*, 207-214.

Noworolnik, K., & Jaśkiewicz, B. (2018). Influence of various soil conditions on yielding of winter triticale cultivars. *Fragmenta Agronomica*, *35*(1), 62-71.

Quinkenstein, A., Wöllecke, J., Böhm, C., Grünewald, H., Freese, D., Schneider, B.U., & Hüttl, R.F. (2009). Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. *Environmental Science & Policy*, *12*, 1112-1121.

Pawlak, J. (2010). Economic profitability of willow biomass production for energy purpose. In A. Grzybek (Ed.), *Modeling of biomass utilization for energy purpose*, *FOKUS Bioforsk*, *5*(6), 82-92.

Petsakos, A., & Rozakis, S. (2015). Calibration of agricultural risk programming models. *European Journal of Operational Research*, *242*(2), 536-545.

Pudełko, R., Kozak, M., Jędrejek, A., Gałczyńska, M., & Pomianek, B. (2018). Regionalisation of unutilised agricultural area in Poland. *Polish Journal of Soil Science*, *1*, 119-132.

Pudełko, R., Borzecka-Walker, M., Faber, A., Borek, R., Jarosz, Z., & Syp, A. (2012). The technical potential of perennial energy crops in Poland. *Journal of Food, Agriculture and Environment*, *10*(2), 781-784.

Regier, G.K., Dalton, T.J., & Williams, J.R. (2013). Impact of genetically modified maize on smallholder risk in South Africa. *AgBioForum*, *15*(3), 328-336. Available on the World Wide Web: http://www.agbioforum.org.

Rozakis, S., Kremmydas, D., Pudełko, R., Borzęcka-Walker, M., & Faber, A. (2013). Straw potential for energy purposes in Poland and optimal allocation to major co-firing power plants. *Biomass & Bioenergy*, *58*, 275-285.

Santiago-Freijanes, J.J., Pisanelli, A., Rois-Diaz, M., Aldrey-Vazquez, J.A., Rigueiro-Rodriguez, A., Pantera, A., et al. (2018). Agroforestry development in Europe: Policy issues. *Land Use Policy*, *76*, 144-156.

Skevas, T., Swinton, S.M., Tanner, S., Sanford, G., & Thelen, K.D. (2016). Investment risk in bioenergy crops. *GCB Bioenergy*, *8*(6), 1162-1177.

Stolarski, M.J., Krzyżaniak, M., Tworkowski, J., Szczukowski, S., & Niksa, D. (2016). Analysis of the energy efficiency of short rotation woody crops biomass as affected by different methods of soil enrichment. *Energy*, *113*, 748-761.

Stolarski, M.J., Olba-Zięty, E., Rosenqvist, H., & Krzyżaniak, M. (2017). Economic efficiency of willow, poplar and black locust production using different soil amendments. *Biomass & Bioenergy*, *106*, 74-82.

Stolarski, M.J., Szczukowski, S., Tworkowski, J., Krzyżaniak, M., & Załuski, D. (2017) Willow biomass and cuttings' production potential over ten successive annual harvests. *Biomass & Bioenergy*, *105*, 230-247.

Świerzewski, M., & Gładysz, P. (2017). Environmental and economic assessment of a biomass-based cogeneration plant: Polish case study. *MAZOWSZE Studia Regionalne*, *22*, 97-114.

Szymańska, D., & Chodkowska-Miszczuk, J. (2011). Endogenous resources utilization of rural areas in shaping sustainable development in Poland. *Renewable and Sustainable Energy Reviews*, *15*(3), 1497-1501.

Tsonkova, P., Böhm, C., Quinkenstein, A., & Freese, D. (2012), Ecological benefits provided by alley cropping systems for production of woody biomass in the temperate region: A review. *Agroforestry Systems*, *85*, 133-152.

Tscharnke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., & Ties, C. (2005). Landscape perspectives on agricultural intensification and biodiversity—Ecosystem service management, *Ecology Letters*, *8*, 857-874.

Tzilivakis, J., Warner, D.J., Green, A., & Lewis, K.A. (2015). *Guidance and tool to support famers in taking aware decisions on ecological focus areas* (Final Report for Project JRC, IPR/2014/H. 4/0022/NC). Brussels: European Commission, Joint Research Centre (JRC).

Wieck-Hansen, K., Overgaard, P., & Larsen, O.H. (2000). Cofiring coal and straw in a 150 MWe power boiler experiences. *Biomass & Bioenergy*, *19*(6), 395-409.

Acknowledgments

Research presented is conducted in the frame of the project "New Strategies on Bioeconomy in Poland" funded by the program H2020-WIDESRPEAD-14-2 ERA Chairs (grant agreement No 669062). Robert Borek appreciates the financial support from SustainFARM project (FACCE SURPLUS ERA-NET program, grant agreement No 652615, funded in Poland by the National Centre for Research and Development [NCBiR]). The authors wish to thank Małgorzata Kozak and Anna Jędrejek for providing elaborated spatial data.

Appendix 1

Table A1. Information on arable unutilized/abandoned land soil class distribution.

