Greenhouse gasses (CO_2, N_2O and CH_4) emission levels of for wheat, triticale, maize and rye cultivated for the production of bio-ethanol

and rape cultivated for bio-diesel

Warsaw, October 2011

Contents

1. Introduction

Pursuant to Article 17 of Directive 2009/28/EC of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources, all those participating in bio-fuel production cycle are obliged to fulfil sustainable development criteria, of which the most important is a requirement to reduce greenhouse gas emissions (GHG) within a full cycle of bio-fuels and bio-liquids' production. The reduction should not be less than 35% (as of 1 April 2013 for installations operating as at 23 January 2008), 50% in 2017 and 60% in 2018 (for installations which shall have started operation after 1 January 2017).

Annex V to Directive 2009/28/EC provides for default values of GHG emissions as a result of the production within the EU of agricultural raw materials intended for fuels. According to the Directive concerned, default values of GHG emissions may be applied if raw materials for bio-fuels or bio-liquids' production were grown on areas, for which a normal level of agricultural production related GHG emissions does not exceed the emission level defined under 'Disaggregated default values for cultivation' in Part D of Annex V to the Directive.

Pursuant to Article 19 (2) of Directive 2009/28/EC:

> *"By 31 March 2010, Member States shall submit to the Commission a report including a list of those areas on their territory classified as level 2 in the nomenclature of territorial units for statistics (NUTS) or as a more disaggregated NUTS level in accordance with Regulation (EC) No 1059/2003 of the European Parliament and of the Council of 26 May 2003 on the establishment of a common classification of territorial units for statistics (NUTS)(1) OJ L 154, 21.6.2003, p. 1. where the typical greenhouse gas emissions from cultivation of agricultural raw materials can be expected to be lower than or equal to the emissions reported under the heading 'Disaggregated default values for cultivation' in part D of Annex V to this Directive, accompanied by a description of the method and data used to establish that list. That method shall take into account soil characteristics, climate and expected raw material yields."*

Estimation of emissions was performed to estimate, by using a methodology provided for in Directive 2009/28/EC, GHG emissions (CO_2, N_2O and CH_4), expressed in grams of CO_2 equivalent per MJ of fuel, which are produced during the cultivation of wheat, triticale, maize and rye intended for bio-ethanol and the cultivation of rape for bio-diesel, and then to define average amounts of agricultural emissions for those crops against voivodships (NUTS 2) and to compare them with the default values of agricultural emissions, which are provided in the Directive, in order to determine the voivodships, in which emissions are lower than the default values.

The calculation also accounts for agricultural emissions resulting from the cultivation of rye and triticale. The Directive does not account for these crops, although they may be used for bio-ethanol production, provided that real emissions' estimates are made for all the crops' suppliers on case by case basis . If, however, emissions related with these crops proved to be sufficiently low, it would be possible to initiate a legislative procedure to amend the Directive so that it includes default emission values also for rye and triticale. If this happened, they could be treated in the same way as wheat and maize. Thus, the aim of analysis concerning rye and triticale was to define in advance whether it is really possible to produce bio-ethanol from these crops in a sustainable way. Such research is conducted in certain Member States (e.g. in Germany as far as triticale and barley are concerned).

2. Summary of research results

By virtue of Directive 2009/28/EC Poland is obliged to indicate voivodships (NUTS2), in which normal level of GHG emissions, resulting from agricultural crops production, may be lower than the level stipulated under the heading: “Disaggregated default values for cultivation” in Annex V Part D to the Directive.

The calculation was aimed at estimating, by applying the methodology provided for in the Directive, agricultural emission volumes of greenhouse gasses (CO2, N2O, CH4), expressed in grams of CO_2 equivalent per MJ of bio-fuel, which are produced in agricultural holdings during the cultivation process of wheat and maize intended for bio-ethanol and the production of rape for bio-diesel, followed by definition of average values of agricultural emissions for these crops against voivodships (NUTS2) and indication in which of them emissions are lower than the standard ones provided for in the Directive.

The analysis included farms producing or capable of producing raw materials for the goals concerned. The farms were selected at random so that the populations analyzed (which for winter wheat, maize and rape equalled 297, 275 and 1217 farms respectively) correspond approximately to a sample of 3% of the total of farms producing raw materials intended for the goals concerned. The number of farms in particular voivodships reflects a share of crops under analysis in the overall crop structure. The farms produced their crops on various types of soils and in various weather conditions between 2005-2010, with the exclusion of farms exposed to extreme weather conditions.

Estimations were made by means of Biograce calculation tool (version 4 public), in which only the volumes of GHG emissions related with the production of nitrogen fertilizers were changed, because it was established, based on the data collected from all the Polish producers of the fertilizers, that the volumes of these emissions are lower in Poland than the average values adopted for the EU. In the case of wheat and maize the adopted value of emissions as a result of fertilizers production was 3414,2 N, and in the case of rape it was 3253,2 g CO_2 eq/kg N.

Comparisons of the estimations obtained and default agricultural emission values of GHG, together with a list of voivodships, in which the estimated emission levels are lower than the defaults values are provided for in Tables A and B.

