

Scotland's Rural College

The expansion and changing cropping pattern of rapeseed production and biodiesel manufacturing in Poland

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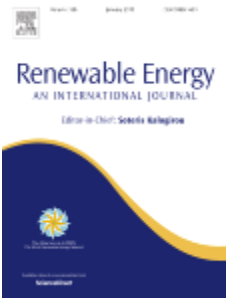


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6 **The expansion and changing cropping pattern**
7 **of rapeseed production and biodiesel**
8 **manufacturing in Poland**

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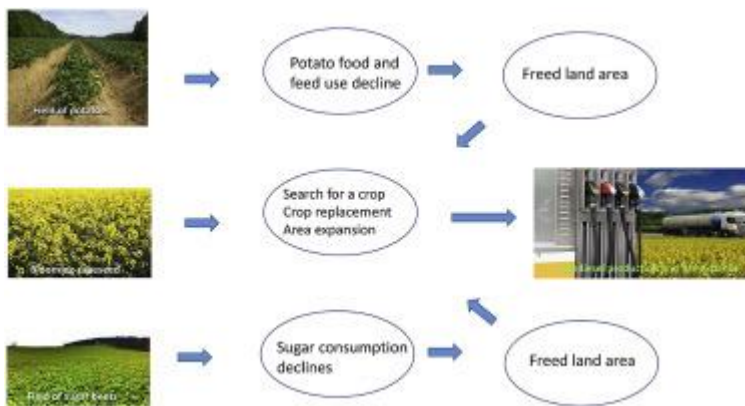
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22 Poland depends on imports for its transportation fuel supply and EC renewable energy policy
23 encourages rapeseed conversion into biodiesel. This paper discusses changes in winter rapeseed
24 production following changes in sugar policy, decreased dependence on potato use as feed and

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28 growing rapeseed are more cost efficient in all regions, and while regions with long experience in
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30 Subsidies offered under the EU support program likely initiated expansion and the expansion
31 continues after the program expired. Less efficient farms can be encouraged to enter rapeseed
32 production through farm outreach services and competitive prices in relation to other crops since the
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34 Graphical abstract



35

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38 Keywords

39 Rapeseed
40 Farm efficiency score
41 Sugar policy
42 Potato use
43 Spatial production variability
44

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71 **1. Introduction**

72 The European Commission (EC) mandate to increase the share of renewable feedstock in
73 energy generation requires member-countries to reach the required level by 2020. The European
74 Union (EU) directive obligates its member-countries, including Poland, to utilize renewable energy
75 and reach a 15% share of renewable energy consumption by 2020 [1]. Additionally, the newly
76 adopted, but not yet approved (by the European Parliament) goal aims at the share of renewable
77 energy use at 32% by 2030 [2]. The share of renewable energy in total energy consumption
78 amounted to 4.3% in Poland in 2013 [3] and Poland placed tenth among the world's largest
79 biodiesel producers [4]. Biodiesel production reached about 0.8 million tons in 2016 [5] and
80 increased to nearly 0.9 million tons in 2017 [6]. Poland is heavily dependent on imports of
81 transportation fuels and expanding the domestic supply of biodiesel is consistent with renewable
82 energy policies and increases energy security.

83 Biodiesel is the most important among the many types of biofuels produced and used in the
84 European Union (EU) [7]. France and Germany lead among the EU countries in biodiesel
85 production followed by Poland. EU countries manufacture biodiesel primarily from rapeseed
86 (*Brassica napus* L.), which is the main oil seed crop in Poland, while the EU is the largest rapeseed
87 producer (33% of world production) [8]. Biodiesel production is driven, among other reasons, by
88 both EU agricultural, climate change, and energy policies. The various policy objectives have
89 affected the global trade in biodiesel feedstock and are reflected in large EU imports of palm oil for
90 the purpose of biodiesel production. The EU is the second largest palm oil importer and 45% of the
91 global palm oil production was used in transportation (as biodiesel) in 2014 [9]. However, palm oil
92 as a biodiesel feedstock was subject to severe criticism as the EC identified palm oil production as
93 detrimental to the environment [9] due to, among other reasons, the effect of clearing land for palm
94 oil plantations and was inconsistent with the desired indirect land use change (ILUC). The EC
95 intention has been to eliminate palm oil as biodiesel feedstock after 2021 [10]. Such changes create
96 additional demand for rapeseed, including rapeseed grown on Polish farms. Since Poland's

97 accession to the EU, the number of farms producing rapeseed more than doubled and the rapeseed
98 share in area planted increased from 4% to 9% in the period 2013-2015 [8]. The effect of expanding
99 rapeseed production lowered the share of grains which is undesirable from an environmental
100 standpoint.

101 Winter rapeseed is favored mostly in the southwestern and western parts of Poland as well
102 as along the Baltic Sea coast. The spatial variability reflects biophysical factors including suitable
103 soils and adequate moisture for proper plant growth, both conditions important in rapeseed
104 production [11]. The crop is also sensitive to frost, but these regions tend to have mild spring
105 weather. However, the production of rapeseed was also undertaken in neighboring regions,
106 including Wielkopolska (located in west-central Poland), which has been traditionally recognized
107 for its farmers' excellent management practices (Map 1). Rapeseed growers are familiar with
108 regional agro-ecological conditions and have accumulated experience in managing rapeseed
109 production risks. To meet the mandated renewable energy use will require that more rapeseed be
110 planted in traditional and non-traditional production areas of Poland. Farmers in the non-traditional
111 rapeseed growing areas are driven by competitive returns in undertaking rapeseed production,
112 availability of new varieties, and government policy.

113 In the context of the pending renewable energy mandate imposed by the EC, the expected
114 growing demand for biodiesel feedstock resulting from transportation needs, and restrictions on
115 palm oil imports, this study examines policies adopted in Poland after the transition to a market
116 economy in 1989 that indirectly and directly contributed to the growth of rapeseed area planted
117 (Figure 1) and production. The consideration of changes in spatial variability accounts for various
118 agro-ecological conditions and the overall management skills of farmers. The latter continually
119 change, are difficult to measure, and are embedded in the observed changes in the crop area in this
120 study. Additionally, biodiesel support program effects on rapeseed production are discussed. Next,
121 we examine spatial differences in cost efficiency index values for all farms and, separately, for oil-
122 seed producing farms using binary variables for each voivodship with Wielkopolskie Voivodship as

123 the benchmark. Wielkopolskie Voivodship has been viewed as the leading region in terms of farm
124 productivity and has been a traditional area of rapeseed production. Since growing conditions
125 favoring rapeseed production vary across the country, regional analysis allows drawing inferences,
126 such as what regions have relatively higher cost efficiency than Wielkopolskie Voivodship. The
127 regional level of analysis supplements numerous studies evaluating biofuel policies in aggregate
128 [12]. The study uses FADN data for the period 2004 to 2011, which included the 2008-2010 oil
129 seed EU support program.