Valuation class (I - VIz) in the total uncultivated area according to land use classes		Thousand ha
I	Best quality soils	0
II	Very good quality soils	20
III	Good quality soils (Ł, Ps)	0
IIIa	Good quality soils (R, S)	65
IIIb	Fairly-good quality soils (R, S)	105
IVa	Better medium quality soils	210
IVb	Worse medium quality soils	205
V	Poor quality soils (Ł, Ps, R, S)	360
VI	The poorest quality soils (Ł, Ps, R, S)	300
VIz	The poorest quality soils	5
	TOTAL	1,270

Source: Pudelko et al. (2018)

Table A2. Number of parcels by size and province.

Province	<0.3-0.5 ha	<0.5-1 ha	<1-2 ha)	<2-5 ha)	>5 ha	Total	Index
Dolnośląskie	18,146	12,869	4,748	1,655	359	37,777	106
Kujawsko-Pomorskie	9,573	5,414	1,624	559	114	17,284	115
Łódzkie	19,985	11,507	2,852	476	38	34,858	100
Lubelskie	30,486	15,314	3,142	430	53	49,425	75
Lubuskie	7,170	4,639	1,588	509	78	13,984	91
Małopolskie	54,684	28,867	4,738	491	59	88,839	86
Mazowieckie	42,159	25,087	6,702	1,111	109	75,168	88
Opolskie	4,494	2,429	702	283	100	8,008	119
Podkarpackie	51,180	23,605	3,259	392	71	78,507	83
Podlaskie	7,292	4,584	1,650	369	37	13,932	94
Pomorskie	8,778	6,674	2,953	1,049	239	19,693	106
Śląskie	31,086	16,351	3,477	763	146	51,823	93
Świętokrzyskie	19,358	11,048	2,365	303	20	33,094	81
Warmińsko-Mazurskie	13,560	8,857	4,106	1,810	465	28,798	102
Wielkopolskie	13,016	7,774	2,464	924	249	24,427	116
Zachodniopomorskie	13,623	9,861	4,651	1,990	570	30,695	105

Table A3. The perennial plantations in Poland, Source (Grzybek & Hryniewicz, 2010, p. 17).

Province	Willow	Miscanthus	Pennsylvanian mallow	Perennial grass	Reed canary	Poplar
Lower Silesian	599.97	11.03				
Kuyavian-Pomeranian	197.99		1.30	281.63		0.50
Lublin	305.65	10.75	3.42		14.69	5.01
Lubusz	409.42			0.90		
Łódź	210.92	1.59				
Lesser Poland	61.83	9.48				
Masovian	762.44	1,200.04	30.13			0.23
Opole	226.50	7.51	1.00	28.65	19.11	2.02
Subcarpathian	651.63	42.13	12.68			45.24
Podlaskie	156.52		3.83			4.01
Pomeranian	394.43	17.37	0.20			487.70
Silesian	258.91	2.85	39.24	17.17		0.71
Świętokrzyskie	98.64		0.50	28.49		
Warmian-Masurian	571.03	382.09	26.70		8.31	5.61
Greater Poland	765.57	31.74		21.89	10.50	13.09
West Pomeranian	488.97	116.22	2.60	985.42		83.79

Table A4. Costs and profitability of production of energy crops.

Items	Willow		Miscanthus		Sida hermaphrodita	
Plantation area, ha	W1	W2	M1	M2	S1	S2
Useful life, years	1.6	70.9	5.0	20.0	1.0	4.0
Transport distance, km	20	19	16	16	16	16
Date of planting (sowing)	1.5	2.0	1.25	4.0	0.3	2.0
Density of plant., 1000 pcs./ha	IV.2005	XI.2005	IV.2006	IV.2006	IV.2008	IV.2004
Number of harvesting cycles	29	18	10	10	28	29.6
Form of harvested biomass*	1+6	6	15	15	15	15
Yield of fresh mass, t/ha/year	long shoots	chips	bales	bales	chaff	bales
Humidity of biomass, %	15.30	17.78	14.93	15.83	13.20	11.6
Dry matter yield, t/ha/year	0.55	0.55	0.30	0.30	0.18	0.20
Calorific value, GJ/t f.m.	6.88	8.00	10.45	11.08	10.82	9.28

Source: Muzalewski (2010)

Table A5. Payoffs in PLN per ha for triticale for different outcome and related probability.