Table A. Comparison of obtained estimates of agricultural emissions of GHG with default emission values provided for in Directive 2009/28/EC (g eq CO_2 MJ^{-1} of bio-fuel)

Voivodship	Wheat		Maize		Rape	
	Estimate	Standard*	Estimate	Standard*	Estimate	Standard*
Dolnośląskie	**22.69**	23	**19.20**	20	24.60	29
Kujawsko-Pomorskie	**22.97**	23	**19.82**	20	25.5	29
Lubelskie	**22.47**	23	**19.36**	20	**24.65**	29
Lubuskie	**22.20**	23	**19.24**	20	**22.19**	29
Łódzkie	**20.84**	23	**19.51**	20	**24.40**	29
Małopolskie	**22.51**	23	**19.13**	20	**25.43**	29
Mazowieckie	**22.77**	23	**18.59**	20	**24.0**	29
Opolskie	**22.69**	23	**19.65**	20	**25.79**	29
Podkarpackie	**19.80**	23	**18.61**	20	**21.32**	29
Podlaskie	**22.33**	23	*(19.57)*	20	**28.25**	29
Pomorskie	**22.80**	23	*(25.47)*	20	**26.56**	29
Śląskie	**22.75**	23	**19.87**	20	**25.54**	29
Świętokrzyskie	**21.59**	23	*(20.55)*	20	**24.08**	29
Warmińsko-Mazurskie	**22.84**	23	*(27.17)*	20	**24.02**	29
Wielkopolskie	**22.05**	23	**17.94**	20	**21.79**	29
Zachodnio-Pomorskie	**22.83**	23	*(24.88)*	20	**23.74**	29

*default emission values

Table B. Voivodships with normal levels of agricultural emissions, lower (X) than default emission values provided for in Directive 2009/28/EC

Voivodship	Crop		
	Wheat	Maize	Rape
Dolnośląskie	X	X	X
Kujawsko-Pomorskie	X	X	X
Lubelskie	X	X	X
Lubuskie	X	X	X
Łódzkie	X	X	X
Małopolskie	X	X	X
Mazowieckie	X	X	X
Opolskie	X	X	X
Podkarpackie	X	X	X
Podlaskie	X		X
Pomorskie	X		X
Śląskie	X	X	X
Świętokrzyskie	x		X
Warmińsko-Mazurskie			X
Wielkopolskie	X	X	X
Zachodnio-pomorskie	X		X

3. Measurable prospective economic effects on the bio-fuel sector

An innovation applied in the calculations involved taking account, for the purpose of agricultural emission estimations, of real emission values which result from the production of nitrogen fertilizers in Poland. This enabled to lower the value which is approved in the UE as a standard (default value), namely 5880,6 CO_2 eq $kg^{-1}N$, to 3253,2 CO_2 eq kg^{-1} N for rape and to 3414,2 CO_2 eq $kg^{-1}N$ for wheat and maize.

4. Materials and methodology

Farms were selected for research at random. The size of sample was established at the level of 3% of the number of farms which produce or are capable of producing raw materials intended for bio-fuels. The crops cultivated in these farms were produced on various types soils and in various weather conditions between 2005-2010, with the exception of extreme conditions (especially farms located on areas exposed to floods and seeping groundwater in 2010).

4.1 Characteristics of weather conditions and soils and the contents of organic coal in the arable layer of soil in farms selected for research

Weather conditions

2005

Sowing winter grains in autumn 2004 and spring crops in spring 2005 took place in general in not advantageous weather conditions. Late coming spring and variable degree of soil moistening as well as quite low temperatures in April adversely affected germination and growing of spring cereals, and were unfavourable for winter grains vegetation. Low level of soil moistening which persisted since mid June, especially in lighter soils, i.e. in the regions of central, north-eastern and eastern Poland adversely affected the yields.

2006

The sowing of winter grains in autumn 2005 and spring grains in the spring of 2006 was performed in generally unfavourable weather conditions. Lack of sufficient soil moistening in autumn 2005 delayed sowing, germination and further development of winter grains; however, long and warm autumn, despite significant increase of soil moistening level, enabled good growth of winter grains before the crops entered the stage of winter hibernation. Weather conditions in winter 2005/6 were in general favourable for winter grains. Only 1.9% of the area sowed with winter grains was ploughed as a result of winter damage, and the condition of winter grains at the beginning of vegetation – in spring 2006 – was good. Variable level of soil moistening and low temperatures in spring delayed sowing and germination of spring grains. Improvement of agro meteorological conditions in May had favourable impact on crops, however, soil draught escalating from the third decade of June and a prolonged period of high temperatures and strong insolation resulted in poor grain filling, shortened period of vegetation and accelerated harvesting season. Heavy rainfalls in August made harvest difficult and depreciated the quality of grains harvested, along with further yield decline.

2007

Sowing of winter grains in the autumn of 2006 was conducted in quite unfavourable agro meteorological conditions. Due to warm, sunny and dry September, insufficient soil moistening was observed, especially in respect of light soils, which constrained sowing and germination of winter grains. Warm and sunny October with rainfalls below multiannual average had unfavourable effect on soil moistening. In that month winter grains sprouting was observed all around Poland; where the ground was dry - sprouting was slow. Cold November weather, together with snowfalls and sleet stopped the living processes of plants only for a short while. High temperatures noted in the second and third decade of November and good moistening of soils influenced longer vegetation. Winter grains grew and tillered properly before winter. Agro meteorological conditions in the winter of 2006/07 were overall favourable to winter grains. Only 0.3/5 of the area sown with winter grains was ploughed or intended for ploughing as a result of winter damage, and the condition of winter grains at the beginning of vegetation – in spring 2007, was estimated as good (evaluations for all winter crop varieties were higher than in the previous years).

