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Economic and legal aspects of the direct processing of sugar beet to ethanol

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Abstract. Sugar beet is a key resource in a future chemical platform of a sugar biorefinery. Decontrol of production amounts of sugar in the European Union in 2017 necessitates the search for other profitable production alternatives in the sugar industry. One possible approach is based on the direct processing of beetroot to bioethanol. This paper discusses research which has described and compared process flows (PFD) as well as incomes and financial expenditures (CAPEX and OPEX) of two technological variants that involve the direct processing of sugar beet to ethanol: one with the use of Betaprocess® technology, and the other serving as a reference technology. The Betaprocess® technology is an original pretreatment method whereby plant cells are degraded efficiently, owing to which the feedstock is fed directly to digesters, where it is fermented effectively. The research results show that the whole processing cycle is improved by inclusion of Betaprocess®, with such gains as lower investment and operational costs of the installation in comparison to the reference technology. This paper also contains an analysis of the direct processing of sugar beet to ethanol in view of the binding law, including the legal regulations on liquid biofuels and biocomponents.

1. Introduction

Rational use of agricultural raw products is becoming a key issue in the system approach to sustainable management of natural resources. It is foreseen that products made from agricultural raw materials will be gradually replacing products manufactured from fossil fuels, thus creating a new market of bioproducts, including biofuels [1, 2]. One of energy carriers and, simultaneously, the most promising input product for generating a wide range of marketable bioproducts is ethanol, commonly named bioethanol to underline the renewable character of the raw material from which it is made. Thus, bioethanol, often in the sense of renewable fuel (biofuel), is ethyl alcohol obtained by alcohol fermentation of simple sugars extracted directly from biomass or following a process of relatively simple hydrolysis (starch material) or more advanced pretreatment and hydrolysis (lignocellulose material) (figure 1) [3].

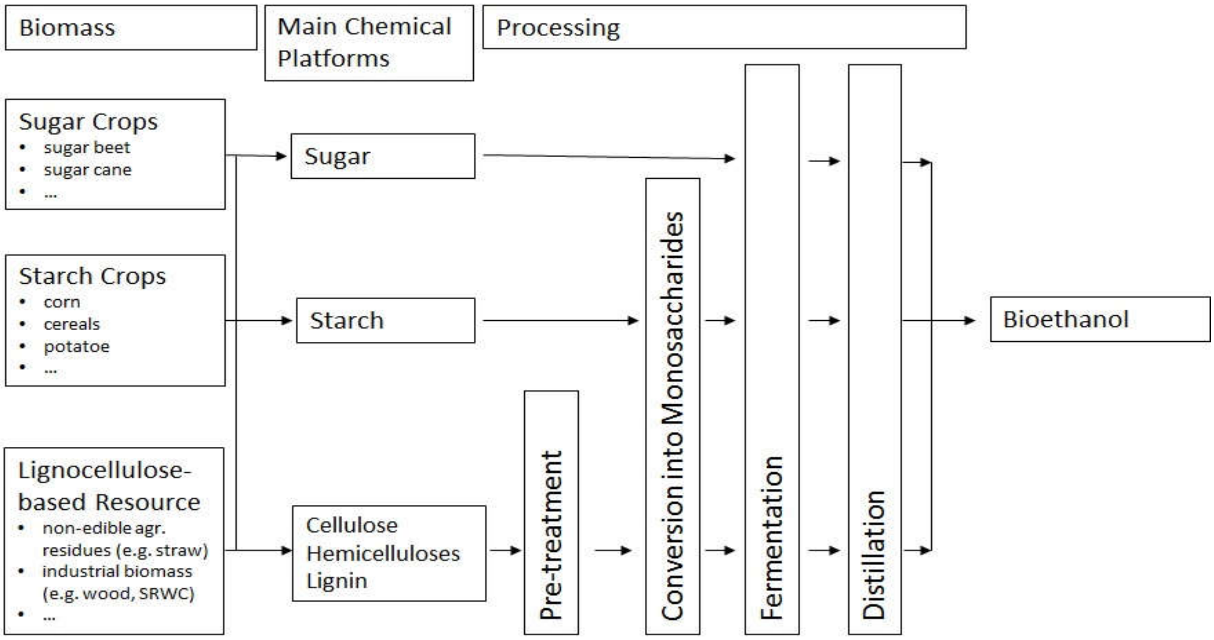

Figure 1. The integration of sugar, starch, and lignocellulosic raw materials and main processes in bioethanol production.

Traditionally, the main raw material for production of ethanol has been the plant material from starch crops: cereals and potato, and from sugar plants – sugar beet and sugar cane, or the by-product from sugar production, that is molasses. Geographical conditions and climate determine main areas of cultivation and specific characteristics of crops grown for fermentation. In Europe, fermentation processing crops are sugar beet and cereals, in Asia – these are sugar cane and cassava, in the USA – corn and, to a lesser extent, sugar beet, while in Brazil – it is sugar cane.

Bioethanol market. In 2014, the global production of ethanol was 93.0 billion liters, of which 54.1 billion l were made in the USA and 23.4 billion l in Brazil, which in total made up 83.3% of the world's production (figure 2). The United States exports ethanol to 51 countries around the world, mostly to Canada (41% of ethanol export), China (13%) and the United Arab Emirates (10%). The ethanol market in the USA generates a substantial positive contribution to the American economy. In 2014, this translated to 83,949 employment places directly connected with the ethanol market and 295,265 jobs with indirect connections, 53 billion dollars contributed to the GDP, 27 billion dollars of household incomes, and 10 billion dollars in tax returns. Production of ethanol in the USA in 2007-2010 showed a strong increasing tendency (over 50% annually), only to stabilize in the subsequent years at a level of 50-54 billion liters a year. In Brazil, the ethanol production level has been relatively stable for years, and equals 23-24 billion liters. In Europe, there was a steady increase in ethanol production from 2 billion liters in 2007 to 5.5 billion liters in 2014 [4].

Bioethanol as biofuel – regulation aspects. The technology of producing ethanol for food purposes has been cultivated for centuries and is relatively well-known. However, production of ethanol for fuel creates new challenges, both technological and socio-environmental ones. Ethanol was one of the first fuels used to power car engines [5]. Pure ethanol used in fuels containing 85-100% of ethanol can be a substitute of petrol in engines with spark ignition or can be added to a fuel mixture, most often at a ratio of 5 to 25%. The use of bioethanol for fuels is strictly connected with the fuel market and regulations on the use of biofuels and fuel biocomponents, especially in the context of costs of petrol. The growth of the market of bioethanol for fuel purposes is linked with the economic and social spheres. Production of ethanol can improve the fuel market balance by substituting imported crude oil with fuel produced and usually consumed locally. Indirectly, it can effect an increase in employment in rural areas and a greater diversification of farmer incomes. In consequence, the local production of biofuels contributes to the fuel security in the country. The principal raw material for production of bioethanol in the EU is sugar beet. The decision to develop sugar beet production for fuel purposes has been stimulated by deregulation of sugar quotas, imposed by the EU in 2006 in order to achieve balanced sugar production and effective until 2017. Surplus amounts of sugar beets allocated to biofuel production and to the chemical and pharmaceutical industries are excluded from the quotas. Once the sugar quotas are lifted, it is expected that sugar market prices will decline; production-wise, another foreseeable consequence is the multi-product processing of sugar beet.

