www.jard.edu.pl http://dx.doi.org/10.17306/J.JARD.2017.00289

Journal of Agribusiness and Rural Development

pISSN 1899-5241
eISSN 1899-5772

2(44) 2017, 263–275

DETERMINANTS FOR LIQUID BIOFUELS PRODUCTION IN POLAND AFTER 2006 – MODEL APPROACH

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Abstract. Liquid biofuels from agricultural raw materials (mainly cereals and oilseeds) are produced in Poland on an industrial scale since 2005. Poland, implementing guidelines for the energy policy of the European Union, is committed to ensuring that the share of liquid biofuels in the total fuel consumption in transport is at least 10% by 2020. On the one hand, the development of the liquid biofuels market is dependent on institutional factors (legal and administrative regulations), and on the other hand, primarily on the condition of agricultural raw materials markets (supply-demand relationships and prices) and macroeconomics factors, mainly crude oil prices. This paper is aimed at the empirical identification of determinants for the production of liquid biofuels (bioethanol and biodiesel) in Poland. For this purpose, two econometric models based on multiple regression were built based on multiple regression, indicating exactly which factors contribute to the increase or decrease in the production of liquid biofuels. For bioethanol, production importance are mainly sales of bioethanol. The variables concerning the cereals market (prices, purchase and export) and macroeconomic factors – interest rate, GDP growth rate (change) and USD/PLN exchange rate. Important determinants for the biodiesel production include total sale of biodiesel, production of rapeseed oil, import of rapeseed and vegetable oils (rapeseed oil and palm oil) and their prices, as well as crude oil prices, which represent the macroeconomic environment.

Keywords: liquid biofuels production in Poland, bioethanol, biodiesel, agricultural markets

INTRODUCTION

As an EU member country, Poland is committed to implement the general objectives set out in various policies, including the energy policy and the guidelines of the climate and energy package (the 3x20 package). Accordingly, by 2020, the share of liquid biofuels in the total transport fuel consumption must be 10% or more (Dyrektywa…, 2009), with biofuels made from agricultural products and biofuels based on non-agricultural raw materials representing a share of 7% and 3%, respectively (Portal Gospodarczy, 2014). Pursuant to the Act of July 22, 2016, liquid biofuels are liquid fuels, i.e. liquid energy products. Liquid biofuels include motor gasoline (with a content of more than 10% of biofuel components by volume or more than 22% of ethers by volume), diesel fuel (with a content of more than 7% of biofuel components by volume) as well as biofuel components such as bioethanol or ester. Bioethanol is an ethyl alcohol made of biomass while ester (biodiesel) is defined as methyl ester or ethyl ester of fatty acids made of biomass. In turn, biomass means the biodegradable fraction of products, waste and residues from biological origin from agriculture, forestry and fisheries (Obwieszczenie…, 2015; Ustawa…, 2014; Ustawa, 2016). Although liquid biofuels (vegetable oil biodiesel, mostly including rapeseed oil and bioethanol from cereals) have been manufactured in Poland on an industrial scale

*This article was financed by the National Sience Centre granted on the basis of the decision number UMO-2013/11/N/HS4/03194. The title of the research project is „Economic factors of the development of liquid biofuels sector in Poland and Germany after 2004. The attempt of comparison".

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since 2005, the dynamic production growth became noticeable several years later. Currently (2016), the share of biofuel use on a countrywide basis is at the level of 6% (Eurostat). It follows from the above that the development of the biofuel sector depends both on institutional factors (legal and administrative regulations) and, primarily, on the condition of markets for agricultural raw materials used as energy products (supply-demand relationships and market prices) and on external (macroeconomic) factors, mainly including oil prices.

PURPOSE AND METHODOLOGY OF STUDIES

The purpose of this paper was to empirically identify the determinants of liquid biofuels (bioethanol and biodiesel) production in Poland after 2006, and to identify and structure the key factors. For that purpose, two econometric models were developed based on multiple regression, because the assumption was made that ethanol production determinants need to be separated from the variables affecting the production of biodiesel. Therefore, a model was developed for bioethanol production determinants and another one for biodiesel production determinants[1]. In these models, the dependent variable was biofuel production while exogenous factors included other variables from the biofuel sector and agricultural markets, as well as macroeconomic variables. The models were based on quarterly data from the 2006–2014 period. To specify the seasonal effects on the dependent variables, dummy variables corresponding to subsequent quarters were added. To capture the trend, the list of explanatory variables was extended with a linear trend variable[2]. Also, lagged variables were used in the empirical analysis, based on the assumption that the effect some of them have on biofuel production could be delayed by a quarter[3]. Prior to the study, the time series were checked for stationarity with the augmented Dickey-Fuller test in two variants[4] for each variable. The multiple regression analysis was supplemented with CLS (classical least squares) models with robust standard errors. As a consequence, the estimations are not influenced by outliers. The regression analysis was based on backward stepwise regression[5]. After the models were established, the Durbin-Watson autocorrelation test, the White's test for heteroskedasticity of random effects, and the test for normal distribution of residuals were performed.