Vegetation was resumed very early in spring 2007 – in the western part of Poland in the first decade of March, and in the remaining area – in the second decade of that month. Sowing and planting crops started more than 2 weeks earlier than in the average years, which allowed for longer vegetation, which is so favourable for crops. Temporary periods of soil dryness at the turn of April and May adversely affected the crops, especially spring ones. Rains, cold and wind which dominated the weather since half May until the first decade of June improved soil moistening, however triggered sudden outbreaks of fungi diseases and the appearance of pests. Intensive rainfalls in numerous regions of Poland during harvest resulted in lodging of crops, which delayed the use of agricultural machinery and made it difficult to operate it in the fields, as well and deteriorated the quality of harvested grains.

2008

Sowing of winter grains in autumn 2007 was conducted in generally favourable agro meteorological conditions. Soil moistening facilitated fast germination and growth. October featured small amount of rainfalls and was quite cool. Significant temperature drop in the second decade of the month slowed down the plant living processes. The first half of November was generally warm and moist, it was only in the second half of November that the temperatures dropped significantly, with ground frost and sleet or snowfalls. The plants slowly entered the state of winter hibernation. At the final growth stage the winter grains were well grown – those sowed in September tillered properly, and those sowed in October had 2-3 leaves. Agro meteorological conditions in winter 2007/08 were in general favourable for winter grains. Big temperature drops lasted for a short time only and did not damage the winter grains. Vegetation started early in spring 2008. Increase of air and soil temperature at the end of February triggered physiological plant processes all around Poland. Warm and sunny weather in the first and second decade of March made it possible to start sowing spring crops, which was continued in April (following a short break in the third decade of March when winter came back). A persistent lack of rain starting from the end of May and in June accompanied by intensive sun and high temperatures resulted in the topsoil becoming dry, especially in north-western and central Poland. Poor soil moistening in those regions resulted in deterioration of the crops – specially spring grains. Inflorescence emergence of spring grains was rather poor, spikelets were small or poorly packed. Intensive rainfalls occurring in July and August improved soil moistening, which contributed to significant weight increase of winter grains, but it did not had a significant impact on the improvement of the condition of spring crops. Harvesting was difficult due to recurrent rainfalls, also storms, often accompanied by strong winds. Harvesting season was delayed in numerous regions of Poland.

2009

Temperature and moisture conditions in late summer and early autumn 2008, i.e. in winter crop sowing season , were variable, however they were mostly favourable for plant germination, growth and development. Sowing winter grains was commonly done in September. Frequent and in some regions – heavy rainfalls – facilitated fast germination and growth of winter grains. Crops sowed in September started to tiller at the end of October, and those sowed in October sprouted gradually. High air and soil temperatures in the first and second decade of November provided for good conditions for further growth and development of winter grains. Noted temperature drops in the third decade of December and the first decade of January, as well as in the third decade of February did not cause significant damage to the winter grains. The weather in March was also favourable. In the third decade of the month vegetation of winter grains started in the western part of Poland. At the end of the month first field works started, and locally in the west oats was sowed. Spring grains were sowed commonly in the first days of April and the work was completed in the third decade of the month. Sprouting of early sowed spring grains, in good moisture and temperature conditions, followed quickly; spring grains sowed later, when agro meteorological conditions worsened, were late and not parallel. Insufficient soil moistening all around Poland since a half of April hampered spring grains from sprouting and developing and depreciated the quality of winter grains. In the second decade of April, and in a vast area of Poland – in the third decade, winter rye and triticale, and sometime later winter wheat entered the stem elongation stage. Winter grains in the second and third decade of May entered inflorescence emergence stage, and at the end of the month they started to flower on a prevailing area of Poland. The inflow of cool air in the first half of June contributed to temporary slow-down of the crops' growth and development, however rainfalls occurring in the third decade of May and in June improved soil moistening. Frequent and recurring heavy rainfalls, especially on heavier soils, caused over moistening in some regions, which resulted in unfavourable phenomena, such as the spread of fungi diseases (while the effectiveness of fighting the diseases declined) and cereal lodging.

2010

The productivity of winter grains was adversely influenced by: weather conditions in winter (as a result of winter damage over 5% of winter crop areas were ploughed); fat snow cover lying until the beginning of March, which protected plants against freezing, but resulted in worse access of oxygen to the soil at the same time; cold and moist in May, which resulted in delays in sowing spring crops and local floods and groundwater seeping incidents. Yields were also decreased by low level of application of mineral fertilizers and plant protection measures as well as poor effectiveness of herbicides due to recurrent rainfalls.

The above review of agro meteorological conditions shows that material subject to analysis originated from the years which featured quite broad variability, which may be deemed typical of

Poland. However, weather conditions prevailing in 2010 in numerous voivodships were extremely unfavourable for plants, especially cereals. This resulted in the exclusion of farms on flooded areas and those where groundwater seeping incidents occurred from the analysis. Exclusion applied also to those farms where crops did not persevere over the snowy winter. As a consequence, the number of questionnaires for wheat and maize was in some voivodships fewer than the required number of 20 .

Soil condition

Cultivations under analysis followed on all agronomic categories of soils (Table 1), and in the case of winter wheat and winter rape sometimes even on very light soils, which otherwise exclude such cultivations.

Table 1. Percentage share of plant production technologies under analysis against soil category

Crop	Soil category			
	Very light	Light	Medium	Heavy
Wheat	11	31	35	22
Maize	17	28	34	2
Triticale	27	32	31	9
Rye	38	38	19	5
Rape	11	31	35	22

Contents of organic carbon in arable layer of soils

The contents of organic carbon in arable layer of soils, on which cultivations under analysis were performed, exceeded slightly the average contents of carbon for particular soil categories, as a rule. This proves good soil culture.