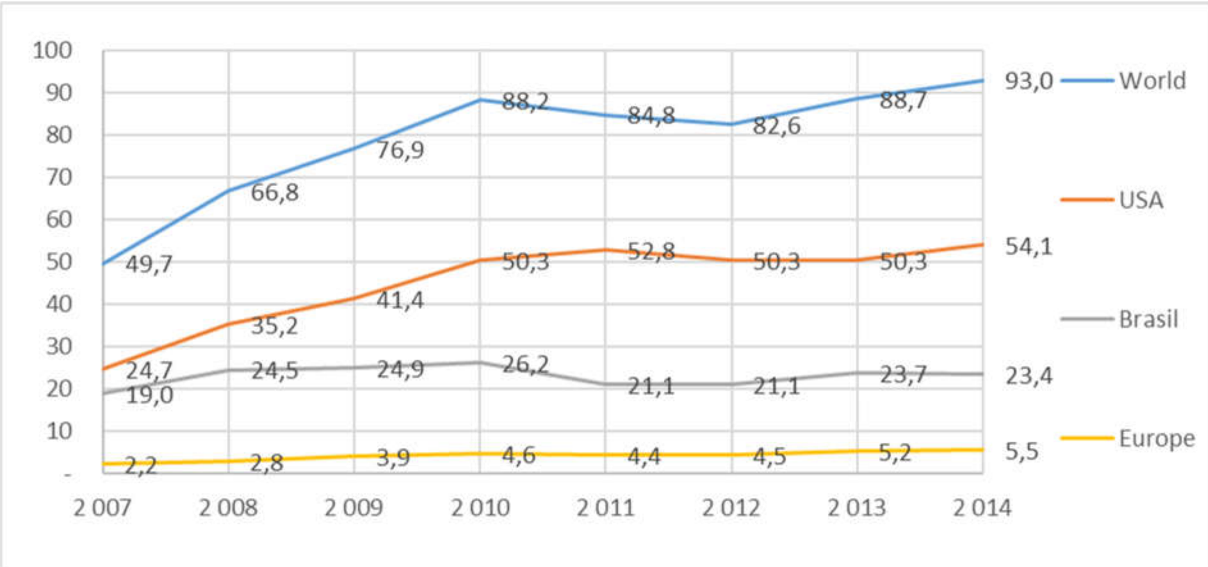

Figure 2. Production of bioethanol in billions of liters (Source: the authors, based on: [4]).

Ethanol fermentation process in the context of current sugar production technologies. Sugar beets are a rich source of sucrose, a disaccharide consisting of two simple sugar molecules: glucose and fructose. The raw material for production of sucrose is the sugar beet root, which is conical in shape and typically weighs between 0.5-1.0 kg. The distribution of sugar within a sugar beet root is not even. The highest sugar concentration is in the root's core layer. The chemical structure of sugar beet roots varies depending on the geographical location of fields.

Figure 3 shows a diagram illustrating the process of making sugar from sugar beet roots, in which semi-products having different concentrations of simple sugars are distinguished.

Theoretically, extracted sweet juices in the form of raw juice, thin juice or thick juice, as well as end-products, i.e. sugar and molasses, can be used for fermentation. In practice, because of the varied technological quality of these substrates as well as inputs, fermentation processes achieve different degrees of efficiency.

Economic aspects of processing sugar beet to ethanol. The processing of sugar beet to ethanol may reverse the undesirable trend on the market, consisting of a limited production and less interest in sugar due to low prices. Outlays dedicated to production of sugar and ethanol from sugar beet are higher compared to sugar cane as a raw material (Table 1). The lowest cost of ethanol production is achieved in manufacture from sugar cane in Brazil (0.21 $/l), and the cost of producing ethanol from corn in the USA is about 40% higher (0.27-0.28 $/l), while that of making ethanol from sugar beet is around three-fold as high in the USA (0.62 $/l) and in the EU (0.76 $/l). For all the analyzed crops, the cost of raw material is twice as high as the cost of processing it to ethanol (Table 1).

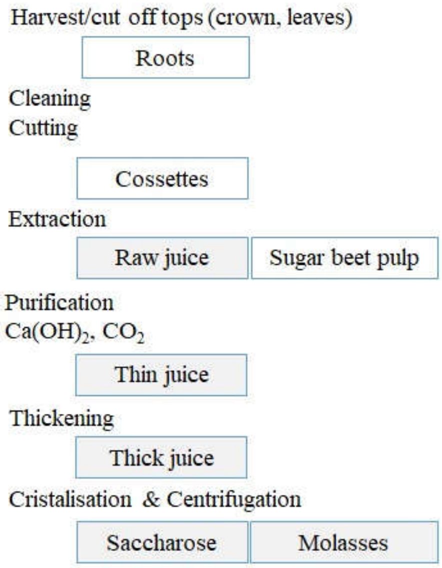

Figure 3. General phases in sugar processing from sugar beet (intermediates with different concentration of sugars and a potential in ethanol production are described in shaded boxes).

Table 1. Cost of producing ethanol from different raw materials in $/l [6].

Origin of raw material	Raw material	Cost of raw material	Cost of processing	Total
USA	corn (‘wet’ milling)	0.10	0.17	0.27
	corn (‘dry’ milling)	0.14	0.14	0.28
	sugar cane	0.39	0.24	0.63
	sugar beet	0.42	0.20	0.62
	molasses	0.24	0.10	0.34
	raw sugar	0.82	0.10	0.92
	refined sugar	0.95	0.10	1.05
Brazil	sugar cane	0.08	0.13	0.21
EU	sugar beet	0.26	0.51	0.76
On average		0.38	0.19	0.57

Noteworthy is the cost of producing ethanol from molasses, which is half the cost of making this substance from sugar beet. However, molasses is a by-product of the cost-consuming sugar production and should be considered in the context of producing sugar as raw material for making ethanol. Sugar remains the most expensive product derived from sugar beet, while the other by-products such as molasses, beet pulp or calcium compounds are estimated at 14 USD/t of sugar beet [7].
Thus, one of the way to raise the competitiveness of sugar beet on the sugar crop market is the direct ethanol production and rational use of the potential hidden in post-production waste. Economically speaking, the process of sugar extraction from sugar beet is relatively simple. Sugar-rich extract is obtained from washed and fragmented beet roots, that is cut roots. Once purified, they can be fermented directly to ethanol. This is the way to omit such stages as crystallization, centrifugation and drying. The essential stages are fermentation and distillation.

Costs of constructing a distillery are relatively high. The balance of construction costs and operational effects of a distillery comprises the following component costs [8]:

- costs of furnishing the installation, including additional equipment for water intake and transport as well as systems for washing the equipment and treating the wastewater;
- costs of raw materials, including yeasts, chemicals and carbon dioxide;
- prices of end-products: ethanol, pulp, molasses, biogas and others;
- running and maintenance costs: consumption of energy carriers (electric power, water steam), cooling water and others;
- capital outlays;
- annual and unit production costs;
- sensitivity analysis.

Production volume and prices of sugar beets, examples from the Netherlands and Poland. The volume of harvested sugar beet in Poland is twice as high as in the Netherlands, whereas the sugar beet yield obtained in Poland corresponds to around 66% of yield achieved in the Netherlands. For example, the average sugar beet root yield in Poland in 2014 was 54.8 t/ha, whereas in the Netherlands it reached 87.4 t/ha (figure 4). In 2015, 8000 t of sugar beet roots were harvested in Poland, which was nearly half the quantities harvested in the previous years. Likewise, the 2015 harvest in the Netherlands was 4500 t in total, being 500-1500 t lower than in the previous decade.