The econometric model for bioethanol production was developed with the use of the relevant sales data and data from the cereals market. In turn, as regards biodiesel production, the variables included ester sales data and data from the oilseeds market. Also, macroeconomic variables were used in both models. Products from the cereal markets used in the analysis included wheat, rye and maize, i.e. the species which, while having key importance to the Polish agriculture, are excellent raw materials for the ethanol industry (Szajner, 2015; Zegar, 2012). In Poland, and elsewhere in the EU, wheat is the main raw material in the bioethanol production process (Ajanovic, 2011). Other authors emphasize the growing role of maize and the declining importance of rye in the raw materials mix. However, wheat continues to be the primary commodity (Flach et al., 2013). Variables from the cereals market were the purchase volumes and prices, and exports and imports of selected species. Additional variables were the relations between industry consumption and the purchase, export or import volumes of selected cereal species[6]. The Polish oilseeds market was, and continues to be, dominated by rapeseed (and colza). Therefore, this study relied mainly on variables related to rapeseed and rapeseed oil (production, domestic consumption, exports, prices), in addition to variables related to other vegetable oils of importance

[1] The primary purpose of these models is to identify the direction (sign) of relationships between specific determinants and the domestic production of liquid biofuel. Thus, this is not about providing a detailed interpretation of regression coefficients (b*) which indicate the relatively most important factors for the liquid biofuel production models.

[2] A linear function was selected because it was best fitted to the variation of biofuel production in Poland.

[3] For instance, oil prices or rapeseed oil production in 1Q 2006 have an effect on the production of biodiesel in 2Q 2006. There variables are designated as *t*-1.

[4] These include the test without intercept and the test with intercept.

[5] The backward stepwise regression means successively removing the independent (explanatory) variables with the least significant effect on the explained variable (Poczta-Wajda, 2010).

[6] In a sense, these variables are artificial parameters, all the more so since the quarterly industry consumption is assumed to be ¼ of the annual consumption. The purpose of these coefficients is to identify a relationship illustrating the portion of the purchase, export or import volume represented by industry consumption of wheat, rye or maize.

to the Polish biodiesel industry, i.e. palm oil and soybean oil (Rosiak et al., 2011). For the Polish ester industry, the key raw material is rapeseed oil. However, note that palm oil has gained in importance over recent years, and becomes increasingly important for the global biodiesel sector. The empirical analysis of biofuel production determinants also includes the key macroeconomic data which represents the external environment. This allowed to position the liquid biofuel sector in its external environment (macroeconomic environment) and determine whether that group of variables affects the changes of liquid biofuel production in Poland. These include: the changes of the national income (Gross Domestic Product), the reference interest rate, the inflation rate, currency exchange rates (the following pairs: EUR/PLN and USD/PLN) of the National Bank of Poland, and the oil price. As mentioned earlier in this paper, the development of the liquid biofuel sector is strongly affected by the biofuel policy (legal and administrative regulations) which, however, is not directly included in the estimated models. Instead, it is indirectly reflected by the "biofuel sales" (bioethanol or biodiesel sales) variable as the sales of biofuel components are significantly affected by the aforesaid policy (this is manifested, for instance, by the applicability of National Target Indicators which specify the minimum required percentage rate of biofuel in the total transport fuel consumption). This paper is based on data from the Federal Reserve Bank of St. Louis, the Central Statistical Office, the Institute of Agricultural and Food Economics – the National Research Institute, the Ministry of the Economy, the Ministry of Agriculture and Rural Development, the Energy Regulatory Office and the "Cereals market: current state and future prospects" market analyses.

ANTICIPATED RESULTS

The empirical studies allowed to identify the key economic determinants of liquid biofuel production in Poland. However, prior to the regression analysis, an attempt was made to anticipate the results. The foreseen relationships between, and target levels of, specific factors are as follows:

- biofuel (bioethanol/biodiesel) sales: a positive relationship with biofuel production is expected, assuming that the increased demand (expressed as increased sales levels) leads to increased supply (represented by biofuel production) because increased production volumes are the producers' response to the increase in demand;
- oil prices: the changes in oil prices should have a positive effect on the production of liquid fuels; if oil becomes expensive, there should be an increase in biofuel production volumes (as an alternative source of energy for the transport sector)[7]; if oil prices are low, the production of biofuels is believed to be unprofitable;
- changes in GDP: assuming, as a major simplification, that the economic growth is expressed by the increase in GDP, a positive relationship with biofuel production may be expected; this is because as the country advances in civilization and makes socio-economic progress (as reflected by the growth in GDP), there is an increasing interest in developing the industry of renewable energies, including the liquid biofuel sector, which leads to an increased level of investments; meanwhile, the economic progress involves additional expenditure (including large energy inputs) and searching for alternative energy sources, which explains the interest in renewable energy sources; thus, it may be concluded that the increase in national income will contribute to the development of the liquid biofuel sector and to the increase in liquid biofuel production volumes;
- interest rate: a negative relationship with biofuel production is expected because the declining interest rates are a driver of economic growth and an investment incentive for the entrepreneurs; it seems reasonable to apply that pattern to the biofuel sector;
- inflation rate: a positive relationship may be expected between the inflation rate and the biofuel production volumes; for the economy, creeping inflation is a desirable level which provides conditions for growth, including the development of the biofuel industry; also, when analyzing the relations between inflation and the biofuel sector, note that biofuel production might have an impact on the prices of food and agricultural raw materials which will be reflected in the inflation rate;

[7] Note however that a consistent increase in oil prices must not necessarily be a indication of a long-term development of the biofuel sector. This is because high crude oil prices with a lag will lead to higher prices of agricultural raw materials which, in turn, will result in lower profitability and smaller scale of production activities.