Soils cultivated with wheat and rape featured significantly varied contents of organic carbon statistically in the first three soil categories (Table 2). The contents of organic carbon in heavy soils was bigger than in light soils, but the same as in the case of medium soils.

The contents of organic carbon in light soils cultivated with maize was significantly smaller than in medium and heavy soils (Table 3). However, the differences within light medium and heavy soil categories were not proven statistically.

Table 2. Average contents of organic carbon in arable layer of soils cultivated with wheat and rape.

Soil category	Number of samples	Average contents of C org (%)	Difference significance
Very light	64	1.25	X
Light	27	1.29	X
Medium	67	1.55	XX
Heavy	37	1.6	X

*x in the same column means no significant statistical differences in C-org contents

Table 3. Average contents of organic carbon in arable layer of soils cultivated with maize

Soil category	Number of samples	Average contents of C org (%)	Difference significance
Very light	22	1.00	X
Light	37	1.24	X
Medium	44	1.69	X
Heavy	27	1.88	X

The contents of organic carbon in soils cultivated with triticale were also significantly different (Table 4). They did not differ significantly within the categories of very light and medium soils and from light to heavy ones.

Table 4. Average contents of organic carbon in arable layer of soils cultivated with triticale

Soil category	Number of samples	Average contents of C org (%)	Difference significance
Very light	54	1.25	X
Light	64	1.35	XX
Medium	17	1.74	XX
Heavy	62	1.79	X

Contents of organic carbon in soils cultivated with rye did not differ from those determined in other crops, with one difference, however, that they did not differ significantly from statistical point of view in particular categories of soils (Table 5). A vast variability of carbon contents in the soils could indicate the deterioration of their culture.

Table 5. Average contents of organic carbon in arable layer of soils cultivated with rye

Soil category	Number of samples	Average contents of C org (%)	Difference significance
Very light	83	1.15	X
Light	40	1.30	X
Medium	82	1.35	X
Heavy	10	1.68	X

Dependence of yields on fertilization and soil condition

The relationship between yields and the applied dose of nitrogen fertilization, contents of organic carbon in arable layer of soil (C-org) and pH of that layer were analysed with a method of multiple regression analysis. Factors which had significant impact on yields have been shown in Table 6.

Table. 6. Factors which have significant impact (x) on yields in farms covered with production technology inventory

Crop	Factor		
	N dosage	C-org	pH
Wheat	X		X
Maize	X		
Triticale	X		X
Rye			
Rape	x		X

The yield was influenced by a dosage of fertilization with nitrogen, except rye. Yields grew when the dosage of nitrogen grew. In the case of wheat, triticale and rape yields grew also when pH grew. No significant dependencies between yields and carbon contents in soil were observed.

4.2 Emission estimates made based on questionnaire analysis conducted on farms

Data to estimate emissions originated partially from the inventory of production technology of crops under analysis, which was conducted in 2010 based on a special questionnaire prepared by IUNG-PIB (Annex 5.6). Farms subject to questionnaire inventory were selected at random from a data base of over 14000 farms, which are included in FADN kept by the Institute of Agricultural and Food Economy (IERiGŻ). These farms are covered also with a broad range of advisory services conducted by Agricultural Advisory Centres (ODRs) and systematic supervision in terms of applying good agricultural practice. Farms selection criteria included: fulfilment of all necessary conditions for receiving area payments, proper crop rotation including energy crops, sufficient amount of production and economic viability of a farm. FADN data base was reviewed and random selection of farms was done by IERiGŻ.

All selected farms were visited by trained ODR experts who, by means of direct interview with a producer and based on accountancy records, prepared questionnaires on crop production inventory. Filled-in questionnaires were filed to IUNG-PIB where they were reviewed in formal and technical terms. Discovered gaps in information, wrong or incredible records were returned to the expert who made an inventory in order to make necessary corrections.

Due to the fact that the Directive requires that emissions estimates be made taking account not only of various soils and crop yields, but also climate (Article 19.2), a need appeared to expand the data set collected in 2010 production technology inventory. To this end, archived data from 2005-2009 were obtained from various agricultural institutions and raw materials and used accordingly. The data were collected by means of a simplified questionnaire (Annex 5.7), as obtaining broader information proved impossible.

The total number of farms subject to analysis amounted to: 297 as far as wheat, 320 as far as triticale, 275 as far as maize, 320 as far as rye and 1217 as far as rape was concerned.

The methodology of assessing GHG emissions resulting from the production and application of transport fuels, bio-fuels and bio-liquids is defined by Directive 2009/28/EC (Annex V, C). Despite the development of proper calculation tools in numerous Member States, the European Commission has not yet notified the application of any of them. Each Member State has freedom to choose an already developed calculation tool or to develop its own one. To estimate emissions of selected crops in Poland Biograce calculation tool was selected (version 4 public), developed by an international consortium within the framework of a project funded by EU (http://www.bio-grace.net/). It was selected due to the following reasons:

- full compliance with the methodology described in the Directive,
- compliance with additional requirements stipulated in EC communications,
- current harmonization of calculation procedures,
- free of charge availability ad systematic update of the calculation tool according to future requirements of the Directive for the period of 5 years as of 2012.

The calculation tool enables to calculate agricultural emissions as well as emissions and emission reductions in the full life cycle of bio-fuels for three out of five crops under analysis: wheat, maize and rape. Making estimations for triticale and rye required the feeding in of data concerning ethanol productivity. They were assumed as follows: 0.5350 MJ ethanol/MJ triticale and 0.5096 MJ ethanol/MJ rye, respectively (conf. Bassam N.E. 2010 Handbook of bioenergy crops).