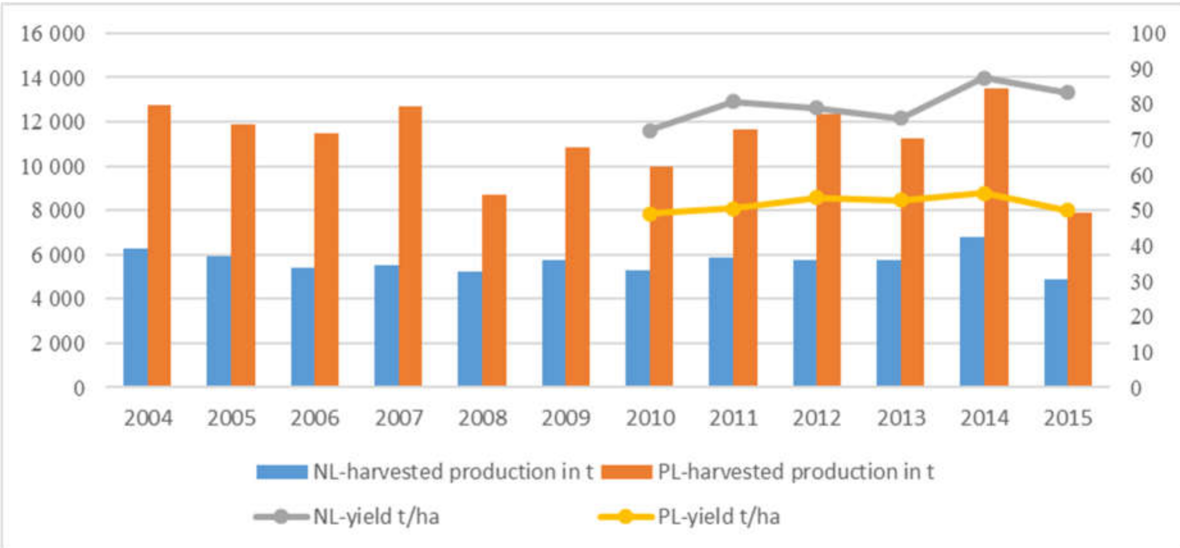

Figure 4. Volume of sugar beet root harvest (the left axis) and yields (the right axis) in the Netherlands and in Poland [9].

Meanwhile, prices for sugar beet roots in euro/t in 2005-2014 oscillated around 26.73 (2009) and 43.57 (2005), and equaled 30.16 in 2014. In the Netherlands, they ranged from 36.90 (2007) to 61.00 (2013), at 50.12 in 2014 (figure 5). It is expected that regulatory changes on the sugar beet market will depress prices for sugar beet by 10-50% [10].

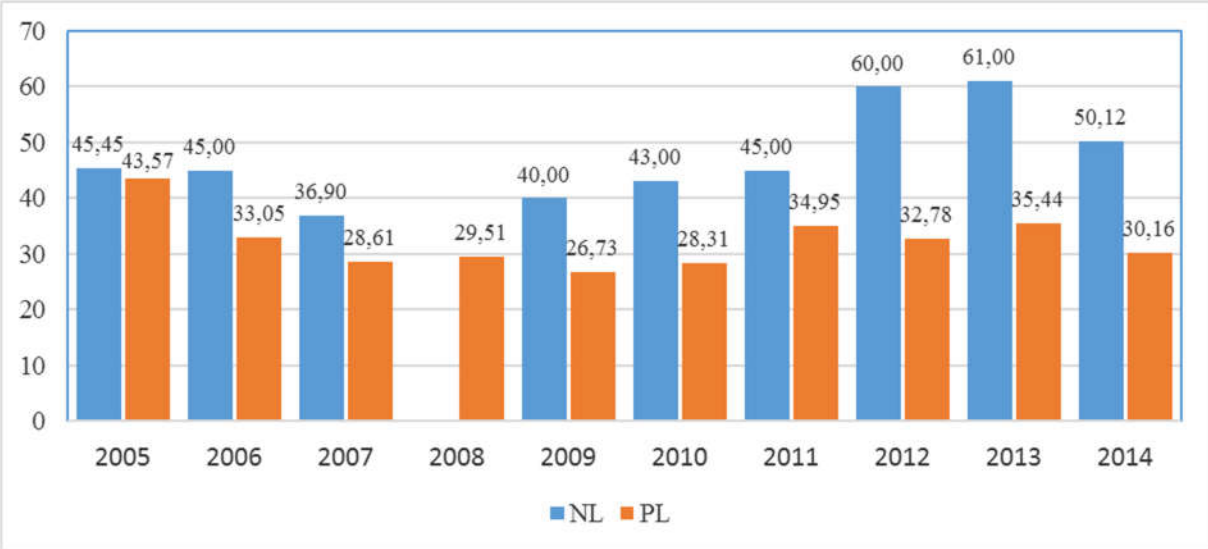

Figure 5. Prices for sugar beet in Poland and in the Netherland in euro/t [9].

Availability of the raw material all year. Ensuring an all-year-round supply of raw materials for processing is a technological challenge in the context of maintaining an economic balance of a business enterprise such as a sugar biorefinery orientated towards ethanol production [11], while analyzing the potential of a sugar biorefinery in the American conditions, noted that the supply of sugar cane for this type of an installation would only be possible in about 3 months a year. This means that the economic balance must also take into account other plant raw materials with approximately the same technological parameters, which would ensure that this type of a biorefinery would operate throughout an entire year. This is why the cited authors analyzed a supplementary use of energy cane, with an elevated content of lignocellulosic compounds, and sweet sorghum, two plants which can be harvested at other seasons than sugar cane. By putting these plants in a sequence and considering how long each could be used to supply a biorefinery, the authors determined the theoretical ethanol efficiency of sugar cane, energy cane and sweet sorghum at 3609, 12938 and 5804 kg/ha, respectively. The relevant literature lacks analogous simulations for a sugar refinery operating under European conditions.

The concept of this research arises from an economic analysis and selected legal aspects associated with the direct processing of sugar beet to ethanol and with the market of biofuels and fuel biocomponents. The study included simulation processing data regarding direct conversion of sugar beet to ethanol in a business model with the pretreatment technology Betaprocess (BP) and a reference model without the Betaprocess (BP) technique (RM) [10].

2. Material and Methods

Simulation processing models of conversion of sugar beet roots to ethanol, without pretreatment (RM) and with Betaprocess pretreatment (BP) are illustrated in figure 6.