Dolnośląskie average yield case				stdev	181,6418	164,5516
	Triticale per ha income				Fodder wheat	Triticale
Prob	**Frequency**	**Price**	**Yield**	**PLN payoff**		
4.09%	1.36%	350	3.392	-1509.968	-1.35255	1.352553
4.09%	1.36%	350	4.24	-1232.46	-1.27953	1.279529
4.09%	1.36%	350	5.088	-954.952	-1.21045	1.210448
15.91%	5.30%	450	3.392	-1192.816	-1.26942	1.269424
15.91%	5.30%	450	4.24	-836.02	-1.182	1.181995
15.91%	5.30%	450	5.088	-479.224	-1.10059	1.100588
1.82%	0.61%	550	3.392	-875.664	-1.1914	1.191404
1.82%	0.61%	550	4.24	-439.58	-1.0919	1.091896
1.82%	0.61%	550	5.088	-3.496	-1.0007	1.000699
7.73%	2.58%	650	3.392	-558.512	-1.11818	1.11818
7.73%	2.58%	650	4.24	-43.14	-1.00867	1.008665
7.73%	2.58%	650	5.088	472.232	-0.90988	0.909877
25.00%	8.33%	750	3.392	-241.36	-1.04946	1.049456
25.00%	8.33%	750	4.24	353.3	-0.93178	0.931779
25.00%	8.33%	750	5.088	947.96	-0.8273	0.827297
45.00%	15.00%	850	3.392	75.792	-0.98496	0.984956
45.00%	15.00%	850	4.24	749.74	-0.86075	0.860753
45.00%	15.00%	850	5.088	1423.688	-0.75221	0.752212
0.45%	0.15%	950	3.392	392.944	-0.92442	0.92442
0.45%	0.15%	950	4.24	1146.18	-0.79514	0.795141
0.45%	0.15%	950	5.088	1899.416	-0.68394	0.683941
		Expected value		236.17	EXP Utility	0.966258
		Certainty equivalent		172		

Table A6. Certainty equivalent for triticale versus willow for different RAC and size of parcels.

Certainty equivalent, €/ha	Triticale annual net margin				SRC willow annualized net margin			
Abs. risk aversion	**<0.5 - 1 ha)**	**<1 - 2 ha)**	**<2-5 ha)**	**>5 ha**	**<0.5 - 1 ha)**	**<1 - 2 ha)**	**<2-5 ha)**	**>5 ha**
0.0000	59.1	64.2	145.7	185.0	-26.3	11.0	104.1	147.0
0.0002	55.5	60.5	141.0	179.8	-26.4	10.9	104.0	146.9
0.0004	51.8	56.8	136.4	174.6	-26.5	10.9	103.9	146.8
0.0006	48.1	53.0	131.7	169.5	-26.6	10.8	103.8	146.7
0.0008	44.4	49.3	126.9	164.2	-26.8	10.7	103.6	146.6
0.0010	40.7	45.5	122.2	159.0	-26.9	10.6	103.5	146.6
0.0012	36.9	41.7	117.5	153.8	-27.0	10.5	103.4	146.5
0.0014	33.2	37.9	112.7	148.6	-27.1	10.4	103.3	146.4
0.0020	22.0	26.6	98.6	132.9	-27.5	10.2	102.9	146.2
0.0030	3.5	7.8	75.2	107.2	-28.1	9.8	102.4	145.8
0.0040	-14.6	-10.6	52.6	82.4	-28.7	9.4	101.8	145.4
0.0050	-32.0	-28.2	31.0	58.9	-29.3	9.0	101.2	145.0

Appendix 2

Quality Classification of Arable Land in Polish Territory

Arable land is divided into good, medium, and bad quality land. The following quality classes are distinguished within each:

Good quality land—(fertile land) the following quality classes are distinguished:

- Class I—Arable soils of the best quality
- Class II—Arable soils of very good quality
- Class III (a)—Arable soils of medium-good quality

Medium quality land—(medium fertile land) the following quality classes are distinguished (comprehensive description):

- Class III (b)—Arable soils of medium-good quality; usually belonging to very good rye complexes, while the heavier ones belong to good wheat or strong cereal-fodder complexes. The following types of soils are classified as Class III (b) soils: brown, lessive and stagno-gleyic soils, black soils, and intrazonal soils, as well as peat-muck and peat arable soils not requiring drainage (or drained).
- Class IV (a)—Arable soils of medium quality, higher; generate average crops, even if good agrotechniques are applied; sometimes found at worse land-surface locations, on the higher land slopes, often prone to water erosion; heavy soils of this Class are abundant in nutritive components, characterized by high potential fertility, but they are not very permeable, cold, with low biological activity, and usually difficult to cultivate. The majority of Class IV (a) soils show periodically too high levels of ground water and require drainage, after which they can be allocated to higher classes. They belong to strong cereal-fodder complexes, or to defective wheat complexes, while the lighter soils are rye-potato soils. This Class covers the following types of soil: brown, lessive, podisolic, and stagno-gleyic soils of higher quality, as well as marshy Chernozemic soils, heavy alluvial soils, intrazonal soils, drained peat, and peat-muck soils.
- Class IV (b)—Arable soils of medium quality, lower; show similar properties as Class IV (a) soils, but are more defective (either too dry or too humid). Heavy soils are usually marshy, too heavy to cultivate, and located in bad physiographic conditions. Heavy soils which belong to this Class are classified to the cereal-fodder or defective wheat complexes. Heavy and flat soils on permeable layers usually belong to the agricultural rye complexes, usually of good quality. Light Class IV (b) soils are rye-potato soils, though they often show vulnerability to drought.

Bad quality land—(barren land) the following quality classes are distinguished:

- Class V: Arable soils of poor quality
- Class VI: Arable soils of the poorest quality

Source: Central Statistical Office (www.stat.gov.pl)