Estimations of agricultural emissions of GHG, emissions in the life cycle of biofuels and emission reductions were conducted for:

- Cycle of producing bio-ethanol from wheat, triticale and rye, in which technological fuel has not been indicated (Chapters 5 and 6) and for the cycle of producing bio-ethanol from wheat in which natural gas used for steam boiler was used as technological fuel (Chapter 8),
- Cycle of producing bio-ethanol from maize, in which energy for technological purposes originated from a power house powered with natural gas,
- Cycle of producing fat acid methyl ester (FAME) from rape seeds.
  For the purpose of making estimations, Biograce sheet was fed with data specified in Table 7.

Table 7. Input data for Biograce sheet

Data	Unit	Crop				
		Wheat	Maize	Triticale	Rye	Rape
Yield	kg $ha^{-1}r^{-1}$	x	x	x	x	x
Moistening	%	x	x	X	x	x
Straw yield	kg $ha^{-1}r^{-1}$	X	x	x	x	-
Straw collected from field	kg $ha^{-1}r^{-1}$	X	x	x	x	x
Fuel consumption (ON and OO)	MJ $ha^{-1}r^{-1}$	X	x	x	x	x
Fertilization N	kg $ha^{-1}r^{-1}$	X	x	x	x	x
Fertilization CaO	kg $ha^{-1}r^{-1}$	-	x	-	-	x
Fertilization K_20	kg $ha^{-1}r^{-1}$	x	x	x	x	x
Fertilization P_2O_5	kg $ha^{-1}r^{-1}$	x	x	x	x	x
Pesticide dosage (active substance)	kg $ha^{-1}r^{-1}$	x	x	x	x	x

Amount of sowed seeds	kg $ha^{-1}r^{-1}$	x	x	x	x	x
Field N_2O emission	kg $ha^{-1}r^{-1}$	x	x	x	x	x

Straw yields determined from the relationship of grain to straw amounted to: wheat – 1:0,9; maize and triticale 1:1, rye 1:1,2 and rape 1:1,3.

While calculating agricultural emissions of GHG particular importance is attached to a volume of those emissions produced as a result of nitrogen fertilizers production. Analyses of methodologies described in the reports of certain Member States (available on the Transparency Platform; Emissions from cultivation – Article1(2); http:/ec.europa.eu/energy/renewable/transparency_platform/emissions_en.htm) which noted lower than default emissions of GHG for NUTS2 show that sometimes the result was achieved by means of lowering standard emission resulting from the production of nitrogen fertilizers. According to EU assumptions, an average emission resulting from nitrogen fertilizers production is **5880,6** g eq CO_2 kg^{-1} of pure component. Some Member States (Transparency Platform) assumed lower values rather than this one, based on data acquired from a portion of or all the producers of nitrogen fertilizers. In order to obtain reliable data on Poland, all the nitrogen works were applied to provide emission data for the assortment of fertilizers produced. Figures obtained this way were listed against assortments (Table 8) and as weighted average amounts (for the amount of fertilizer production) for particular assortments (Table 9) were used in further calculations..

The following emission values for nitrogen fertilizers were used for calculating: for rape **3253,2** g CO_2 eq/kg N (assuming the use of 60% N in RSM and 40% in ammonium nitrate, which resulted from the knowledge of PSPO on fertilizing rape in farms producing for energy purposes), for cereals **3414,2** g CO_2 eq/kg N.

Obtaining emission figures for fertilizers produced in Poland and assuming the above mentioned values for making estimations was of a key importance for the volume of the estimated agricultural emissions of GHG and contributed to lowering thereof by as much as 6 g CO_2 eq/MJ at an average level of wheat, maize and rape fertilization, in relation to the standard emission value for nitrogen fertilizers which is assumed by the EU. In such a way the values decreased from the level exceeding the default values for NUTS2 to the level below them.

N_2O emissions resulting from the application of nitrogen fertilizers (half of N_2O emissions) were calculated in Biograce sheet according to IPCC methodology in accordance with the European Commission recommendation. Estimations of that parameter were made under an assumption of 60% of rape straw and the entire cereal straw harvested from the fields.

Table 8. Emissions of greenhouse gasses as a result of the production of nitrogen and multi-component fertilizers, according to the reports of fertilizer producers of July 2011.

Name of Producer	Type of fertilizer	Emission (CO_2 eq kg^{-1} of pure component)	Market share of product (%)
Industrial plant 1	Urea	4100	8
	Ammonium nitrate	3465	52
	RSM	3080	29
	Ammonium sulphate	872	11
Industrial plant 2	Ammonium nitrate	3072	58
	Nitrochalk	3149	42
Industrial plant3	Ammonium sulphate	6145	39
	Nitrochalk	4590	37
	Saletrosan (ASN)	5333	24
Industrial plant 4	CAN (Salmagi)	5312	59
	Ammonium nitrate	5012	21
	Urea	3371	20
Industrial plant 5	Urea	3468	24
	N(PK)	2377	63
	N(P)	2887	13
Industrial plant 6	P_2O_5	1062	-
	K_2O	244	-
UE*	N	5880,6	-
	P_2O_5	1010,7	-
	K_2O	576,1	-

*Values adopted in JRC EC and provided for in JEC E3-database (version 31-7-2008); Fosfan figures have not been accounted for in this analysis because even following a correction the emissions for K_2O are more than twice less than those adopted for the EU, which seems incredible.