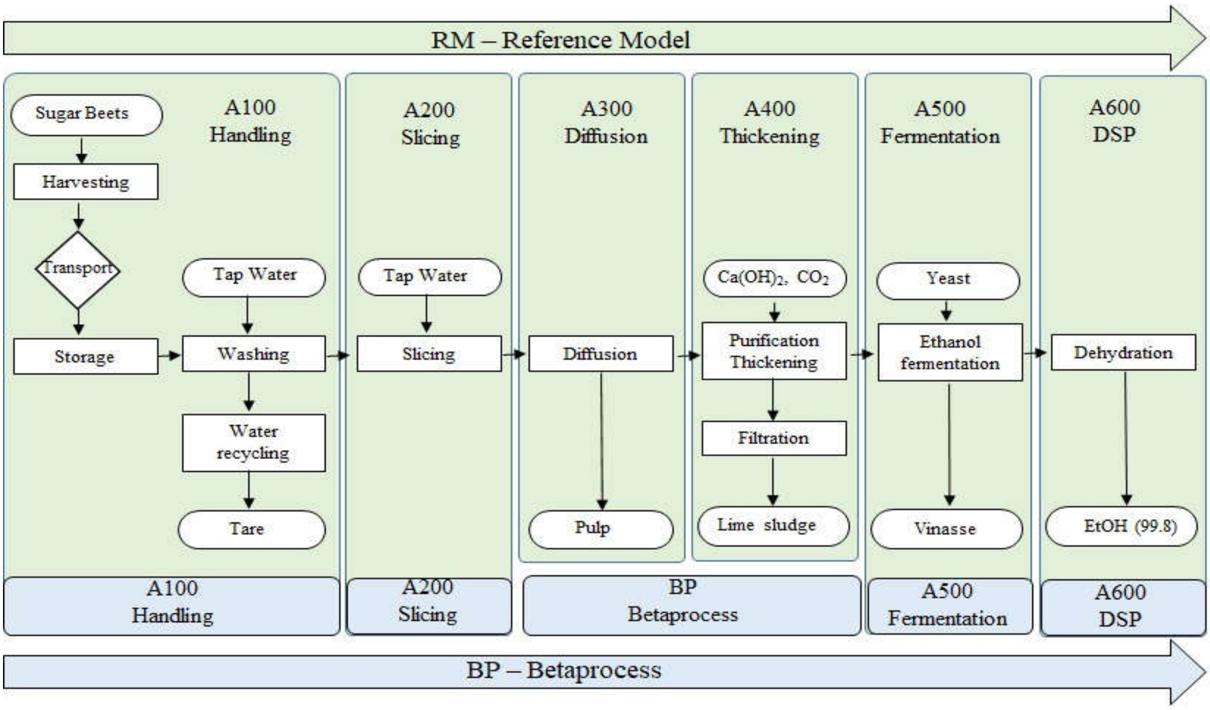

Figure 6. Process modules in the direct processing of sugar beet roots to ethanol: without Betaprocess pretreatment (the top, A100-A600) and with Betaprocess (A100-A200, Betaprocess, A500-A600)

The raw material obtained in the RM process undergoes pretreatment consisting of removal of impurities from beet roots (A100) and fragmentation to cut roots (A200), which is followed by extraction of juice with beet pulp as a by-product (A300) and juice thickening (A400). Betaprocess, which substitutes modules A300 and A400 in the reference model, is a pretreatment method which involves thermal and vacuum treatment, and this approach raises the degree of biomass degradation and release of simple sugars, In the BetaProcess® method, after beet roots have been washed and fragmented, substrate is heated up to the required temperature, between 60 and 65°C, after which sugar beet cells 'explode' under vacuum conditions releasing fiber (a mixture of polysaccharides, mainly cellulose, pectins and hemicellulose), cell membranes (phospholipids, proteins and lipids) and cell walls (biopolymers) and sugars as well as other cell components [12]. Next, the material is cooled down to 40°C and transported to a fermentation chamber. From that moment on, the two processes are convergent and lead to the production of ethanol and post-fermention residue, vinasse (A500), followed by distillation (A600) included in the Down-Stream-Processing DSD model [10].

In the process of modelling particular ethanol production modules within the variants with and without Betaprocess, according to the schematic presentation in figure 6, mass balances were obtained, to be subsequently applied in an economic assessment.

The economic evaluation comprised an analysis of investment costs, operational costs as well as profitability of production, supported by the following indices: NPV, IRR and DPBP, which play a dominant role in evaluations of investment projects in biofuel production [13,14,15].

The indices were calculated according to formulas:

- $\boldsymbol{NPV = \sum_0^n (1+i)^{-n} \cdot CF_n}$

where:

CF_n – cash flow in year n (profits minus costs)
n – duration of an investment
i – discount rate

- $\sum_{t=0}^{T}(S_t - K_t) \cdot (1+IRR)^{-t} - \sum_{t=0}^{T}(I_t) \cdot (1+IRR)^{-t} = 0$
- $\sum_{t=0}^{DPBP}(S_t - I_t - K_t) \cdot (a_t) = 0$

Additionally, a comparative analysis was made covering the costs from sub-systems of ethanol production from sugar beet in both technologies (scenarios 1 and 2). The quantity of produced ethanol (and possibly other co-products, i.e. animal feed or CO_2), consumption of electric and heat energy, technological steam (generated from electric power or natural gas), yeast and supplements, fuel for transport (diesel oil) were analyzed. The process-specific data were obtained from DSD company, which owns the right to the BetaProcess® technology, developed based on patent PCT/EP08/09734, 30 August 2010, and called 'an improved technology of producing ethanol from plant material'.

The legal assessment is based on a dogmatic legal analysis. The EU legislation, including mostly secondary law, i.e. regulations and directives, as well as Polish regulations dealing with the research subject matter, will be discussed.

3. Results

3.1. Mass flows in processing pathways with and without Betaprocess.

It was assumed that 2 Mt of sugar beet per day (83333 kg/h) would be processed in the target installation. The installation can be supplied with sugar beet feedstock for about 200 days a year. It was assumed that the biorefinery would operate for 300 days a year, and therefore supplementary raw materials to be used for the remaining 100 days should ensure approximately the same ethanol productivity. The conversion rate would be 90%, and retention time - 30 h for RM and 24 h for BP. The amount of wash water should be double the mass of incoming sugar beets, while 90% of the water should be recycled. The composition of sugar beet roots entering processing would be as follows: water 66.8%, sucrose 15.6%, soluble solids 2.2%, non-soluble solids 4.5%, tare 11%. The mass flows for the two processing pathways RM and BP are shown in figure 7.

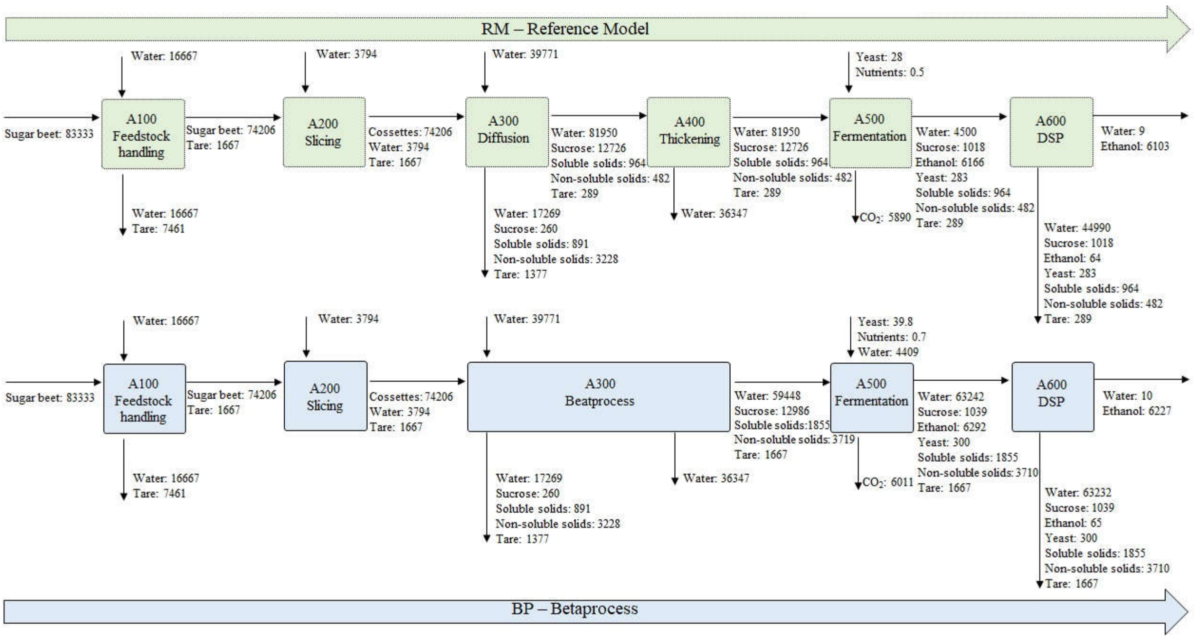

Figure 7. Mass flows for Reference Model (upper) and Betaprocess– all figures are given in kg/h [Based on: 11]

The amount of ethanol in the simulation of the processing without Betaprocess (RM) and with Betaprocess was 6103 kg/h and 6227 kg/h, respectively.