130 **2. Methods**

131 *2.1. Spatial changes in crop area*

132 Data used in the description of spatial changes in crop area in Poland were obtained from the
133 Main Statistical Office (GUS). Several publications were used to obtain the series discussed in this
134 study. The methodology of reporting was the same throughout the considered period.

135 *2.2. Modeling cost efficiency*

136 In general, improved input use or improved varieties make an inefficient farm more
137 productive [13]. This study examines cost efficiency among farms producing oil seed crops and all
138 farms to examine which of these two groups of farms is more cost efficient. The analysis is
139 conducted at a regional level and accounts for spatial variability of winter rapeseed production. The
140 available data and applied approach extend previous research that examined spatial aspects of
141 rapeseed production from a country viewpoint [14].

142 Polish farms providing the information represent well the farms engaged in commercial
143 agricultural production. Farms share details about their outputs, crops grown, and other details
144 about farm operation using unified accounting principles. The monetary measures are converted
145 from domestic currency to euros for countries outside the euro-zone such as Poland.

146 The study applies a stochastic cost frontier framework. The index of most efficient farms
147 equals one and such farms are positioned on the frontier function. [15] proposed the fixed effects
148 stochastic cost frontier model in

149 (1) $\ln E_{it} = \ln C(Q_{it}, W_{it}, \tau_t; \Omega) + v_{it} + u_i$,

150 where i denotes farms and t the periods. The observed expenditure $\ln E_{it}$ is in the logarithm and the
 151 deterministic cost function, $\ln C(Q_{it}, W_{it}, \tau_t; \Omega)$ depends on the outputs Q_{it} , the input prices W_{it} ,
 152 a deterministic trend τ_t that captures technological change, and a vector of parameters Ω in
 153 equation (1). Except the trend, all the variables are in logarithms. The statistical error, v_{it} , is with
 154 mean zero and variance σ_v^2 . The inefficiency term u_i is positive and time invariant.

155 Prior to estimation, it is necessary to select the functional form for the deterministic part of
 156 the stochastic cost frontier (i.e., $\ln C(Q_{it}, W_{it}, \tau_t; \Omega)$). Following [16], this study applies a
 157 generalized multiproduct translog cost function. The latter imposes fewer a priori restrictions than
 158 alternative functional specifications. [16] note that in the context of multiproduct estimation, a farm
 159 may not generate a specific output causing the logarithm used in the translog function to produce an
 160 error. A Box-Cox transformation can then substitute for the logarithm of the output terms. This
 161 study applies $f(Q) = Q$ as a hybrid between the translog function and the quadratic function. The
 162 cost function for n inputs and m outputs is:

$$(2) \quad \ln C(Q_{it}, W_{it}, \tau_t; \Omega) = \alpha_0 + \varphi_0 \tau_t + \varphi_0 \tau_t^2 + \sum_{j=1}^n \alpha_j \ln W_{jt} + \frac{1}{2} \sum_{j=1}^n \sum_{k=1}^n \beta_{jk} \ln W_{jt} \ln W_{kt} \\ + \frac{1}{2} \sum_{j=1}^m \sum_{k=1}^m \delta_{jk} f(Q_{jit}) \ln W_{kt} + \sum_{j=1}^m \gamma_j f(Q_{jit}) + \frac{1}{2} \sum_{j=1}^m \sum_{k=1}^m \rho_{jk} f(Q_{jit}) \cdot f(Q_{kit}).$$

164 The stochastic cost frontier has to satisfy the properties of any cost function [31]. The
 165 imposition of price homogeneity and symmetry conditions in (2) followed from placing restrictions
 166 on the parameters (3):

$$(3) \quad \sum_{j=1}^n \alpha_j = 1; \quad \sum_{j=1}^n \delta_{jk} = 0; \quad \sum_{j=1}^n \beta_{jk} = 0; \quad \sum_{k=1}^n \beta_{jk} = 0; \quad \sum_{j=1}^n \sum_{k=1}^n \beta_{jk} = 0; \quad \beta_{jk} = \beta_{kj}$$

168 The inefficiency coefficient is assumed to be time invariant and was estimated using a fixed
 169 effects panel data model of a stochastic cost frontier estimation [15; 18; 19]. However, the use of a

170 fixed effect model precludes the use of time invariant variables in estimation. To overcome this
 171 restriction, in the context of cost function estimation, the parameters linked to input prices are
 172 estimated from the cost share equations, where the inefficiency terms (i.e., the fixed effect terms) do
 173 not appear.

174 The equation to be estimated, with the intercept $\alpha_{0i} = \alpha_0 + u_i$ is:

$$(4) \quad \ln E_{it} = \alpha_{0i} + \varphi_0 \tau_t + \varphi_0 \tau_t^2 + \sum_{j=1}^n \alpha_j \ln W_j + \frac{1}{2} \sum_{j=1}^n \sum_{k=1}^n \beta_{jk} \ln W_j \ln W_k + \frac{1}{2} \sum_{j=1}^m \sum_{k=1}^n \delta_{jk} f(Q_{jit}) \ln W_k \\ + \sum_{j=1}^m \gamma_j f(Q_{jit}) + \frac{1}{2} \sum_{j=1}^m \sum_{k=1}^m \rho_{jk} f(Q_{jit}) \cdot f(Q_{kit}) + v_{it}.$$

175

176 The dataset does not contain input prices for each farm, but it is common in cross section estimation
 177 to assume that all farmers face identical prices (e.g., [20]). However, in a cost function estimation
 178 applying panel data, prices are introduced under the assumption that all farmers face the same input
 179 prices within a year (i.e., across farms), while allowing prices to change over time. In a different
 180 context, similar assumptions can be found in the estimation of demand systems, where price
 181 elasticities are sometimes estimated from time series because of the lack of variability of prices in
 182 cross section datasets [14]. Table 1A reports the calculated elasticities of substitution among five
 183 input categories.

184 Costs and outputs by farm category were computed directly from the FADN data. Labor and
 185 land input prices were estimated from the FADN data. This data only presents input expenditures
 186 and not the prices paid for inputs (or their used quantities) needed for the cost function estimation.
 187 Therefore, Eurostat's input price indices data (base year 2005) were used for agricultural materials,
 188 energy, and capital as an estimate of those prices paid by farmers over the study period.