- currency exchange rates (EUR/PLN, USD/PLN): negative relationships should be expected because the increase in exchange rates means the appreciation of the euro or dollar with respect to the zloty, or the depreciation of the Polish currency with respect to foreign currencies; in this case, two scenarios of causal relationships are possible: (1) increase of prices of foreign raw materials → decrease in imports of agricultural raw materials → decrease in domestic supply of raw materials (which includes imported volumes) → reduction of the resource base, including for the liquid biofuel sector; with the reduced resource base, the production of biofuels will tend to decline; (2) increase in prices of foreign raw materials → increase in production costs of liquid biofuels → reduced production profitability → reduced levels of biofuel production;
- purchase of agricultural raw materials (wheat, rye, maize): the relationship with biofuel production is anticipated to be positive; purchasing means demand for cereals which may include demand related to energy production (in the ethanol sector); thus, increased purchasing of cereals may result from increased interest in alternative uses thereof (outside the food and feed sector, e.g. in the bioethanol industry);
- variables represented by ratios: (1) industry consumption / increased purchasing of cereals; (2) industry consumption / maize exports; (3) industry consumption / maize imports, are (to some extent) artificial variables, especially because the industry consumption is assumed to be ¼ of the annual consumption level; the essence is to present the share of cereals purchased or the share of maize exports and imports which was used for industrial purposes; in a sense, the industry consumption may be treated as use for energy production purposes; the relationships between the above parameters and the biofuel production may be positive; this would mean that a relatively larger part of purchased, exported or imported cereal volumes is used for energy production purposes;
- domestic consumption of rapeseed oil: just as in the case of purchases of agricultural products, positive relationships may be expected because the total increase in raw materials consumption may largely result from the increased demand generated by the biodiesel industry;
- rapeseed oil production: positive relationships with ester production volumes should be expected because of a simple assumption that the growing production of rapeseed oil (the basic raw material in the biodiesel sector) strengthens the resource base of the domestic industry and stimulates the development of that sector;
- prices (purchasing, sales, import prices) of agricultural raw materials (cereals, vegetable oils): the relationship with biofuel production is expected to be negative; the increasing prices of agricultural products whose purchase is the basic cost of biofuel production (70–80% of total costs) should adversely affect the production level; in turn, low (and decreasing) prices of agricultural raw materials should be a growth driver for the industry which would be reflected by an increase in liquid biofuel production volumes;
- import and export of agricultural raw materials (cereals, oilseeds, vegetable oils): the relationships between external trade and liquid biofuel production may be interpreted in two ways; in the first reasoning, the imports and exports should demonstrate a positive and a negative relationship, respectively; this is because agricultural imports expand the domestic base of resources used for liquid biofuel production, which may have a positive stimulating effect for the biofuel sector; the export of cereals, seed or oils has an opposite effect as it reduces the resource base and restricts the production capacity of biofuel components; in the second interpretation, the external trade is looked at from the following perspective: if biofuel is produced domestically from agricultural raw materials, this could suggest that the country concerned (Poland, for instance) is a large agricultural manufacturer with surplus raw materials which are used for various purposes, including energy production or exports; in this case, the increase in biofuel production volumes could be accompanied by an increase in imports, and therefore the relationship would be positive; a similar reasoning can be applied to imports: although the imported quantities of agricultural raw materials are increasingly lower, the biofuel production levels remain high and keep increasing because the country concerned is a large agricultural producer with an extensive raw material base (supported by a small volume of imports or with no imports at all); in this case, agricultural

imports have a relatively small impact on the domestic production of biofuel; therefore, there could be a negative relationship; the author of this paper tends towards the first interpretation of external trade; accordingly, the imports and exports should have, respectively, a positive and a negative impact on the levels of liquid biofuel production.

BIOETHANOL PRODUCTION DETERMINANTS

According to empirical studies aimed at identifying the determinants of bioethanol production in Poland, the production volumes are affected by variables from all groups, i.e. the ethanol sector, the macroeconomic environment and the cereals market. The multiple regression analysis resulted in a model with 11 variables significant at $\alpha = 0.05$ (or $\alpha = 0.07$ for one variable), cf. Table 1. The estimated model is well fitted. The adjusted R^2 is close to 0.89 which means that 89% of the variation of the Polish ethanol production is explained by the model. The standard error of the estimation does not exceed 9% of the average volume of ethanol production throughout the period concerned which suggests the model has good forecasting abilities.

In the augmented Dickey-Fuller test, the p value indicates that the series is stationary in the case of each variable in both scenarios. The Durbin-Watson statistic for the model is 1.55 which means the correlation test is not conclusive (the DW test does not suggest the presence of autocorrelation between residuals). Based on the outcomes of the test for normal distribution of residuals, it was concluded that there was no evidence to reject the null hypothesis of normal distribution of the variable. In turn, based on the White's test for heteroskedasticity of residuals, it was concluded that there was no evidence to reject the null hypothesis of the absence of heteroskedasticity (constant variance). Having in mind the values of b* regression coefficients, the following had the lowest values in the estimated model: interest rate (–0.993), wheat exports (–0.565), changes in GDP (–0.552) and purchasing price of wheat (–0.532). In turn, the highest coefficients were recorded for the purchasing of maize (0.688), purchasing prices of maize (0.653) and domestic sales of bioethanol (0.528).