3.2. *Economic analysis.*

A comparative analysis was carried out for two installations/technologies of producing ethanol from sugar beet. The first installation is considered to be a reference model, while the other installation includes BetaProcess®. According to the assumptions made for the economic analysis, the daily demand for raw material is 2000 t, and the installations will work for 300 days a year. In the reference installation, the annual production output of ethanol (99.7%) will be 55,690 m^3, while the installation with BetaProcess® will produce 56,917 m^3 of ethanol. Beet roots will be transported in lorries, each of the capacity of 30 t.

The first stage in the determination of investment costs was to enumerate pieces of the equipment necessary to perform the process. Based on the processing assumptions for both variants, the size of individual equipment items was determined. To build economic models, detailed processing and economic data were derived, mainly from the literature [16]. Although the said report deals with a lignocellulose biorefinery, some of the equipment is the same as in this project's installations.

Prices for all pieces of equipment in each technological stage were either found in the literature (standard appliances) or calculated based on the data provided by the company DSD which owns the patent for modules involved in BetaProcess® (Table 2).

First, costs were recalculated to correspond to the scale of the installation. Based on prices of the equipment of a specific size (capacity), according to the formula given underneath, and using the rescaling factor, the costs of purchase of particular pieces of equipment and appliances in the adopted model were calculated.

Table. 2. Equipment costs for the conventional process and Direct Processing [based on 10].

Base process			Betaprocess ®		
	Purchase costs (EPC) (k€)	Installed costs (INEC) (k€)		Purchase costs (EPC) (k€)	Installed costs (INEC) (k€)
Feedstock handling	2 132	3 624	Feedstock handling	2 322	3 947
Slicing	353	599	Slicing	366	623
Sugar extraction	8 020	14 460	Betaprocess ®	1 875	2 868
Thickening	589	1 087			
Fermentation	4 610	7 163	Fermentation	4 768	7 062
Destilation	3 973	8 044	Destilation	4 020	8 143
Waste water treatment, Steam, Truck, Vent, Cooling tower	3 200	5 760	Waste water treatment, Steam, Truck, Vent, Cooling tower	2 896	5 212
Total (k€)	22 876	40 738	Total (k€)	16 247	27 854

For determination of total investment costs (TIC) it is necessary to take into consideration the consecutive direct and indirect costs involved in the investment process. Total direct costs (TDC) comprise the following constituent costs:

- warehouses,
- development of premises
- costs of connection to facilities (electricity, water, gas, sewers, etc.).

These costs are estimated on the basis of the costs of installing machines and equipment.

Another group of costs consisted of total indirect costs (TIC), which include:

- costs of insurance policies and remunerations paid to installation developers
- costs of maintaining the premises
- office and administration costs

- unpredictable costs
- additional costs, turnkey costs

The sum of the above costs including the price of land and necessary turnover capital corresponded to the total investment costs (Table 3).

The sum of direct and indirect costs allows one to estimate total investment costs.

Table 3. Total investment cost according to Nrel 2011 [16].

Base process			Betaprocess		
Installed equipment	percentage	cost	Installed equipment	percentage	cost
Warehouse	4.00%	1 630	Warehouse	4.00%	1 114
Site development	9.00%	3 666	Site development	9.00%	2 507
Additional piping	4.50%	1 833	Additional piping	4.50%	1 253
Total Direct Costs (TDC) (k€)		47 867	Total Direct Costs (TDC) (k€)		32 728
Prorateable costs	10.00%	4 787	Prorateable costs	10.00%	3 273
Field expenses	10.00%	4 787	Field expenses	10.00%	3 273
Home office & construction fee	20.00%	9 573	Home office & construction fee	20.00%	6 546
Project contingency	10.00%	4 787	Project contingency	10.00%	3 273
Other costs (start-up, permits, etc)	10.00%	4 787	Other costs (start-up, permits, etc)	10.00%	3 273
Total Indirect Costs (TIC) (k€)		28 720	Total Indirect Costs (TIC) (k€)		19 637
Fixed Capital Investment (FCI) (€ mln)			Fixed Capital Investment (FCI) (€ mln)		
Land	0.45%	344	Land	0.45%	235
Working capital	5.00%	3 829	Working capital	5.00%	2 618
Total capital investment (k€)		80 760	Total capital investment (k€)		55 219

Following the assumptions, the sugar extraction and thickening process was replaced by BetaProcess®. This is a process carried out under vacuum and slightly raised temperature. Such conditions mean that the costs of purchase/manufacture of equipment needed to conduct the process are lower than in the traditional process, where pressurised water steam is used. The remaining estimates are derived from costs of the purchase of machines and equipment, which generate a further difference in the value of total investment costs. Based on the assumptions made and methodology of costs estimates, it was assessed that the total investment costs for the base process were 81 M€, while the total investment costs for the installation with BetaProcess ® were about 55 M€. The contribution of individual elements of total costs is illustrated in figure 8.

Operational costs (Table 4.) were estimated based on the budget of mass flow, fixed costs were derived from the literature and rescaled to the planned size of the installation using to this aim factors found in the literature. The operational costs taken for the analysis were divided into two groups: variable and constant operational costs. The variable operational costs include the costs of raw materials and consumables, such as energy, water, etc. Fixed operational costs are the costs of labour, maintenance and insurance. Certain costs connected, for example, with the purchase of chemical preparations for cleaning were omitted, and fixed operational costs were rescaled according to the Nrel 2011 report [16], while the consumption of electric power was determined according to the power of the equipment pieces and their working time.

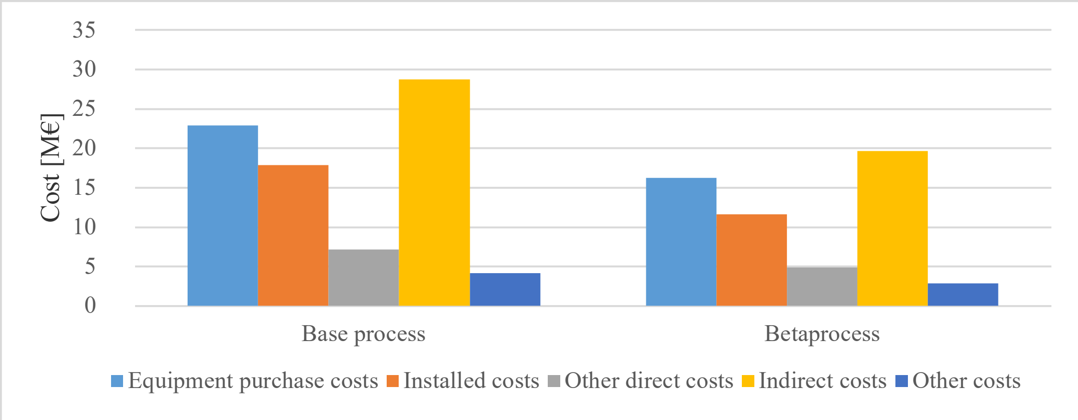

Figure 8. Total capital investment CAPEX.