Table 9. Average weighted emissions of greenhouse gasses for fertilizer assortment produced in Poland (production volume was the weight)

Fertilizer	Emission (CO_2 eq kg^{-1} of pure component)
Urea	3683,9
Ammonium nitrate	3494,5
RSM	3080,0
Ammonium sulphate	1969,2
Nitrochalk	4007,6
Saletrosan (ASN)	5333,0
CAN (Salmag)	5012,0
Multi-component fertilizers NPK*	2577,0
Multi-component fertilizers NP*	2887,0
P_2O_5	1062,0
K_2O	244,0
Average weighted emission for N fertilizers	**3414,4**
UE** N	5880,6
P_2O_5	1010,7
K_2O	576,1

*emission for N; ** Values adopted in JEC E3-database (version 31-7-2008)

In order to calculate agricultural emissions in Biograce sheet one does not need meteorological data. European Commission, while expecting such data, wanted probably to have certain guarantee that emission estimates were made for figures obtained in years featuring typical weather changeability.

GHG emissions resulting from industrial processes and full cycle of bio-fuels were calculated, except agricultural emissions, with the application of standard indicators for EU which have been accounted for in Biograce. This is why these values are not sufficiently well established in the reality of bio-fuels production in Poland. However, efforts failed to obtain real values from bio-fuel industry.

All the input data for estimating agricultural emissions, emissions produced in full life cycle of bio-fuels and reductions of emissions were archived.

4.3 Carbon sequestration in soils as a result of improvements in agricultural technology

Agricultural technology improvements which lead to increased carbon sequestration in the soil may be achieved by means of:

- increased amount of post-harvest residues being ploughed under in traditional tillage system
- Introducing simplifications involving a partial reduction of tillage and increased incorporation of post-harvesting residues into the soil,
- Introducing no-till farming and leaving post-harvest residues on the field in the form of mulch

Estimations concerning the increase of carbon sequestration in the ground during multiple years were made for Poland depending on climate, soil type and amount of incorporated post-harvest residues in the system of traditional tillage, reduced tillage and no-till systems. The estimations take account of all the methodological requirements stipulated in *Commission Decision of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC (notified under document C(2010) 3751)(2010/33/EU)*.

The climate was assumed as cool and moist, including the whole of Northern Europe. Selected soil types, according to FAO classification, included: 1 – high clay activity mineral, 2 – sandy, 3 – spodic. Incorporation of soil residues was taken account of according to its amount: 1 – small amount of post-harvest residues collected from the field, 2 – medium (all the post-harvest residues are left on the field or if they are collected, regular fertilization with manure follows), 3 – big excluding manure (post-harvest residues are left on the field and in addition intercrops are cultivated) and 4 – big including manure (as in 3 including additional regular fertilization with manure).

Estimations were made in accordance with IPCC methodology recommended by the European Commission, with the application of a calculation tool developed by Colorado State University (USA).

4.4 GHG Emissions and GHG emissions reductions in the full production cycle of bio-fuels in farming systems including and excluding improvement of agricultural technology

The Directive favours improvement of agricultural technology with GHG reduction in bio-fuel life cycle and, as a result, with increased emission reductions. However, one should take account of the fact, that improvement of agricultural technology **does not reduce the volume of agricultural emissions, but increases them as a result of higher level of N_2O emissions from nitrogen produced by post-harvest residues**. However, improvement of agricultural technology reduces GHG emissions in bio-fuel life cycle and increases emission reductions.

Effect of agricultural technology improvements on emissions and emission reductions was estimated for wheat, maize and rape cultivated on soils composed of high clay activity mineral, because the inventory of production technologies showed that these crops were cultivated mostly on medium and heavy soils (Table 1). The share of cultivations in this soil category was 57%, 55% and57% respectively. The estimations took account of leaving all post-harvest residues in the field (medium level of post-harvest residues' incorporation). They were made for farms which produced average agricultural emissions in particular voivodships in variants with and without agricultural technology improvement for cold and moist climate and for farming in traditional tillage system, reduced tillage and no till farming system (288 combinations).

5. Results of average agricultural emissions of greenhouse gasses in voivodships calculated based on questionnaire research

5.1. Wheat

The yields of winter wheat cultivated in Poland were by 6 quintals bigger than the default figures assumed in the EU for calculating agricultural emissions (Table 11). Such yields were obtained at a similar dosage of N fertilizers, increased fertilization with P and K, reduced consumption of pesticides and higher standard of seed sowing.

Table 11. Average characteristics of wheat production technology in the farms under analysis and in Europe

Parameter	Unit	Results of technology inventory			JEC value*
		average	minimum	maximum	
Yield	Kg $ha^{-1}r^{-1}$	5816	3500	8121	5200
Moistening	%	15	-	-	13,5
Diesel consumption	MJ $ha^{-1}r^{-1}$	3607	1584	6336	3716
N dosage	Kg N $ha^{-1}r^{-1}$	110	0	236	109,3
Manure dosage	Kg N $ha^{-1}r^{-1}$	-	-	-	-
P_2O_5 Dosage	Kg P2O5 $ha^{-1}r^{-1}$	52	0	190	21,6
K_2O Dosage	Kg K_2O $ha^{-1}r^{-1}$	56	0	170	16,4
CaO Dosage	Kg CaO $ha^{-1}r^{-1}$	135	0	753	-
Pesticide dosage	Kg s.a. $ha^{-1}r^{-1}$	1,79	0,02	3,94	2,3
Sowing standard	Kg $ha^{-1}r^{-1}$	223	140	321	120
Field N_2O emissions	Kg N_2O $ha^{-1}r^{-1}$	2,67	0,61	5,13	1,84

*JRC Excel file with input data relevant to calculating default GHG emissions from biofuels according to RE Directive Methodology (http://re.jrc.ec.europa.eu/biof/html/input_data_ghg.htm)

Agricultural emissions of GHG in all the voivodships were lower than the default values and ranged between 19,80 – 22,97 g CO_2 eq MJ^{-1} (Table 12).