The explanatory variables in the bioethanol sector (domestic and foreign sales) proved to be significant for the estimated model. Their regression signs are as expected, i.e. positive. The results should be interpreted as follows: for the domestic industry, the growing sales of bioethanol (whether sold in Poland or internationally) is an incentive to increase the production volumes, and therefore the relationship is positive. It could be concluded that the growing sales contributed to the increase of production volumes which was a kind of response to the high sales levels (which reflect the demand). Note however that domestic sales of bioethanol have been relatively low since 2013, reaching a level of several thousand tons (compared to a production volume of over 41,000 tons), and the exports are zero.

Just as anticipated, two variables from the macroeconomic environment, i.e. the interest rate and the USD/PLN exchange rate, demonstrate negative relationships with bioethanol production. It seems reasonable to conclude that a long-term reduction of the interest rate is a growth driver for the production of bioethanol, as lower interest rates are an investment incentive. This is also applicable to investments in the renewable energies sector (including the bioethanol industry), all the more so since the bioethanol production start-up costs (essential infrastructure investments and bioethanol manufacturing facilities) are relatively high. According to Hryniewicz (2008), a CAPEX (capital expenditures) of up to several million PLN is required to initiate the production of bioethanol. Therefore, access to low-cost loans seems to be of key importance for the development of the biofuel sector. In the period under consideration, the USD/PLN exchange rate was relatively stable, ranging from 2.18 to 3.44, with a coefficient of variation of barely 11%. Except for one period (from mid 2005 to mid 2008), no specific growth or decline trends could be identified. Hence, it cannot be unambiguously concluded that the long-term decline in the USD/PLN exchange rate contributed to the growth of bioethanol production in Poland. However, generally, a decrease in the USD/PLN exchange rate may be a growth driver for liquid biofuel production because foreign raw materials become relatively cheaper. While the changes in the Gross Domestic Product proved to be statistically significant in this model, the results were not as expected. When anticipating the results, the author assumed that biofuel production (as a manifestation of economic growth and increased interest in environmental protection) should grow together with the GDP. However, it was not the case in this model. While GDP grew on a quarter-to-quarter basis in the period considered, a declining trend

Table 1. Marginal effects for bioethanol production in Poland based on the regression analysis
Tabela 1. Efekty marginalne dla produkcji bioetanolu w Polsce na podstawie analizy regresji

Specification Wyszczególnienie	b*	Standard error Błąd stand.	b	Standard error (robust standard error) Błąd stand. (odporny błąd stand.)	t(24)	*p*
Constant Wyraz wolny			97 463.4	13 440.014 (8 733.33)	7.25173	0.000000
Sales of bioethanol in Poland Sprzedaż bioetanolu w Polsce	0.528161	0.102290	0.589084	0.114089 (0.094531)	5.16336	0.000027
Interest rate Stopa procentowa	–0.992945	0.118454	–8 562.463	1 021.463 (804.917)	–8.38255	0.000000
GDP growth rate (change) Zmiana PKB	–0.552016	0.080669	–2 361.864	345.152 (311.433)	–6.84296	0.000000
USD/PLN exchange rate Kurs USD/zł	–0.475104	0.118149	–13 987.204	3 478.330 (2049.12)	–4.02124	0.000499
Purchase price of wheat Cena skupu pszenicy	–0.532383	0.272761	–25.691	13.163 (12.0131)	–1.95183	0.062722
Wheat exports Eksport pszenicy	–0.565033	0.129807	–0.018381	0.004223 (0.002763)	–4.35287	0.000215
Purchase of rye Skup żyta	0.301957	0.086754	25.483	7.322 (5.520)	3.48060	0.001933
Purchase of corn Skup kukurydzy	0.687510	0.100415	18.340	2.679 (1.629)	6.84667	0.000000
Industrial use/corn exports Zużycie przemysłowe/eksport kukurydzy	–0.217375	0.084282	–374.308	145.129 (100.743)	–2.57913	0.016462
Purchase price of corn Cena skupu kukurydzy	0.653485	0.255469	39.067	15.272 (10.982)	2.55798	0.017264
Bioethanol exports Eksport bioetanolu	0.244253	0.074782	0.327986	0.100419 (0.095573)	3.26619	0.003271

The dependent variable is production of bioethanol in Poland. The regression coefficient b* (standardized) indicates the contribution of each independent variable to predict the dependent variable. In the column "Standard error (robust standard error)" there are values of robust standard errors estimated classical least squares methods (CLS).
Source: Own calculation and study based on the data: Federal Reserve Bank of St. Louis, Główny Urząd Statystyczny, Ministerstwo Gospodarki, Ministerstwo Rolnictwa i Rozwoju Wsi, Urząd Regulacji Energetyki oraz Analizy Rynkowe: Rynek zbóż. Stan i perspektywy.
Zmienną objaśnianą jest produkcja bioetanolu w Polsce. Współczynnik regresji b* (standaryzowany) stanowi wkład każdej zmiennej objaśniającej do predykcji zmiennej objaśnianej. W kolumnie „Błąd stand. (odporny błąd stand.)" w nawiasach podano wartości odpornych błędów standardowych oszacowane klasyczną metodą najmniejszych kwadratów (KMNK).
Źródło: Obliczenia i opracowanie własne na podstawie danych: Federal Reserve Bank of St. Louis, Głównego Urzędu Statystycznego, Ministerstwa Gospodarki, Ministerstwa Rolnictwa i Rozwoju Wsi, Urzędu Regulacji Energetyki oraz Analiz Rynkowych: Rynek zbóż. Stan i perspektywy.

was also apparent: the GDP growth rates were increasingly smaller[8]. At the same time, the bioethanol production volumes have grown at a small but consistent rate. This suggests the production was independent from the evolution of GDP and resulted from the energy policy in place. The fact remains that the economic growth continues to be based on conventional energy sources[9] and the importance of the biofuel sector, reflected for instance by the share of biofuel in the total transport fuel consumption, is relatively low.