189 As shown in [15], the relative cost efficiency index (CEI_i) for a sample size N was
 190 computed as equation (5) based on the estimated fixed effect intercepts (i.e., $\hat{\alpha}_{0i}$), where for the
 191 most cost efficient producers it has a value equal to one:

$$(5) \quad CEI_i = \exp \left\{ - \left(\hat{\alpha}_{0i} - \min_i \{ \hat{\alpha}_{0i} \} \right) \right\} \quad i = 1, \dots, N.$$

192

193 The results of the cost function estimations for two farm categories, i.e., those growing oil seed
194 crops and for the whole sample provided insights into cost efficiency differences.

195 The estimation of the cost functions allowed not only produced efficiency scores but also
196 factor substitution elasticities (Table 1A). All obtained elasticities are statistically significant at $\alpha =$
197 0.01 and, in general, have the expected signs. There appears to be a complementarity rather than
198 substitution between energy and materials. This possibly results from the aggregate nature of the
199 category “Materials”. Similar complementarity between land and energy could reflect the
200 technology used on Polish farms, which are relatively small, especially if compared to farms in
201 other EU countries.

202 The cost function was estimated for five inputs and three outputs (see Appendix) using
203 Iterative Seemingly Unrelated Regression Equations (ISURE) to obtain the coefficients in the
204 reduced model. Second, all the remaining parameters of the cost function, except the fixed effect
205 terms (i.e., output terms not associated with prices) were estimated using the within estimator
206 (ordinary least square applied to the variables expressed as deviations of the means by farm as in
207 [21]). Finally, the fixed effect terms used in the construction of the relative cost efficiency indices
208 were estimated by evaluating the function at the mean value of the variables by farm [15; 22; 23].¹
209 Finally, to identify regional differences in cost efficiency, scores of rapeseed producing farms were
210 regressed on economic size of each farm and a binary variable indicating a specific region. The
211 estimation applied the White heteroskedasticity-consistent regression.

212 *2.3.Data*

213 Data used in this paper are from the Farm Accounting Data Network (FADN) database,
214 initiated in 1965. In the case of Poland, FADN data were available only since the 2004/05
215 production year (after the country's accession to the EU on May 1, 2004). The voluntary

¹ The farm level estimated fixed effects used to compute the relative cost efficiency indices were assumed to be constant over time due to the short period covered by the sample (in the best case, information was available for some farms for eight years) [22] 2003, p. 170).

216 participation of each farm causes some farms to drop from the panel and the available set is
217 unbalanced panel data. The data are annual observations for the period 2004/05-2011/12. The
218 unbalanced panel applied in this study included 19,455 farms, representing 93,916 observations.
219 The study examines the cost efficiency of farms of all types included in the sample.

220 Table 1 shows the number of all farms and oil seed producing farms by voivodship in the
221 FADN sample for the period 2004-2011. The number of all farms in the sample varies across years,
222 but in eight voivodships reporting the largest area planted with rapeseed (Figure 2), the number of
223 farms in the FADN sample increased over time (except in Wielkopolskie), i.e., Dolnośląskie,
224 Lubuskie, Kujawsko-Pomorskie, Opolskie, Pomorskie, Warmińsko-Mazurskie, and Zachodnio-
225 Pomorskie Voivodships (Map 1). The share of oil seed producing farms also increased in seven out
226 of the eight voivodships with the largest area planted with rapeseed. The exception was Zachodnio-
227 Pomorskie Voivodship, but in 2004 this voivodship reported the largest share of oil seed producing
228 farms (45.2%). The observed tendency in the number of oil seed producing farms also characterizes
229 the changes in the sample composition of the remaining voivodship stressing the increased interest
230 in oil seed production in general in Poland.

231 **3. Policies affecting rapeseed production**

232 Rapeseed has been the primary oil seed crop in Poland prior to the transition to an open economy
233 based on market mechanisms in 1989. Prior to 1989 the government relied on the state, cooperative,
234 and private farm sectors to grow a crop subjected to unpredictable weather and dictated to state
235 farms the area they had to dedicate to highly risky crop. The whole crop was sold at government
236 procurement prices. The fixed price system, however, prevented any sustained supply response or
237 change in demand. Rapeseed cake, a valuable co-product, provided a source of animal feed, but
238 because the varieties grown at that time (before 1989) were characterized by different nutritional
239 qualities than the current double-zero varieties, the cake was not well tolerated by some farm
240 animals. Annual animal production targets faced by each state farm allocated by the government

241 also reflected the importance of meat production. Any disruption of food production could lead to
242 shortages on the domestic food market and social unrest [24].

243 The pressure to meet government assigned numerical goals resulted in contradictions
244 between centrally allocated rapeseed production quotas, the reality of available arable land, and the
245 unpredictable weather events during each growing season. But, varying weather patterns and soil
246 quality, administratively driven production goals, and available technology shaped crop
247 management skills that under the fixed price system had to focus on balancing costs and yields.
248 The 1989 transition to a market economy eliminated the state monopoly on foreign trade. The
249 immediate effect was the easing any food or agricultural input shortages including animal feed and
250 feed concentrates. The imported feed quickly substituted the traditional feed of steamed potatoes
251 mixed with crushed grains in the hog production. The open economy policy induced a near
252 elimination of potatoes from the cropping pattern. Poland, which for decades belonged to the top
253 potato-producing countries in the world, witnessed farmers choosing to purchase commercial feed
254 and increasing the planting of grains. The area planted with potatoes amounted to 1.835 million
255 hectares in 1990 [25]. In 2004, the year of Poland's accession to the EU, the area planted with
256 potatoes was 713,000 hectares, a 61.1% decline since 1990. The rapidly decreasing use of potatoes
257 as feed coincided with its declining consumption by households. Between 1990 and 2015, per capita
258 consumption of potatoes decreased by 30.6% and continues to its decline [26; 27]. In 2015, the area
259 planted with potatoes amounted to 300,000 hectares or 83.7% less than in 1990 [25].

260 The reduction of potato area without exception in all regions of the country, released about
261 one million hectares to grow other crops. Farmers sought crops that required fewer inputs and
262 focused on grains. The change in cropping patterns is undesirable because planting grain after grain
263 lowers yields and increases weed pressure [28]. Potato production required more inputs than grains.
264 The consequence of the opening of the economy was a decrease in potato plantings allowing the
265 expansion of rapeseed area for farmers seeking profitable although risky crops.