Table 4. Operational costs [based on 10].

Assumption [year]	Base process			Betaprocess		
variable operational costs						
Raw materials	ammount [t]	cost/unit [€]	cost [€/year]	ammount [t]	cost/unit [€]	cost [€/year]
Sugar beets	600 000	30	18 000 000	600 000	30	18 000 000
Yeast	20 032	1.9	38 060	28 680	1.9	54 492
Nutrients	3 940	1	3 940	5 136	1	5 136
Total [€/year]			18 042 000			18 059 628
Utilities	ammount	cost/unit [€]	cost [€/year]	ammount	cost/unit [€]	cost [€/year]
Transport	600 000	4.5	2 700 000	600 000	4.5	2 700 000
Natural gas	22 889 906	0.15	3 433 486	11 690 012	0.15	1 753 502
Electricity	3 768 843	0.10	376 884	4 563 915	0.10	456 392
Process water	433 665	0.02	8 673	179 348	0.02	3 587
Cooling water	7 107 761	0.02	142 155	6 515 296	0.02	130 306
Total €/year]			6 661 199			5 043 786
Fixed Operating Costs						
position	personnel	cost	cost [€/year]	personnel	cost	cost [€/year]
General manager	1	128 828	156 740	1	128 828	156 740
Plant engineer	1	61 347	74 638	1	61 347	74 638
Maintenance supervisor	1	49 954	60 777	1	49 954	60 777
Maintenance technician	7	35 055	298 552	7	35 055	298 552
Shift supervisor	2	42 067	102 362	2	42 067	102 362
Operators	12	35 055	511 803	12	35 055	511 803
Yard employees	2	24 539	59 712	2	24 539	59 712
Clerks and secretaries	2	31 550	76 771	2	31 550	76 771
Total salaries			1 341 356			1 341 356
Labor burden (90%)	28	90%	1 207 220	28	90%	1 207 220
Suma [€/rok]			2 548 576			2 548 576

Other overhead						
Maintenance	3%	INEC	1 222 131	3%	INEC	835 621
Property insurance	0.70%	TCI	565 323	0.70%	TCI	386 534
Total [€/year]			1 787 454			1 222 154
OPEX			29 039 229			26 874 144

The technological process generates the main product, which is ethanol, and two by-products of marketable value, such as animal feed and CO_2. The unit prices for the products and sale values are set in table 5. The average profitability threshold was different for the both variants, much higher for the conventional process than for the one including BetaProcess®.

Table 5. Structure of revenues and profitability threshold for each installation. [based on 10].

Assumption [year]	Base process				Betaprocess			
Product	amount	unit /year	price/unit [€]	Income [€/rok]	amount	unit/ year	price/unit [€]	Income [€/rok]
Ethanol	55 690	m3	500	27 844 791	56 917	m3	500	28 458 599
Animal feed	63 766	t	100	6 376 600	62 180	t	100	6 218 002
CO2	42 411	t	50	2 120 570	43 277	t	50	2 163 847
Total [€/rok]				36 341 961				36 840 448
Break-even-point								
BEP	amount	Unit /year	price/unit [€]	Income [€/rok]	amount	unit/ year	price/unit [€]	Income [€/rok]
Etanol	40 877	m3	500	20 438 380	26 569	m3	500	13 284 625
Animal feed	9 025	t	100	902 474	5 866	t	100	586 594
CO2	3 185	t	50	159 260	2 070	t	50	103 517
Total [€/rok]				21 500 114				13 974 736

The annual revenue in both analysed cases was similar, but the profitability of the installation with BetaProcess® arose from much lower investment costs and slightly lower operational costs.

The analysis was carried out for a 20-year period, in which two years were allocated to the investment process, while the remaining 18 years were devoted to production, the discount rate adopted for the analysis was 6%. The base process is profitable at the internal return rate of 4% (Table 6.).

Table 6. Economic profitability indicators

Indicators	Base process	Betaprocess
CAPEX [€]	80 760 373	55 219 117
Income [€/year]	36 341 961	36 840 448
OPEX [€/year]	29 039 229	26 874 144
Revenue [€/year]	7 302 732	9 966 303
NPV	-9 293 951	30 454 017
IRR	4%	13%

The discounted period of return for the installation producing ethanol with the inclusion of BetaProcess® is about 10 years (figure 9). The assumptions made by DSD resulted in the ethanol production in a conventional installation being unprofitable.

The analysis of life cycle costs confirmed that the decrease in the costs in an installation equipped with BetaProcess® relative to the base process is the element which built the economic advantage of this solution (figure 10).

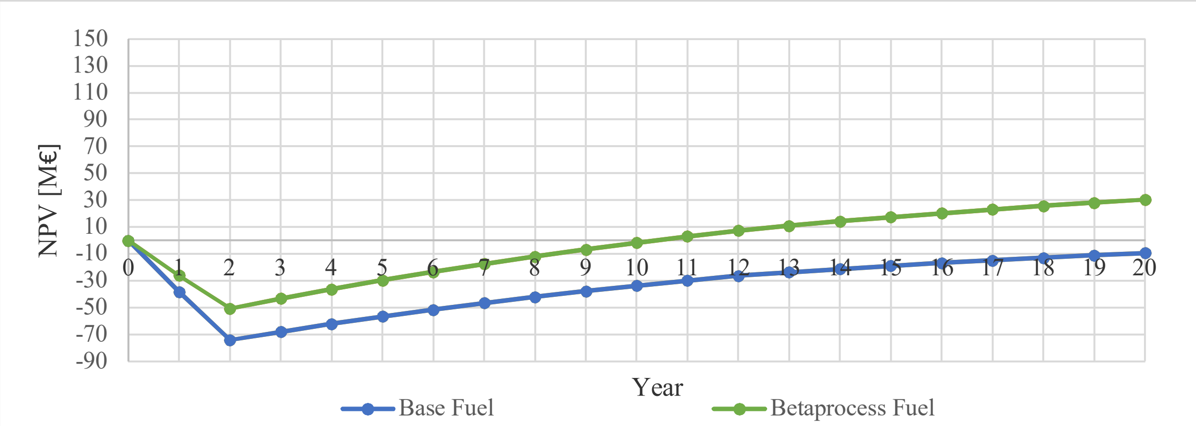

Figure 9. Discounted pay-back period.