As regards the cereals market, some variables proved to be significant for the domestic ethanol production, including the purchase volumes, exports and prices of certain species and the ratio of industry consumption to the exported maize volume. As the model includes the purchase of rye and maize, note that both variables have a positive impact (positive coefficient signs), as expected. Assuming that the purchase volume represents the total domestic demand for cereals from various industries (including the ethanol industry), it seems reasonable to conclude that the increase in purchased volumes results from the increased interest in using cereals for non-food purposes, such as ethanol production. This is supported by the fact that the industrial consumption of all cereals has clearly increased during the last decade: the reported annual average growth rates for wheat, rye and maize were nearly 8%, over 4% and nearly 40%[10], respectively. This could mean that all of the above cereals are valuable resources for the ethanol industry. Wheat has a wide range of applications and is supplied in the largest quantities. Rye is attractive to the ethanol sector due to relatively low prices and relatively low cultivation requirements. Currently, the share of rye in the consumption of resources used for ethanol production in Poland is 10–11% (Skarżyńska, 2011). In turn, maize has higher yields compared to other cereals and demonstrates high efficiency: during fermentation, as much as 70% of the grain is processed into ethanol (Michalski and Mystkowski, 2009).

As regards the wheat market, exports and purchase prices are significant for the model of determinants of ethanol production. As expected, both the price and the exports of wheat have an adverse effect on the domestic production of bioethanol. The negative impact of prices should be interpreted as follows: an increase in wheat prices adversely affects the production of bioethanol in Poland as it leads to increased manufacturing costs, and thus could be a restraining factor for the development of that sector. According to some authors, the purchasing costs of raw materials may reach even 70–80% of the total biofuel production costs (von Braun, 2007; Gao et al., 2010; Wigier, 2012). Similarly, wheat exports have an adverse effect on the domestic production of bioethanol as the raw materials sold internationally reduce the domestic resource base which could be used for various purposes, including energy production. This is exacerbated by the fact that Poland has recently become (from mid 2012) a large net exporter of wheat. Having in mind the estimated model and the data on the raw materials mix used in ethanol production (Ajanovic, 2011), it may be concluded that the changes in the wheat market have a significant effect on bioethanol production in Poland.

Surprisingly, in the estimated model, there was a positive relationship between the maize purchase prices and bioethanol production. Similarly to the reasoning behind wheat prices, the relationships between these variables should be negative, and the increase in maize prices should have the effect of lowering the ethanol production levels. In that context, a positive relationship could be explained by the previously mentioned case for using maize in ethanol production (the high efficiency of grains), and by the long-term implementation of the biofuel policy. Also, the high efficiency is even likely to compensate for the higher prices of raw materials. Note also that the high and growing demand for maize from the bioethanol industry could add to existing pressures on maize prices and result in a price increase. In this situation, the increase in prices is not accompanied by a decline in bioethanol production which, in a sense, should be a natural consequence. As a statistically significant component, the model includes the ratio of maize consumption in industrial processes to maize exports. That variable could illustrate how much does the industrial

[8] At the beginning of the period considered (2006–2008), the growth rates were around 6.5%. In 2011 and at the end of that period, they reached a level of around 4.8% and below 3.5%, respectively. In 2009 and at the end of 2012, beginning of 2013, a moderate positive level was recorded (cf. data of the Ministerstwo Gospodarki).

[9] In 2014, only 11.5% of energy consumption came from renewable sources (cf. Eurostat).

[10] According to annual data, other uses of cereals (consumption, sowing, grazing) followed a declining trend, except for grazing on maize (an upward trend) and wheat sowing (slow growth), cf. Rynek zbóż...

consumption of maize represent in relation to exports. An increase could be caused by the growing industrial consumption, a decrease in exports or a simultaneous occurrence of both. It could suggest a growing interest in using maize for energy production purposes, and therefore a positive relationship should exist between that variable and bioethanol production. However, surprisingly, there is a negative relationship in the model. In the period considered, the annual industry consumption has grown at an average rate in excess of 40% (over 70% in the two initial years). As the level reached in 2014 was more than 14 times higher than that of 2006 (an increase from 47,500 to 680,000 tons), this could suggest that maize has become an increasingly important raw material for the bioethanol industry. Maize exports (whether on a quarterly or annual basis) were highly variable, and therefore no specific trends could be identified. Note however that from 4Q 2011 onwards, the exports have been relatively high, with an average level of 240,000 tons while the average figures recorded from 2006 to 3Q 2011 were 41,000 tons. It seems that the growing exports of maize were the reason why no positive relations were found between the consumption/exports ratio and the bioethanol production, even though the industry consumption was on a consistent growth path, as mentioned earlier.