266 Similarly to other food products, sugar shortages were periodically experienced under the
267 centrally planned economy in Poland prior to the 1989 transition. Following the transition to the
268 market economy, initially the domestic sugar production continued relatively undisturbed. Growers
269 received cash payment for deliveries and used leaves of beets as fodder, especially in dairy
270 production. Additionally, many farms used beet pulp as feed for all types of livestock. The primary
271 goal of higher yields under the centrally planned economy changed under the market conditions,
272 when sugar processors tested deliveries and structured prices according to beet sugar content. The
273 testing induced changes in cultural practices and plant varieties.

274 Still, in the mid-1990s, the sugar beet area dominated the share of industrial plant crops in
275 Poland [28]. In managing cropping patterns, sugar beets played a crucial role. Sugar beet production
276 limited planting grain after grain, maintaining soil quality. However, in 1994, Poland changed its
277 policy with regard to the sugar industry. It implemented, long before the EU accession, sugar
278 market regulations principally based on EU policy. The regulation involved quotas limiting the
279 volume of sugar intended for domestic markets, subsidized exports, and exports at market prices.
280 Sugar imports were subject to high import tariffs under the WTO arrangements. By 2006, when
281 Poland already joined EU, policy changed again and relied on a strict quota and pricing system. As
282 a result, the 26,718 farmers growing sugar beets in 981 counties (out of the total of 2478) lost sugar
283 beet supply contracts [29]. The number of sugar beet factories rapidly declined. For example, in
284 Dolnośląskie Voivodship (Map 1), the number of sugar processing plants declined from 9 in 2001
285 to 2 in 2011 [29].

286 The decline in the sugar beet planting area has been dramatic since the early 1990s. In 1996,
287 the area planted amounted to 453,000 hectares and dropped by 154,000 (34.4%) in 2004, the year of
288 EU accession [28]. In 2015, the area planted was reported as 180,000 hectares [27], a 60.2% decline
289 since 1996. The domestic sugar production has been fluctuating around two million tons annually
290 and has changed little over time. Improved processing technology and varieties substantially
291 increased yield and quality of the raw commodity [28]. Per capita sugar consumption decreased by

292 8.4% between 1990 and 2015 [26; 27]. It appears that household consumption of refined raw sugar
293 is decreasing, and the food industry is the primary sugar user in Poland.

294 The ecological consequences of limiting sugar beet production are significant because sugar
295 beets produce a larger volume of oxygen than other agricultural crops [28]. There is the possibility
296 of producing sugar beets for bioethanol and farmers in some other EU-member countries have
297 contemplated that option [30]. However, bioethanol is produced mostly from corn in Poland and
298 unless there is a noticeable increase in demand from bioethanol manufacturers due to investment in
299 processing capacity farmers are unlikely to return to sugar beet production. Even the termination of
300 the sugar quota system in September 2017 [31] may not lead to shifts in the cropping pattern in the
301 immediate future.

302 *3.1.Regional rapeseed production and the biodiesel support program in Poland*

303 Rapeseed production has fluctuated in the past two decades (Figure 1). Following the
304 transition to a market-driven economy in the late 1980s and early 1990s, rapeseed production
305 remained high supplying the country with domestic food-grade plant oil. The area planted with
306 rapeseed was decreasing until the accession to the EU in 2004. It appears farmers increased
307 rapeseed areas in their planting decisions in the fall of 2003 in anticipation of the EU accession.
308 It was not until 2004, that the Ministry of Agriculture and Food Economy permitted the production
309 of 172,000 tons of methyl acetate from rapeseed. It was expected that in 2010 the total volume of
310 diesel fuel used in Poland would contain 5% biodiesel [32]. To meet that goal required 400,000 tons
311 of methyl acetate or an increase of rapeseed production by 1-1.2 million tons because Poland
312 produces a negligible volume of other oil seed crops. The rapeseed production increase required an
313 additional 400,000-500,000 hectares, while the area of arable land in Poland is estimated at 12
314 million hectares. The first biodiesel plant in Poland operated in Mochelko and processed up to 0.5
315 ton of rapeseed per hour. The largest biodiesel producer is Trzebinia Refinery in Małopolskie
316 Voivodship. Biodiesel production capacity amounted to 1.269 million tons in Poland in 2013 [33].

317 The area planted showed rapid growth in 2008 (Figure 1), likely in response to the oil seed
318 support program. Between 2007 and 2009, ARiMR (Agency of Restructuring and Modernization of
319 Agriculture) and ARR (Agricultural Market Agency) implemented a financial support program for
320 energy plant production [34]. The effects of that program are illustrated in Figures 1 and 2,
321 recognizing that rapeseed is a winter crop planted in the fall and harvested in the summer the
322 following calendar year. The rapeseed area peaked in 2010 and declined once the program expired.
323 However, the tendency to increase the area planted resumed in 2012 and nearly reached the record
324 level previously reported in 2010. Poland is the fourth largest rapeseed producer in the EU
325 following France, Germany, and Great Britain.

326 The planted rapeseed varieties are only those allowed by Polish and EU regulations. They
327 are characterized by two enhanced characteristics. Varieties have to have low erucic acid content
328 (less than 1%) and low content of glucosinolates. Moreover, for biodiesel production, rapeseed oil
329 must meet additional standards regarding the content of methyl acetate [35; 36]. Polish farmers can
330 choose from 87 rapeseed varieties. It has been suggested that farmers focus on the total amount of
331 fat produced per hectare. However, rapeseed buyers have not been paying for fat content except for
332 buyers located near the border with Germany. The latter purchase rapeseed from Polish farmers,
333 paying for fat content, and try to re-sell it in Germany.

334 *3.2.Regional variation in rapeseed planted area*

335 Figure 2 shows the changes in area planted with rapeseed in all voivodships. Those located
336 in western, southwestern, northwestern, and northern Poland have been traditionally major rapeseed
337 producers favored by weather patterns influenced by the Atlantic Ocean (Map 1). The oil seed
338 production support program boosted the planted area, but its termination did not decrease the area in
339 all voivodships. The initial decrease was mostly in voivodships with a large area planted in
340 rapeseed, but in voivodships with small production, the area planted after 2010 increased in many
341 instances. Because the area planted in voivodships showing an expansion of production was initially
342 small, and those farmers had little experience in growing rapeseed, it is plausible that those who

343 planted rapeseed were seeking novel but profitable crops and might have been encouraged by the
344 support program. It is plausible that well-managed and productive farms tried rapeseed production
345 in voivodships that saw little production in the past. For example, Łódzkie, Małopolskie, and
346 Podkarpackie Voivodships have not been known as producers of rapeseed (Map 1), but appear to
347 have expanded the area planted since 2004. Even farmers in Podlaskie Voivodship, characterized by
348 rather harsh climatic conditions, successfully learned how to grow rapeseed [37].