Table 12 Agricultural emissions of GHG for winter wheat cultivations

Voivodship	Agricultural emissions in CO_2 eq MJ^{-1}	
	estimated	default
Dolnślązkie	22.69	23
Kujawsko-pomorskie	22.97	23
Lubelskie	22.47	23
Lubuskie	22.20	23
Łódzkie	20.84	23
Małopolskie	22.51	23
Mazowieckie	22.77	23
Opolskie	22.69	23
Podkarpackie	19.80	23
Podlaskie	22.33	23
Pomorskie	22.80	23
Śląskie	22.75	23
Świętokrzyskie	21.59	23
Warmińsko-Mazurskie	22.84	23
Wielkopolskie	22.05	23
Zachodnio-Pomorskie	22.83	23

5.2 Triticale

Triticale may be used for the production of bio-ethanol provided that estimations are made of real agricultural emissions of GHG for each farm which produces this crop. In the case of triticale, the yields in Poland are smaller in comparison to wheat (Table 1). The yield is, however, achieved by lesser N fertilization, thanks to which agricultural emissions of GHG were lower in some voivodships than default emissions for wheat (Table 14).

Table 13. Average characteristics of winter triticale production technology in farms under analysis and in Europe

Parameter	Unit	Results of technology inventory			JEC value*
		average	minimum	maximum	
Yield	Kg $ha^{-1}r^{-1}$	4741	1945	9000	n/a
Moistening	%	15	15	15	n/a
Diesel consumption	MJ $ha^{-1}r^{-1}$	3733	2304	6864	n/a
N dosage	Kg N $ha^{-1}r^{-1}$	88	0	200	n/a
Manure dosage	Kg N $ha^{-1}r^{-1}$	-	-	-	n/a
P_2O_5 Dosage	Kg P2O5 $ha^{-1}r^{-1}$	45	0	125	n/a

K_2O Dosage	Kg K_2O $ha^{-1}r^{-1}$	53	0	188	n/a
CaO Dosage	Kg CaO $ha^{-1}r^{-1}$	-	-	-	n/a
Pesticide dosage	Kg s.a. $ha^{-1}r^{-1}$	1,3	0	3,2	n/a
Sowing standard	Kg $ha^{-1}r^{-1}$	217	149	303	n/a
Field N_2O emissions	Kg N_2O $ha^{-1}r^{-1}$	2,12	0,52	4,30	n/a

*JRC Excel file with input data relevant to calculating default GHG emissions from biofuels according to RE Directive Methodology (http://re.jrc.ec.europa.eu/biof/html/input_data_ghg.htm)

Table 14. Agricultural emissions of greenhouse gasses for winter triticale cultivation

Voivodship	Agricultural emissions in CO_2 eq MJ^{-1}	
	estimated	default
Dolnośląskie	26.10	Not determined
Kujawsko-pomorskie	24.78	Not determined
Lubelskie	22.12	Not determined
Lubuskie	21.67	Not determined
Łódzkie	22.91	Not determined
Małopolskie	24.49	Not determined
Mazowieckie	22.33	Not determined
Opolskie	27.05	Not determined
Podkarpackie	22.39	Not determined
Podlaskie	20.70	Not determined
Pomorskie	23.86	Not determined
Śląskie	24.29	Not determined
Świętokrzyskie	23.11	Not determined
Warmińsko-Mazurskie	24.48	Not determined
Wielkopolskie	23.80	Not determined
Zachodnio-Pomorskie	26.25	Not determined

Although the Directive does not provide for default values for triticale, it is possible that the values shall be determined during a period of review, which is to take place every two years.

5.3. Maize

Maize which is cultivated in Poland gives twice as big yields than the average yields assumed for the EU (Table 15). They are achieved, however, by applying twice bigger fertilizer doses. As a rule, maize cultivations are located mainly in 11 voivodships. It is highly probable that the grains shall not mature in the remaining ones. Since for 5 voivodships the numbers of farms are insufficient for calculating credible average values, their emissions have been provided in parentheses for information only. In the remaining 11 voivodships, in which maize cultivated for grain has a significant share in the crop structure, agricultural emissions of GHG were lower than default values (Table 16).

Table 15. Average characteristics of production technology of maize in farms under analysis and in Europe.