In this model, variables that proved to be insignificant included oil prices, imports of cereals, and lagged variables such as average oil prices and cereals purchase prices. As the imports are absent in the models, it means they are of no significance to the production of ethanol in Poland. This should be interpreted as meaning that the domestic resource base was large and strong enough to survive without any imports (for energy production purposes). Indeed, in the period under consideration, Poland remained a net exporter of all cereals covered by this analysis. In the maize market, the trade surplus was relatively low, especially when compared to wheat and rye markets. Another missing variable are the oil prices. This suggests that rather than by the evolution of oil prices, the bioethanol sector's development was impacted by other factors covered by the model or, for instance, by institutional determinants (within the biofuel policy) which, due to difficult quantification, were only indirectly covered by the empirical studies (by introducing the "bioethanol sales" variable whose determinants include the institutional factors).

BIODIESEL PRODUCTION DETERMINANTS

Based on empirical studies aimed at identifying the determinants of biodiesel production in Poland, it can be concluded that the production volumes are affected by variables from all groups, i.e. the biodiesel sector, the macroeconomic environment and the oilseeds market. The regression analysis resulted in a model with 12 statistically significant variables (cf. Table 2). The estimated model is perfectly fitted. The adjusted R^2 is 0.98 which means that 98% of the variation of the biodiesel production is explained by the model. The standard error of the estimation does not exceed 6% of the average volume of biodiesel production throughout the period concerned.

For all variables (in the Dickey-Fuller test without intercept) and for all variables except one (in the Dickey-Fuller test with intercept[11]), the p value indicates the presence of stationarity in the series. Therefore, there is no risk of spurious regression between specific variables and the explained variable, i.e. biodiesel production level. The Durbin–Watson statistic for the estimated model is 2.15 which means the test does not indicate the presence of autocorrelation between residuals (inconclusive results). Based on the outcomes of the Lilliefors test for normal distribution of residuals, it was concluded that there was no evidence to reject the null hypothesis of normal distribution of the variable. Based on the White's test for heteroskedasticity of residuals, it could be concluded that there was no evidence to reject the null hypothesis of the variance being constant over time. Considering the values of b* regression coefficients, it may be concluded that the relatively most important variables are: total sales of biodiesel (0.459), the import price of palm oil (0.24); as well as average sales price of rapeseed oil (-0.382) and changes in GDP (-0.206), the only two variables contributing to the decrease of biodiesel production volumes in Poland, according to the estimated model.

For the estimated model, the total sales of biodiesel (on a domestic and international basis) proved to be a statistically significant variable. Most importantly, as expected, the changes follow a positive trend and the

[11] That variable is the average selling price of rapeseed oil. While the corresponding *p* value is 0.129 and exceeds the 0.05 significance level, the decision was made to keep it in the regression analysis as it was used in one test scenario only.

Table 2. Marginal effects for biodiesel production in Poland based on the regression analysis
Tabela 2. Efekty marginalne dla produkcji estrów w Polsce na podstawie analizy regresji

Specification Wyszczególnienie	b*	Standard error Błąd stand.	b	Standard error (robust standard error) Błąd stand. (odporny błąd stand.)	t(24)	*p*
Constant Wyraz wolny			–73 8219	271 976.027 (221 686)	–2.71428	0.012371
Total sales of biodiesel Sprzedaż estrów razem	0.458786	0.026099	0.386706	0.021999 (0.016017)	17.57859	0.000000
Rapeseed oil imports Import oleju rzepakowego	0.130057	0.049487	0.703257	0.26759 (0.153173)	2.62811	0.015032
Production of raw rapeseed oil; t-1 Produkcja oleju rzepakowego surowego; t-1	0.193855	0.038044	0.217727	0.042729 (0.026662)	5.09551	0.000037
GDP growth rate (change) Zmiana PKB	–0.205831	0.027328	–6 102.526	810.214 (556.921)	–7.53199	0.000000
Consumer price index Wskaźnik cen towarów i usług konsumpcyjnych	0.071709	0.031811	6 083.911	2 698.869 (2 151.56)	2.25424	0.034009
Import price of palm oil Cena importowa oleju palmowego	0.240448	0.034986	52.435	7.63 (5.375)	6.87271	0.000001
Palm oil imports Import oleju palmowego	0.190621	0.034092	0.845277	0.151174 (0.11566)	5.59142	0.000011
Average selling price of rapeseed oil Średnia cena sprzedaży oleju rzepakowego	–0.381688	0.056954	–36.469	5.442 (4.294)	–6.70166	0.000001
Rapeseed imports Import nasion rzepaku	0.121696	0.032333	0.134088	0.035625 (0.027499)	3.76390	0.001009
Average crude oil price Cena ropy naftowej	0.199865	0.041482	670.178	139.097 (75.064)	4.81807	0.000073
USD/PLN exchange rate Kurs USD/zł	0.182461	0.034693	37 222.534	7 077.556 (5 021.69)	5.25924	0.000025
Average crude oil price; *t*-1 Średnia cena ropy naftowej; *t*-1	0.095531	0.035645	314.161	117.222 (96.655)	2.68006	0.013370