349 **4. Results**

350 The cost efficiency scores were estimated next, for all farms and rapeseed growing farms in
351 the FADN sample. The visual evaluation of efficiency scores using histograms (available upon
352 request) showed distinctly different pattern for all farms vs. oil seed producing farms. Figure 3
353 shows the observed differences after grouping the farms with scores falling in the same category. A
354 larger share of the oil seed producing farms than all farms falls into categories with higher cost
355 efficiency scores, although the numbers are not overwhelming. However, the results are consistent
356 with the expectations that rapeseed producing farms tend to be more cost efficient than farms in
357 general, likely implying skillful farm management.

358 *4.1. Effects of location on all farm cost efficiency scores*

359 Table 2 shows the results of regressing the efficiency scores on the economic size of the
360 farm as defined in the FADN sample and dummies representing each voivodship. The link between
361 the economic size and the efficiency score is justified by expectations that a highly productive farm
362 must also be fairly cost-efficient. As expected, the economic size is statistically significant (Table
363 2).

364 Binary variables represent each voivodship. Wielkopolskie Voivodship represents the
365 benchmark region allowing for comparison of potential differences across voivodships to the region
366 commonly perceived as the most agriculturally productive. Coefficients of binary variables indicate
367 that farms in all but three voivodships have lower efficiency scores. The three voivodships, which
368 results suggest that the farm efficiency scores do not differ from those in Wielkopolskie, are

369 Śląskie, Zachodniopomorskie, and Lubuskie Voivodships (Map 1). Śląskie does not play a
370 significant role in the country's agricultural production and its economy is based mostly on mining
371 and industry. The binary variable coefficients of the remaining two voivodships,
372 Zachodniopomorskie and Lubuskie, have negative signs and are marginally insignificant
373 statistically. This is important because the regions are focused mainly on field crops rather than
374 livestock production and farms are of a relatively large size. Overall, Wielkopolskie Voivodship
375 and Warmińsko-Mazurskie farms tend to be more cost efficient than the majority of farms in other
376 areas.

377 *4.2. Effects of location on oil seed producing farm cost efficiency scores*

378 The program favoring oil seed production for biodiesel production must account for
379 differences not only in growing conditions (which can be offset by the development of improved
380 varieties over time), but the implied differences in management skills of farmers. Otherwise, the
381 realized yields may be low and despite the expansion of area planted, gains in crop volume are
382 likely going to disappoint.

383 Results in Table 3 show that as compared to oil seed producing farms in Wielkopolskie, this
384 type of farm in three voivodships, i.e., Zachodniopomorskie, Pomorskie, and Warmińsko-
385 Mazurskie had a higher cost efficiency score. All three voivodships are large rapeseed producers
386 and located in Northern Poland, where the climatic conditions are suitable for rapeseed production.
387 Farms producing oil seeds in three other voivodships, namely Lubuskie, Opolskie, and Kujawsko-
388 Pomorskie, do not differ in their scores from oil seed producers in Wielkopolskie (Map 1). Finally,
389 oil seed producing farms in Śląskie Voivodship also are no different from Wielkopolskie, but the
390 former plays a marginal role in oil seed production (Figure 2).

391 Results show that in the category of oil seed producing farms, Wielkopolskie faces tough
392 competition from several other regions, although out of eight voivodships producing the bulk of the
393 annual rapeseed crop, only three have been confirmed by statistical tests. It appears that farmers in

394 those regions have been growing rapeseed for generations and have gained knowledge about the
395 nuances of growing rapeseed and use it effectively.

396 **5. Discussion**

397 The observed increase in the area planted with rapeseed during that period (reflected in crop
398 rather than calendar years because of the winter rapeseed growing requirements) occurred in
399 traditional and non-traditional production areas. For farmers to continue growing rapeseed a key
400 issue is the ability to recover production costs and outperform the returns to alternative crops,
401 especially because of the crop growing requirements. Farms reporting growing oil seed crops
402 (almost exclusively rapeseed in Poland) have been more cost-efficient than farms in general. The
403 challenges associated with growing rapeseed might have initially led to a decrease in the area
404 planted after the EU-funded support program was terminated, but in more recent years (after 2012)
405 the expansion of the rapeseed area continued, including some non-traditional growing regions as
406 farmers gained experience in growing the finicky crop.

407 In terms of regional participation in rapeseed production, the rapeseed support program
408 resulted in increased production area in the traditional production regions, but also encouraged
409 production in all other regions. The expansion of rapeseed use destined for biodiesel production
410 requires substantial expansion of area planted. Attracting new rapeseed growers must involve less
411 cost-efficient farms. That hypothesis was proven correct after the calculated cost efficiency scores
412 were calculated for all farms and oil seed producing farms through the application of the stochastic
413 cost function framework. Moreover, oil seed producing farms had higher efficiency scores than all
414 farms in the sample (Figure 3).

415 Further, the gap in farm productivity was confirmed by regression results showing the
416 effects of a region on cost efficiency scores for all farms and oil seed producing farms, where
417 individual regional scores were compared to farm cost efficiency scores from Wielkopolska, widely
418 viewed as having the most productive farms. Indeed, farms in all regions (except one) had lower
419 scores than Wielkopolski Voivodship, but in the case of oil seed producing farms some heavy

420 rapeseed-producing regions performed better than Wielkopolska. However, none of the regions
421 attempting to increase rapeseed production was found to have more cost efficient scores. The result
422 suggests that expanding rapeseed production may become costlier and require a continued subsidy
423 offsetting higher farms costs or helping biodiesel plants pay for their feedstock. In the long term, the
424 development of improved rapeseed varieties may reduce the risks faced by farmers. Other
425 technological inventions can also increase rapeseed competitiveness as a feedstock for renewable
426 energy production.