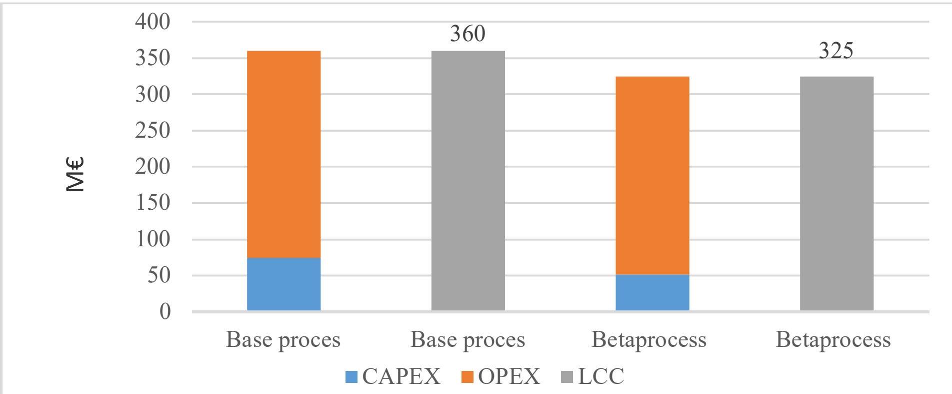

Figure 10. Life cycle cost in the period of 20 years.

3.3. *Legal regulations*

3.3.1. Production of bioethanol in the light of the Act on Biocomponents and Liquid Biofuels. The legal ground for producing bioethanol for energy purposes in the territory of the Republic of Poland is the Act of 25 August 2006 on Biocomponents and Liquid Biofuels (hereinafter referred to as: *ubib*) [17], which is an implementation into the Polish law of the provisions contained in the Renewable Energy Directive of the European Parliament and of the European Council, 2009/28/EC, of 23 April 2009, which amends and consequently repeals the directives 2001/77/EC and 2003/30/EC [18].

Firstly, it is worth clarifying certain legal nuance found in the title of this article. The authors use the term 'ethanol' although in legal terms (compliant with *ubib*), the prefix 'bio' should be added when ethanol is produced from sugar beet roots processed for fuel purposes. The reason why the term 'ethanol' is used throughout this paper is the multidisciplinary nature of this research, which encompasses both social and – to a significant measure - chemical sciences. The latter do not distinguish bioethanol as a substance chemically different from ethanol, and therefore the authors decided to use the original name, although the term 'bioethanol' appears in the paper whenever dictated by ubib.

In the light of *ubib*, bioethanol can be classified as a biocomponent (Article 2, paragraph 1 point 3 of *ubib*), and as a liquid fuel (Article 2, paragraph 1, point 11 of *ubib*). Pursuant to Article 2, paragraph 2, point 4 of *ubib*, bioethanol is defined as „ethyl alcohol produced from biomass, including bioethanol contained in ethyl-tert-butyl ether or in ethyl-tert-amyl ether; the biomass for production of ethyl excludes ethyl alcohol containing over 96% v/v alcohol." It is worth noticing that the legislator agreed to classify bioethanol as a biocomponent or a liquid biofuel subject to specific stipulations. Regarding the biocomponent classification, bioethanol must be used to make liquid fuels or liquid biofuels. In the latter case, bioethanol itself serves as a fuel. In other words, the *ubib* provisions do not apply to substances which, while formally speaking have the same chemical composition, will serve other uses, e.g. in the food industry. The definition of bioethanol given in *ubib* is amended in the Regulation of the Minister of Economy of 17 December 2010, on quality requirements for biocomponents, quality testing, and sampling methods of biocomponents [19], where the technical parameters of bioethanol are determined. Compliant with the appendix to the above regulation, for a given substance to be qualified as bioethanol the following criteria must be satisfied: the maximum content of ethanol and higher alcohols of 98.7%, the maximum content of higher alcohols 2%, the maximum content of methanol 1%, the maximum content of water 0.300 %, the maximum content of inorganic chlorides 20.0 mg/l, the maximum content of copper 0.100 mg/kg, the maximum content of acids expressed as acetic acid 0.005%; visually transparent, free of impurities; the maximum content of phosphorus 50 mg/l; the maximum content of non-volatile substances 10 mg/100ml; the maximum content of sulphur 10.0 mg/kg.

Conducting a business enterprise in the field of producing, storing or trading biocomponents is an activity regulated within the meaning of the provisions of the Act on Freedom of Economic activity [20] and must be entered (following a written application submitted by the producer) into the register of manufacturers, which is maintained and made available by the President of the Agricultural Market Agency. Compliant with Article 5 of *ubib*, an entry in the register requires cumulative fulfilment of the following conditions on behalf of an applicant:

- holding a legal title to the buildings and premises where the economic activity will be conducted (e.g. right of property, but also a rent or lease contract);
- having at disposal adequate technical equipment and buildings which satisfy the requirements as specified by relevant regulations, particularly fire protection, sanitary safety and environmental protection regulations, which enable the applicant to undertake the planned economic activity;
- having a license to operate a tax warehouse (as this commodity is excise levied).

Concurrently, a negative consideration in terms of conducting a business activity in the scope of producing biocomponents and subsequently their sale or disposal, or their use to produce liquid fuels of liquid biofuels by the producer is the applicant's previous conviction for a fiscal offence, or an offence against property, credibility of documents, tax fraud, as well as against the turnover of money and securities valuable papers or against economic circulation, and - with respect to a producer who is a legal person or an organisational entity not being a legal person to which the Act grants legal capacity – it is mandatory that members of the board or authorised representatives, respectively, have not been convicted for any of the aforementioned crimes.

It must be added that bioethanol production carried out by a professional bioethanol producer (including farmers) is subjected to checks pursuant to the Act of 25 August 2006 on the fuel quality monitoring and control [21]. Provisions of this act set forth the foundations of the organisation and management of a system established to monitor and control quality of fuels to be used: 1) in agricultural vehicles, tractors and in machines not moving on roads, 2) in installations for combustion to generate energy and in inland water vessels, 3) in selected fleets, 4) by farmers for own use – in order to control the adverse impact of fuels on the environment and on human health. Specific technical parameters that substantiate the classification of given substance as bioethanol were regulated in executive laws, i.e. in the aforementioned regulation on quality requirements for biofuels, methods for quality checks of biocomponents and for sampling biocomponents and in the Regulation of the Minister of Economy of 22 January 2007 on quality requirements for liquid biofuels used in selected fleets and produced by farmers for own use [22].

What is significant in the adopted legal regulations is the fact that the legislator implemented a simplified procedure for production of liquid biofuels provided that they be made for own purposes and the annual production volume limit should not be higher than an equivalent in net calorific value of 100 liters of diesel oil assigned the code CN 2710 19 43 per 1 ha of agricultural land possessed by a farmer as of 1 January of the year for which the limit is set (Article 21, paragraph 3 of *ubib*). Pursuant to Article 6, point 1 of the Act of 20 December 1990 of social insurance of farmers [23], a farmer is a natural person of full legal age, residing and conducting economic activity within the territory of the Republic of Poland, carrying out personally and for own account farming activities in the farm he owns, also covering activities within a group of agricultural producers and persons who allocated their farmland for afforestation.

The legislator's intention underlying the above regulation was to create a possibility for farmers or groups of farmers to produce liquid biofuels on a small scale, often from raw materials grown on their farms. Concurrently, as already mentioned, unlike regarding professional fuel manufacturers, the right to apply simplified procedures has been restricted to cases of producing biofuels by farmers to be used for own purposes. This means that such biofuels must not be placed on the market, for example through sale to another farmer, transportation company, owner of a petrol station, etc. or in any other way that would substantiate the classification of a given event as an economic activity within the meaning of the Act on Freedom of Economic Activity. Worth noticing is the fact that in the light of the binding regulations farmers are not allowed to produce mixtures with diesel oil or petrol [24].