The dependent variable is production of biodiesel in Poland. The regression coefficient b* (standardized) indicates the contribution of each independent variable to predict the dependent variable. In the column "Standard error (robust standard error)" there are values of robust standard errors estimated classical least squares methods (CLS).
Source: own calculation and study based on the data: Federal Reserve Bank of St. Louis, Główny Urząd Statystyczny, Instytut Ekonomiki Rolnictwa i Gospodarki Żywnościowej – Państwowy Instytut Badawczy, Ministerstwo Gospodarki, Ministerstwo Rolnictwa i Rozwoju Wsi oraz Urząd Regulacji Energetyki.
Zmienną objaśnianą jest produkcja estrów w Polsce. Współczynnik regresji b* (standaryzowany) stanowi wkład każdej zmiennej objaśniającej do predykcji zmiennej objaśnianej. W kolumnie „Błąd stand. (odporny błąd stand.)" w nawiasach podano wartości odpornych błędów standardowych oszacowane klasyczną metodą najmniejszych kwadratów (KMNK).
Źródło: obliczenia i opracowanie własne na podstawie danych: Federal Reserve Bank of St. Louis, Głównego Urzędu Statystycznego, Instytutu Ekonomiki Rolnictwa i Gospodarki Żywnościowej – Państwowego Instytutu Badawczego, Ministerstwa Gospodarki, Ministerstwa Rolnictwa i Rozwoju Wsi oraz Urzędu Regulacji Energetyki.

correlation coefficient between the series (0.83) indicates a strong positive relation. Just as in the case of the Polish ethanol sector, it can be interpreted as follows: for the domestic industry, the growing sales of biodiesel is an incentive to increase the production volumes. An important macroeconomic factor for the development of the biodiesel sector and for the growth of ester production in Poland were the increasing prices of oil. Interestingly, the growth of ester production is positively affected by prices both in the current and in the previous quarter. While some fluctuations in prices of oil (the coefficient of variation is in excess of 20%) were recorded in the period concerned (2006–2014), a growth trend could be identified (the average quarterly growth rate of oil prices was 1.8%). Therefore, the increasing oil prices were a growth driver for biodiesel production. The results provided by the model are as anticipated by the author and are consistent with the view of many scientists who believe that the high and increasing prices of oil are a natural environment for the development of the biofuel sector (the biodiesel industry, in this case) and a production growth driver. According to some of them, oil prices ranging from USD 80 to 100 per barrel lay the grounds for an economically viable production of biodiesel in the European Union (Abbott et al., 2008; Baffes, 2013; Zalewski, 2011; Zalewski and Igras, 2012; Zegar, 2012). Thus, conversely, low prices of oil should lead to a decline in the production of biofuel, including biodiesel. Nevertheless, the importance of changes in oil prices to the liquid biofuel sector should be approached cautiously. The consistent rise in oil prices can have a time-lagged effect on biofuel manufacturers through the increasing prices of agricultural raw materials. Therefore, the biofuel sector itself can become the victim of excessive oil prices. However, It is commonly agreed that the increasing prices of oil are a growth driver for liquid biofuel production.

In Poland, the growth of biodiesel production was largely driven by the growing production of rapeseed oil, as confirmed by the studies. Note however that in this model, rapeseed oil production is statistically significant as a lagged variable. This should be interpreted as follows: rapeseed oil production in the previous quarter drives the growth of biodiesel production in the current period. This demonstrates that the biodiesel industry largely depends on the supply of energy products, including rape and rapeseed oil. In Poland, rapeseed is indeed of key importance to the biofuel industry because the oil plants market is dominated by rapeseed. Currently, 1–1.6 tons of rape are used each year for biodiesel production (Grzyb, 2013; Szajner, 2014). The importance of rapeseed for this industry is also confirmed by Rosiak et al. (2011), and by Ajanovic (2011) who indicates that in the European Union, the share of rapeseed oil in the total consumption of raw materials for biodiesel production is at a level of nearly 80%.

The importance of agricultural resources for the production of biodiesel is also demonstrated by the fact that the model includes three import-related variables, namely: rapeseed, rapeseed oil and palm oil imports. As regards these variables, the development trends are as anticipated. They demonstrate a positive relationship with the production of biodiesel, expressed with correlation coefficients of 0.35 for seed imports, 0.81 for rapeseed oil imports and 0.50 for palm oil imports. This means that the increase in seed or oil imports drives the growth of biodiesel production in Poland because the agricultural products purchased abroad extend the domestic resource base which, in turn, increases the production potential and stimulates the development of the biodiesel sector (manifested by the production growth). The presence of these very variables in the model is a confirmation that rapeseed as well as rapeseed oil and palm oil are the key agricultural commodities for the Polish biodiesel industry. The impact of the rapeseed market on the biodiesel sector was contemplated above. Meanwhile, palm oil has grown in importance in the recent years due to specific benefits, primarily including the low energy inputs required for oil processing, low production costs and a low price. Combined together, these factors are the reason why palm oil is regarded as the best raw material for the biodiesel industry (Rosiak et al., 2011; Rupilius, 2007). The import of raw materials for the biodiesel sector becomes particularly important in the context of the restricted ability to increase the production thereof in Poland, especially as regards rape production. An additional growth driver for the biodiesel sector in the period considered was the decreasing sales price of rapeseed oil. As the decline in prices leads to production growth, the expected impact was confirmed by the study. Therefore, it seems reasonable to conclude that a broad resource base together with relatively low prices are the key conditions for the development of the biofuel industry. In the model considered, these factors are statistically significant.