427 Statements of farmers from non-traditional rapeseed growing areas suggest that they have
428 learned to manage cultural practices required by the crop. The timing of planting, for example,
429 seems to be of major importance but it is highly variable because it depends on weather patterns
430 specific to an area. Since some farmers find the crop profitable, the best policy to expand rapeseed
431 production for biodiesel manufacturing may be to educate farmers in general. Regional agricultural
432 extension centers are scattered throughout the country and experts with experience in growing
433 rapeseed may participate in workshops and field days in other areas. Regional centers have been
434 known for organizing field days and demonstration plots, which are essential in teaching novel crop
435 growing techniques. Improved knowledge helps farmers to improve their individual cost efficiency.
436 Examples of regional cooperative centers engaged in assisting farmers in growing rapeseed already
437 exist [37]. Additionally, regional extension centers cooperate with agricultural input suppliers in
438 some of their events. Such cooperation may be needed in the case of rapeseed grown for biodiesel
439 because of the involved costs of producing the crop. Biodiesel manufacturers have an incentive to
440 absorb the costs in the process of creating a regional supply base. Scattering the production across
441 various regions reduces the risk associated with unfavorable weather events and assures that an
442 adequate volume is produced year after year. Because of the highly concentrated processing
443 capacity, it is also easier for the government to focus any biodiesel subsidy program on
444 manufacturers and require them to pay for farmer education. Subsidies for biofuels would likely

445 originate from a different government agency than additional funding for the regional agricultural
446 centers.

447 Cake is a by-product of rapeseed processing that has been used in animal feed. Because the
448 varieties grown in Poland have an improved nutritional profile, the cake can be fed to all farm
449 animals. An increase in rapeseed production implies larger domestic supplies of cake adding to
450 stability of animal feed prices. Stabilizing feeding costs improves animal farmers' returns, while
451 also enhancing the competitiveness of meat processors. Consequently, rapeseed farmers, biodiesel
452 producers, animal farms, and meat processors have a mutual interest in increasing demand for the
453 crop. The dramatic elimination of two crops, potatoes and sugar beets, traditionally essential for
454 farm revenues, led to the expansion of grain production beyond what is desirable from the
455 standpoint of maintaining soil productivity and weed control. If the rapeseed area expands, the
456 planted grain area will likely decrease without hampering the supply of feed grains in the country.
457 Currently, the grain area is too large from the standpoint of an optimal cropping pattern and may be
458 lowering soil productivity. Moreover, although some of the land has permitted an increase in
459 production of corn used in making bioethanol, this biofuel is produced on a limited scale in Poland,
460 whereas biodiesel manufacturing steadily increases.

461 A program that would allocate additional area away from grains to rapeseed production
462 could benefit soil fertility, improve environmental quality, contribute to sustainability, suppress
463 weeds, provide additional feedstock for biodiesel manufacturing, and increase the domestic supply
464 of cake for animal feed in Poland and the EU. A mechanism to induce such reallocation of land,
465 however, is not obvious and unlikely to occur as a broad agricultural subsidy program because of
466 the desire to eliminate farm support policies. Polish consumers continue to enjoy an abundant
467 supply of edible vegetable oil despite the growth in biodiesel production, while from a global
468 perspective additional supplies of oil from Poland can be highly desirable. In the case of Poland,
469 creating regional rapeseed processing capacity could establish a local biodiesel supply net making
470 biodiesel accessible. Perhaps, if combined with a system of discounts for rapeseed growers, farmers

471 themselves would be the primary users of biodiesel. An alternative is to find additional users of
472 cake and by stimulating the demand for the by-product encourage farmers to grow more rapeseed.
473 [37] suggested additional incentives, not directly linked to rapeseed growing for example, but to a
474 water management scheme or low cost local feedstock. In contrast to the past, food security has not
475 been an issue in Poland since the transition to an open economy.

476 **6. Conclusions**

477 Rapeseed has been traditionally grown in Poland to supply edible oil, but has also become a
478 feedstock for biodiesel production in recent years. Biodiesel production has been stimulated by the
479 EC mandate to increase renewable energy utilization. A program supporting rapeseed production
480 was implemented in Poland between 2007 and 2009 before its termination by the EC, which also
481 funded the program in full. Prior to the program, eight voivodships were the primary rapeseed
482 producers, exploiting the suitable climatic conditions, but also the knowledge and management
483 skills of their farmers.

484 A series of changes in trade policy and sugar policy led to a decrease in potato and sugar
485 beet production. The search for alternative crops to replace potatoes and sugar beets led to an
486 increase in grain area and contributed to a gradual expansion of rapeseed area planted with new
487 “double 00” varieties and better adapted to growing conditions.

488 To expand rapeseed plantings requires the continued development of new varieties better
489 adapted to the regional growing conditions. New improved varieties will alter cost efficiency of
490 farms and their relative regional competitive position. The traditional family farm producing a mix
491 of plant and animal outputs is being replaced by increasing specialization, especially in field crops.
492 This shift in farming is dictated by the recently occurring employment opportunities outside
493 agriculture and demographic changes (many retiring farmers) potentially favor rapeseed area
494 expansion. New regulations regarding land ownership and purchase introduced in 2016 may slow
495 changes in farm size, but will not likely reverse the trend of mixed farms moving to focused field
496 crop farms because of irreversible demographic changes.

497

Conflict of Interest

498 The authors declare no conflict of interest

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500 References

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Table 1. Total number of farms and share of oil seed producing farms in the FADN sample of each voivodship for the period 2004-2011.

Voivodship	2004		2005		2006		2007		2008		2009		2010		2011	
	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms	All farms	Oilseed farms
Lódzkie	1036	8.5%	1001	8.1%	1005	8.4%	969	11.7%	924	12.1%	946	12.8%	841	13.8%	828	14.3%
Mazowieckie	1851	7.0%	1808	7.4%	1822	9.0%	1781	11.4%	1637	11.5%	1654	11.9%	1509	12.6%	1505	12.3%
Małopolskie	479	2.7%	469	2.8%	486	4.1%	473	3.8%	494	5.7%	466	6.2%	427	7.5%	385	6.8%
Śląskie	302	22.2%	304	22.0%	294	22.8%	283	29.0%	312	33.3%	294	32.3%	274	36.5%	273	31.1%
Lubelskie	1116	15.9%	1094	16.9%	1093	19.9%	1082	23.2%	1042	23.5%	982	24.6%	867	26.1%	849	26.4%
Podkarpackie	292	12.7%	307	14.0%	316	16.8%	284	21.1%	284	23.2%	267	21.7%	249	23.7%	233	21.5%
Świętokrzyski	317	12.6%	312	11.5%	331	14.8%	329	15.2%	339	17.4%	343	19.5%	316	16.5%	300	17.7%
Podlaskie	938	1.9%	930	1.7%	929	2.5%	933	4.2%	928	3.9%	928	4.0%	832	5.3%	834	5.8%
Wielkopolskie	1835	13.4%	1822	12.1%	1831	14.1%	1887	16.9%	1966	18.1%	1982	19.9%	1777	21.4%	1764	21.9%
Zachodniopomorskie	330	45.2%	348	40.5%	386	44.8%	419	48.9%	457	47.3%	484	48.8%	430	49.3%	436	39.0%
Lubuskie	182	27.5%	163	22.1%	175	25.1%	216	26.9%	237	31.6%	254	33.9%	225	36.9%	231	37.2%
Dolnośląskie	513	41.5%	535	42.2%	533	48.0%	579	57.2%	634	58.2%	621	55.2%	557	60.0%	551	58.6%
Opolskie	413	41.2%	417	41.5%	418	48.1%	449	53.0%	506	57.7%	514	59.1%	465	61.5%	467	63.2%
Kujawsko-Pomorskie	1097	32.6%	1138	33.1%	1133	34.9%	1195	38.7%	1308	42.7%	1370	48.7%	1227	48.9%	1236	47.7%
Warmińsko-Mazurskie	471	21.7%	473	18.8%	475	21.7%	493	23.5%	527	24.7%	596	24.7%	548	24.5%	549	23.0%
Pomorskie	557	26.4%	569	27.1%	574	30.5%	609	32.5%	608	33.1%	657	37.0%	585	36.8%	586	35.2%