The major formal condition for farmers to start biofuel production is to apply for an entry into the 'register of farmers', which is held (similarly to the case of professional biofuel manufacturers) by the President of the Agricultural Property Agency. Making an entry constitutes a technical-material action, contrary to a refusal to make an entry or a deletion of an entry from the register, which is an administrative decision.

Moreover, an applicant must fulfil similar conditions as set for biocomponent manufacturers, *albeit* less rigorous ones, i.e.:

- having at disposal adequate technical equipment and buildings, which satisfy requirements as specified by relevant regulations, particularly fire protection, sanitary safety and environmental protection regulations, which enable the applicant to produce liquid biofuels;
- having a license to operate a tax warehouse.

In this context, it is worth mentioning that the obligation to operate a tax warehouse by professional bioethanol manufacturers raises no doubt, whereas the same obligation relating to farmers may lead to a certain measure of confusion. Principally, pursuant to Article 63, paragraph 1, of the Act on Excise Duty [25], entities which operate tax warehouses are obliged to provide excise guarantee (e.g. a cash deposit, a bank guarantee). The amount of the guarantee is determined as the amount equal to the maximum amount of the monthly tax liability which may arise if excise goods are not used according to their intended use entitling to the excise exemption or if the conditions of that exemption have been violated (Article 65, paragraph 3 of the Act on excise duty). Although the competent director of the tax office can exempt a farmer, upon the farmer's written request and having fulfilled specific conditions, from the obligation to provide excise guarantee (Article 64 (1) of the Act of Excise Duty), the legal regulation of this matter as presented above can be a barrier to making a decision about bioethanol production, especially as applying for a license to keep a tax warehouse (issued by the competent director of the tax office) involves other requirements. Suffice to mention the obligation to provide adequate technical infrastructure, i.e. having at disposal adequate machinery, fuel tanks, fenced premises, or the obligation to fulfil specific formal requirements, for example presenting a written regulation of the operation of a tax warehouse, or ensuring that a tax warehouse be properly marked, to claim that the discussed legal solution may prove to be excessively rigorous to entities which do no conduct economic activities in a professional manner.

Finally, it is worth mentioning that provisions for lowered excise rates for engine fuels with a share of biocomponents or for biocomponents serving as fuels to power combustion engines were repealed in 2011. These regulations were a contribution to the biocomponent support system, alongside the general mechanism established in *ubib* and termed as the National Index Target (hereinafter the NIT), which presumes that the share of biocomponents on the domestic transport fuel market will reach 10% in 2020 (from 5.75% in 2010) [26]. This system is based on the minimum share of biocomponents and other renewable fuels consumed by all types of transportation media, in the total amount of liquid fuels and liquid biofuels consumed in an entire calendar year in road and railroad carriage, calculated in terms of the net calorific value (Article 2, paragraph 1, point 24 of *ubib*). However, proposed changes expressed in the *ubib* draft amendment of 31 August 2016 (version 1.1) may raise worries, as the NIT is decreased nominally to 8.5% in 2020 and the road map to the achievement of the set level is changed, that is the target is no longer equated with the contribution of biocomponents and biofuels. Despite the ongoing legislative work on the act, the final version of which may yet change, the currently suggested changes, proposed the government, may be seen as a significant signal implicating the legislator’s policy regarding this branch of economy. This is particularly relevant in the view of the fact that after the expiry of the Long-Term Programme for the Promotion of Biofuels and Other Renewable Fuels for 2008-2014 (M.P. of 2007 No 53, item 607), the Council of Ministers has not yet adopted a new document that will define the strategy of the development of biocomponents and biofuels. This situation, especially from the standpoint of a businessman, does not promote investment security.

3.3.2. Legal aspects relating to bioethanol production. One of the by-products generated during the production of bioethanol is feed, which can be used as a feed supply for farm animals. However, for this product to be legally placed on the market, several quality requirements and control checks must be met. In this case, the legal ground consists of the Regulation 2009/767/EC of the European Parliament and of the European Council (EC) on the placing on the market and use of feed [27], the Regulation 2003/1334/EC of the Commission (EC) regulating maximum amounts of in-feed added trace elements [28], and the Regulation 2004/882/EC of the European Parliament and the European Council (EC), regulating official checks of food and feeds [29].

Feed quality checks comprise mainly tests of all basic nutrients, calorific value of feed mixes, feed additives, unwanted substances and impurities (live pests, botanical contaminants, fluorine, nitrates) as well as proper use and marking of feeds containing biologically modified ingredients. Checks of commercial quality serve to verify the conformity between the actual composition of feed with the one declared by the manufacturer on the label, and to ensure that other requirements are met, such as not exceeding maximum concentrations of feed additives in feed mixes or absence of unwanted plant substances in feeds.

Another by-product of bioethanol production is carbon dioxide, CO_2, which can be used, for example, in the food processing industry as an agent accelerating the ripening of greenhouse plants. Although practically there are no specific legal provisions that would regulate this issue in a complex manner, it should be mentioned that the legislator provides norms regarding the transport of CO_2 (via provisions regulating transport of hazardous substances). In this case, the basic legal regulations arise from the international law. The solutions that ought to be mentioned here are: the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), signed in Geneva on 30 September 1957 (Accord européen relatif au transport international des marchandises dangereuses) and ratified by Poland in 1975, the Regulation of the Ministers of Transportation and of Internal Affairs of 2 December 1983, concerning conditions and checks of road transport of dangerous materials [30]. Secondly, with regard to railroad transport, the binding legal act is the Regulation concerning the International Carriage of Dangerous Goods by Rail (RID - Reglement concernant le transport international ferroviaire des marchandises dangereuses), which is Annex I to the the Uniform Rules concerning the Contract for International Carriage of Goods by Rail (CIM), which forms Appendix B to the Convention concerning International Carriage by Rail (COTIF) of 9 May 1980. This convention was ratified by Poland by the Act of 18 October 1984, and made effective by the Ordinance of the Minister of Transportation of 6 October 1987. Finally, it should be mentioned that identical regulations regulate the transport of dangerous goods by sea: IMDG - International Maritime Dangerous Goods Code, and by air: IATA-DGR, and they are the binding law in states which belong, respectively, to the International Maritime Organisation and to the International International Air Transport Association (IATA).

4. Summary

The process and economic analyzes carried out in the paper show that the direct production of ethanol from sugar beet using Betaprocess pretreatment simplifies the production technology. This results in lower investment costs, especially at the stage of construction of the manufacturing infrastructure. This significantly reduces discounted pay-back period and allows the NPV to reach 30 M€. From an economic point of view, the use of Betaprocess technology in the production of ethanol for fuel purposes can foster the development of small and medium-sized enterprises by reducing barriers to entry. The analysis of operating costs has identified a significant reduction in production costs for the consumption of natural gas used in the production of steam from 3.5 M€ to 1.7 M€. In addition, the use of biogas from post-production residues instead of natural gas can reduce operating costs and reduce GHG emissions (a question not analyzed numerically in this paper).

The fact that after the expiry of the "Multi-Year Program for the Promotion of Biofuels or Other Renewable Fuels for the Years 2008 - 2014" (MP No. 53, item 607) is an important argument in the decision-making process regarding investment in direct sugar beet processing. This situation, especially from the perspective of entrepreneurs, is not conducive to the development of this type of investment. This means that, in the absence of predictable and stable support instruments, running a business in the field of biofuel production, including the use of this technology is risky.

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