In addition to oil prices, the estimated model includes three variables from the macroeconomic environment. However, only the consumer price index meets the anticipations, while the changes in GDP and the USD/PLN exchange rate affect the production of biodiesel in a way contrary to the expectations. In the case of the price index, a positive effect on the production of biodiesel could be expected assuming that a low and controlled inflation level is a growth driver for the investments and for the economic progress. The above investment growth may be considered in the context of the biofuel sector which has been demonstrating growth for only a few years. Based on inflation data, it may be concluded that Poland has experienced low, desirable levels of inflation in the 2006–2012 period. A total stabilization of prices (2013) or even deflation (2014) were recorded only in the last two years. However, in that period, the production of biodiesel has grown anyway. Just as in the case of the bioethanol sector, the changes in PKB proved to be statistically significant for the biodiesel industry but the outcomes of the empirical studies were contrary to the expectations. In 2006–2014, the production of biodiesel grew steadily. But while the GDP was increasing throughout that period, the growth rates were increasingly lower. It is therefore likely that the biodiesel sector was developing, in a sense, independently from the changes to GDP, being driven by the adopted energy and biofuel policy which is indirectly represented in the model by the sales of biodiesel, similarly as it was the case for the bioethanol industry.

There is one more similarity between the ester and ethanol industries: the production of biodiesel has grown despite the increasing prices of palm oil, an important raw material for this industry. This could be explained by the fact that Poland has a limited ability to increase the production of rapeseed, and therefore must import agricultural energy resources (including palm oil). In this situation, to ensure the continued development of this industry (as provided for in the biofuel policy in place), it is necessary to accept the external (global) prices. This becomes increasingly important in view of the fact that palm oil imports are a significant determinant for the growth of biodiesel production in Poland. Note also that in the 2006–2014 period, the prices of palm oil were lower than rapeseed oil prices by 10% on average. Therefore, despite an increase in prices, palm oil continued to be a relatively competitively priced resource.

SUMMARY

The purpose of this paper was to specify the determinants of biofuel (bioethanol and biodiesel) production in Poland after 2005. To do so, two models were developed based on multiple regression with the use of quarterly data from 2006–2014. The explanatory variables originated from various areas, namely the liquid biofuel sector, agricultural markets (cereals and oil plants market) and the macroeconomic environment. The estimated models provide answers to the questions as to which are the relatively most important variables for biofuel production, and which of them have a positive or negative effect on production growth. In the 2006–2014 period, drivers of the bioethanol production growth in Poland included the increase in domestic and international sales of bioethanol, the increased purchasing volumes of rye and maize, as well as the reduced levels of such variables as the interest rate, the USD/PLN exchange rate, wheat purchase prices and wheat exports. In this group, the relatively most significant variables (having in mind the values of standardized regression coefficients (b*) were as follows: the interest rate; wheat exports and purchase prices; purchase volumes and purchase prices of maize; and the domestic sales of bioethanol. In turn, in the period under consideration, the growth of biodiesel production in Poland was driven by, without limitation: the increase in the total (domestic and international) sales of biodiesel; the growing production of rapeseed oil (as a lagged variable); the increasing imports of rape and of rapeseed and palm oil; the increase in oil prices (in the current and previous period); and the reduction in rapeseed oil prices. In this group, the relatively most significant variables were as follows: total sales of biodiesel; lagged production and prices of rapeseed oil.

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DETERMINANTY PRODUKCJI BIOPALIW CIEKŁYCH W POLSCE PO 2006 ROKU – UJĘCIE MODELOWE

Streszczenie. Biopaliwa ciekłe z surowców rolnych (przede wszystkim zbóż i roślin oleistych) wytwarza się w Polsce na skalę przemysłową od 2005 roku, jednak dynamiczny rozwój produkcji odnotowano kilka lat później. Polska, realizując wytyczne polityki energetycznej Unii Europejskiej, jest zobowiązana do zapewnienia udziału biopaliw płynnych w łącznym zużyciu paliw w transporcie w wysokości przynajmniej 10% do 2020 roku. Rozwój sektora biopaliw ciekłych jest więc zależny z jednej strony od czynników instytucjonalnych (regulacji prawno-administracyjnych), a z drugiej strony od sytuacji rynków rolnych (relacji podażowo-popytowych i cen) oraz czynników makroekonomicznych, w tym głównie cen ropy naftowej. Celem artykułu było empiryczne określenie determinant produkcji biopaliw ciekłych (bioetanolu oraz estrów) w Polsce. Dla jego realizacji zbudowano dwa modele bazujące na regresji wielorakiej, dokładnie wskazujące, które czynniki przyczyniają się do wzrostu bądź spadku produkcji biopaliw ciekłych. Dla produkcji bioetanolu znaczenie mają głównie sprzedaż tego biokomponentu, zmienne z rynku zbóż (ceny, skup oraz eksport), a spośród czynników makroekonomicznych – m.in. stopa procentowa oraz kurs USD/zł. Z kolei dla produkcji estrów istotnymi determinantami są m.in. sprzedaż estrów, produkcja oleju rzepakowego, import rzepaku i olejów roślinnych oraz ceny tych olejów, a także ceny ropy naftowej, które reprezentują makrootoczenie.

Słowa kluczowe: produkcja biopaliw ciekłych w Polsce, bioetanol, estry, rynki rolne

Accepted for print – Zaakceptowano do druku: 13.12.2016