Table 2. Regression results of cost efficiency scores for all farms in the sample (n=13,462).

Variable name	Coefficient	Std. error	t-statistic	Prob.
Intercept	0.0222	0.0013	17.42	0.00
Economic size	0.0000	0.0000	14.23	0.00
Łódzkie	-0.0021	0.0008	-2.74	0.01
Mazowieckie	-0.0046	0.0007	-6.94	0.00
Małopolskie	-0.0060	0.0010	-5.79	0.00
Śląskie	0.0010	0.0012	0.80	0.42
Lubelskie	-0.0058	0.0008	-7.31	0.00
Podkarpackie	-0.0050	0.0011	-4.49	0.00
Świętokrzyskie	-0.0032	0.0014	-2.21	0.03
Podlaskie	-0.0041	0.0006	-6.51	0.00
Zachodniopomorskie	-0.0028	0.0019	-1.47	0.14
Lubuskie	-0.0026	0.0016	-1.58	0.12
Dolnośląskie	-0.0042	0.0015	-2.81	0.00
Opolskie	-0.0042	0.0015	-2.77	0.01
Kujawsko-Pomorskie	-0.0019	0.0006	-2.98	0.00
Warmińsko-Mazurskie	-0.0042	0.0008	-5.04	0.00
Pomorskie	-0.0022	0.0009	-2.52	0.01
R-squared	0.5945			
Adjusted R-squared	0.5940			

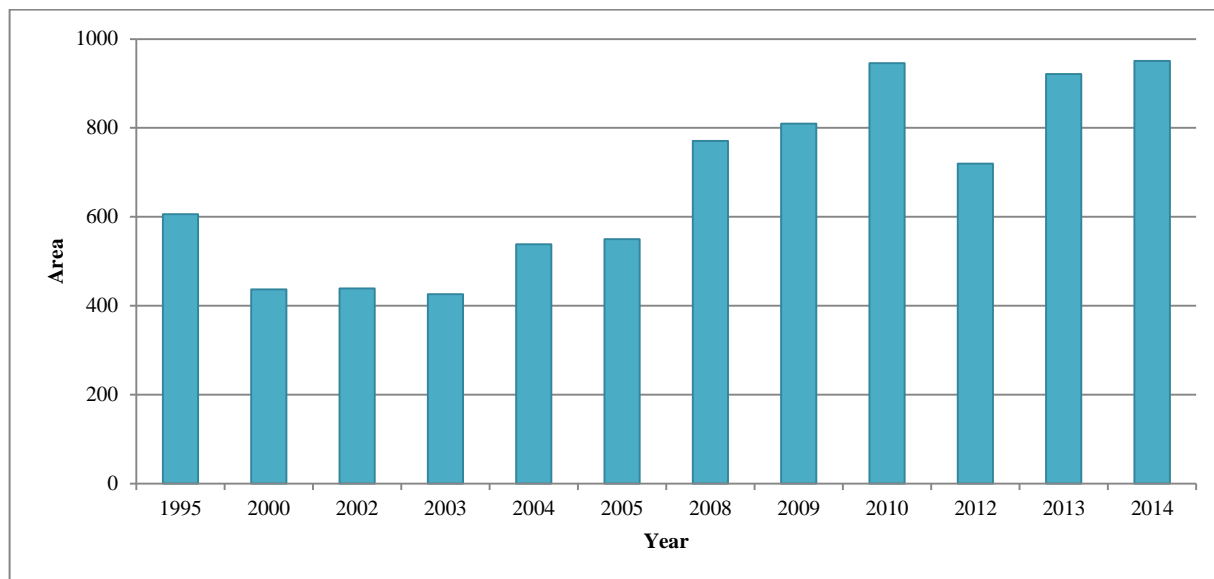
Note: The benchmark for the regional dummy is Wielkopolskie Voivodship. Estimation applied the White heteroskedasticity-consistent regression.

631 Table 3. Regression results of cost efficiency scores for oil seed producing farms in the sample
 632 (N=5,993).
 633

Variable name	Coefficient	Std. error	t-statistic	Prob.
Intercept	0.0426	0.0022	19.78	0.00
Economic size	0.0000	0.0000	8.18	0.00
Łódzkie	-0.0078	0.0029	-2.68	0.01
Mazowieckie	-0.0096	0.0023	-4.13	0.00
Małopolskie	-0.0071	0.0056	-1.27	0.20
Śląskie	0.0042	0.0029	1.45	0.15
Lubelskie	-0.0164	0.0023	-7.12	0.00
Podkarpackie	-0.0092	0.0038	-2.43	0.02
Świętokrzyskie	-0.0109	0.0033	-3.32	0.00
Podlaskie	-0.0011	0.0047	-0.24	0.81
Zachodniopomorskie	0.0209	0.0043	4.90	0.00
Lubuskie	0.0045	0.0043	1.04	0.30
Dolnośląskie	-0.0039	0.0024	-1.62	0.11
Opolskie	0.0049	0.0031	1.60	0.11
Kujawsko-Pomorskie	0.0004	0.0025	0.18	0.86
Warmińsko-Mazurskie	0.0215	0.0045	4.79	0.00
Pomorskie	0.0187	0.0036	5.23	0.00
R-squared	0.4138			
Adjusted R-squared	0.4122			

Note: The benchmark for the regional dummy is Wielkopolskie Voivodship. Estimation applied the White heteroskedasticity-consistent regression.

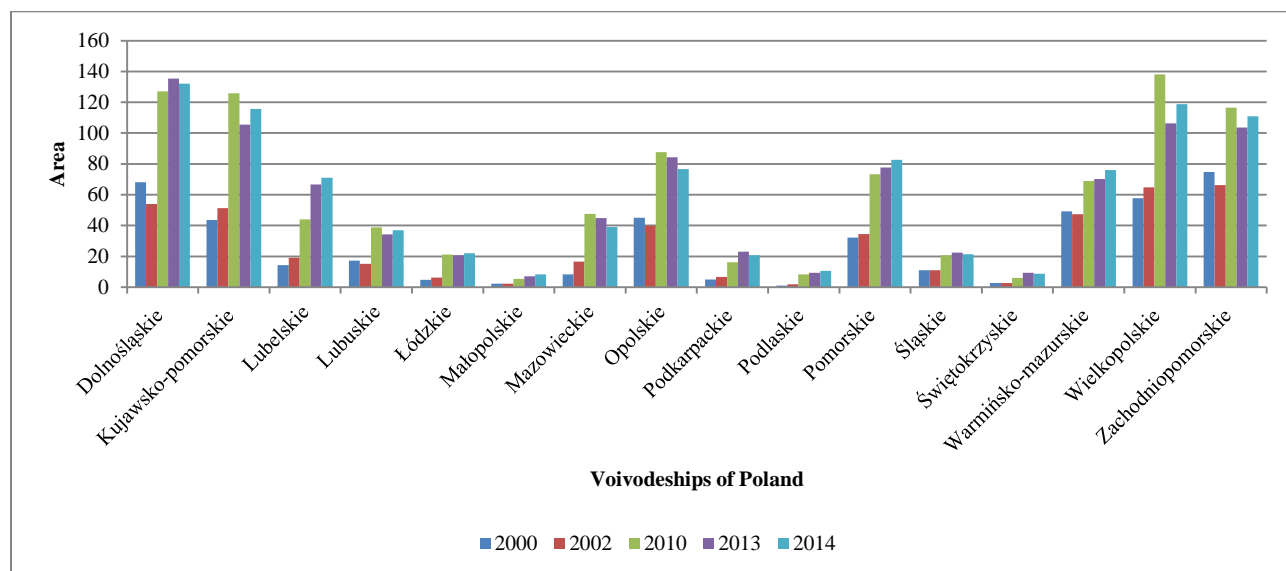
635 Figure 1. Area planted with rapeseed in Poland, selected years, in thousand hectares.



636

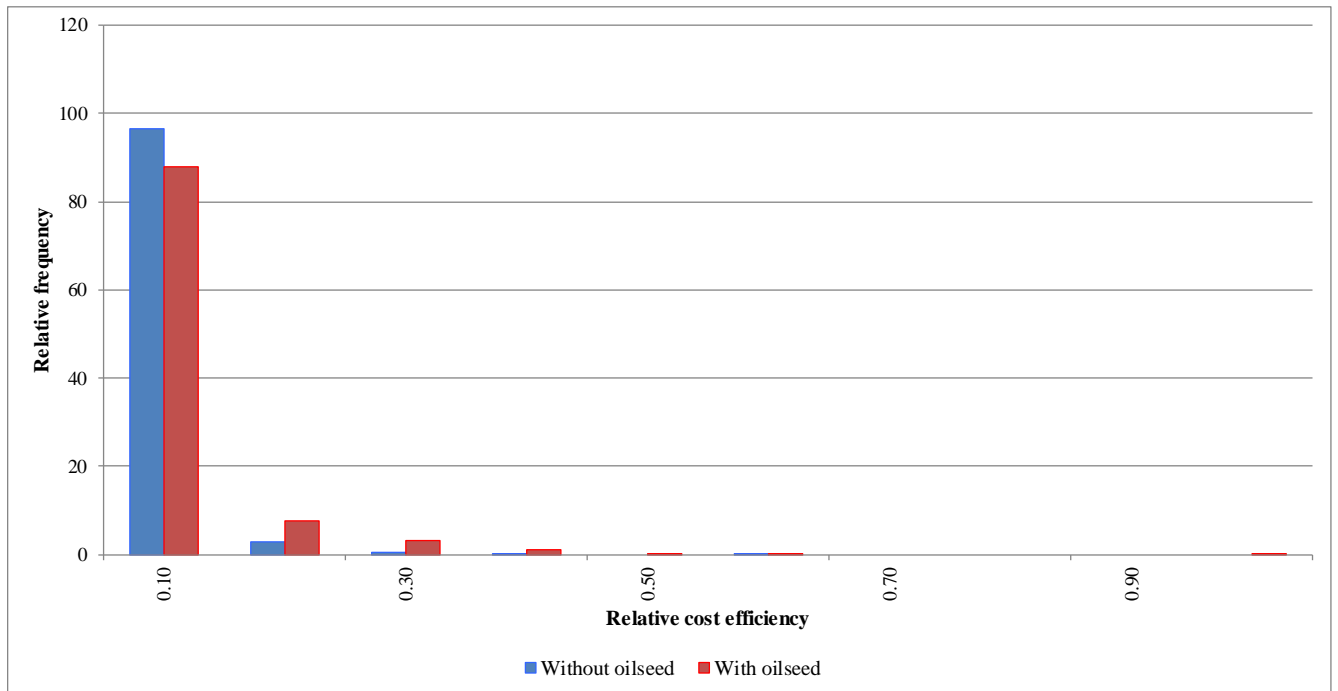
637 Source: Based on GUS [16; 38].

Figure 2. Spatial variability in area planted with rape seed/canola by voivodship in Poland, selected years, in thousand hectares.



Source: Based on GUS [26; 38].

Figure 3. Percent of all farms and oil seed producing farms by calculated cost efficiency score category.



Map 1. Location of 16 voivodships within Poland.



Source: Prepared by authors.

Appendix

Table A1. Estimated elasticities of substitution for Polish farms in FADN sample for the period 2004-2011.

Input	Elasticities				
	Materials	Energy	Labor	Land	Capital
Materials	-1.069 (-34.29)	-0.275 (-4.72)	0.536 (30.13)	0.667 (18.54)	0.870 (29.76)
Energy		-1.368 (-3.37)	0.404 (15.54)	-0.247 (-4.09)	0.376 (4.88)
Labor			-1.354 (-62.34)	0.459 (14.41)	0.454 (31.11)
Land				-12.207 (-123.92)	0.354 (10.21)
Capital					-1.744 (-49.38)

Note: t-statistics in parentheses.

Source: Own calculations.