Parameter	Unit	Results of technology inventory			JEC value*
		average	minimum	maximum	
Yield	Kg $ha^{-1}r^{-1}$	7141	2556	11000	3500
Moistening	%	15	-	-	-
Diesel consumption	MJ $ha^{-1}r^{-1}$	3284	1548	8028	3600
N dosage	Kg N $ha^{-1}r^{-1}$	124	39	205	52
Manure dosage	Kg N $ha^{-1}r^{-1}$	-	-	-	-
P_2O_5 Dosage	Kg P2O5 $ha^{-1}r^{-1}$	63	0	200	34.5
K_2O Dosage	Kg K_2O $ha^{-1}r^{-1}$	78	0	236	25,8
CaO Dosage	Kg CaO $ha^{-1}r^{-1}$	235	0	800	-
Pesticide dosage	Kg s.a. $ha^{-1}r^{-1}$	0,83	0	2,95	2,4
Sowing standard	Kg $ha^{-1}r^{-1}$	29	17	50	-
Field N_2O emissions	Kg N_2O $ha^{-1}r^{-1}$	2,72	1,06	4,31	0,85

*JRC Excel file with input data relevant to calculating default GHG emissions from biofuels according to RE Directive Methodology (http://re.jrc.ec.europa.eu/biof/html/input_data_ghg.htm)

Table 16. Agricultural emissions of greenhouse gasses for maize cultivated for grain

Voivodship	Agricultural emissions in CO_2 eq MJ^{-1}	
	Estimated	default
Dolnośląskie	19.20	20
Kujawsko-pomorskie	19.82	20
Lubelskie	19.36	20
Lubuskie	19.24	20
Łódzkie	19.51	20
Małopolskie	19.13	20
Mazowieckie	18.59	20
Opolskie	19.65	20
Podkarpackie	18.61	20
Podlaskie	(19.57)	20
Pomorskie	(25.47)	20
Śląskie	19.87	20
Świętokrzyskie	(20.55)	20
Warmińsko-Mazurskie	(27.17)	20
Wielkopolskie	17.94	20
Zachodnio-Pomorskie	(24.88)	20

() – too few data to calculate an average, as maize intended for grain is cultivated rarely in those voivodships due to a high probability of lack of grain maturation process

5.4. Rye

Due to a significant share of light soils in Poland and a history of frequent use of rye for the production of bio-ethanol it was justified to estimate the volume of agricultural emissions of GHG for that crop. Rye, as well as triticale, may still be used for bio-ethanol production provided that estimations of real agricultural emissions of GHG are made for all the farms which supply the crop.

In Poland rye is produced extensively, this is why the yield achieved is quite low (Table 17) which, taking account of lower productivity of bio-ethanol, causes the agricultural emissions to significantly exceed the figures for maize and wheat (Table 18).

Table 17.

Average characteristics of rye production technology in farms under analysis and in Europe.

Parameter	Unit	Results of technology inventory			JEC value*
		average	minimum	maximum	
Yield	Kg $ha^{-1}r^{-1}$	3295	1500	8000	n/a
Moistening	%	15	15	15	n/a
Diesel consumption	MJ $ha^{-1}r^{-1}$	3683	2016	6113	n/a
N dosage	Kg N $ha^{-1}r^{-1}$	66	0	213	n/a
Manure dosage	Kg N $ha^{-1}r^{-1}$	-	-	-	n/a
P_2O_5 Dosage	Kg P2O5 $ha^{-1}r^{-1}$	33	0	200	n/a
K_2O Dosage	Kg K_2O $ha^{-1}r^{-1}$	43	0	200	n/a
CaO Dosage	Kg CaO $ha^{-1}r^{-1}$	-	-	-	n/a
Pesticide dosage	Kg s.a. $ha^{-1}r^{-1}$	0,4	0	2,8	n/a
Sowing standard	Kg $ha^{-1}r^{-1}$	166	110	264	n/a
Field N_2O emissions	Kg N_2O $ha^{-1}r^{-1}$	1,56	0,28	4,06	n/a

*JRC Excel file with input data relevant to calculating default GHG emissions from biofuels according to RE Directive Methodology (http://re.jrc.ec.europa.eu/biof/html/input_data_ghg.htm)

Table 18. Agricultural emissions of greenhouse gasses for rye cultivations

Voivodship	Agricultural emissions in CO_2 eq MJ^{-1}	
	estimated	default
Dolnośląskie	26.84	Not determined
Kujawsko-pomorskie	27.27	Not determined
Lubelskie	29.06	Not determined
Lubuskie	31.38	Not determined
Łódzkie	28.76	Not determined
Małopolskie	24.10	Not determined
Mazowieckie	29.73	Not determined
Opolskie	28.82	Not determined
Podkarpackie	29.67	Not determined
Podlaskie	27.68	Not determined
Pomorskie	30.26	Not determined
Śląskie	25.11	Not determined
Świętokrzyskie	29.30	Not determined
Warmińsko-Mazurskie	31.23	Not determined
Wielkopolskie	31.69	Not determined
Zachodnio-Pomorskie	30.47	Not determined

If rye were still considered as a raw material, one could suggest that hybrid varieties be used to this end, the yield of which could be comparable to that of wheat, provided for better habitat.

5.5. Rape

Characteristics of winter rape production technology differed within the random sample of farms under analysis from the inventory of technologies made for Europe by JRC EC (Table 19). In Poland, due to more intensive fertilization and more intensive plant protection, the yields were by 2.2 quintals higher than the average yields in Europe. Agricultural emission levels of GHG were lower than default values in all voivodships (Table 20).

Table 19. Average characteristics of rape production technology in farms under analysis and in Europe

Parameter	Unit	Results of technology inventory			JEC value*
		average	minimum	maximum	
Yield	Kg $ha^{-1}r^{-1}$	3336	1100	5500	3113
Moistening	%	9	8	12	10
Diesel consumption	MJ $ha^{-1}r^{-1}$	2702	1060	5400	2963
N dosage	Kg N $ha^{-1}r^{-1}$	170	50	300	137
Manure dosage	Kg N $ha^{-1}r^{-1}$	0	0	0	-
P_2O_5 Dosage	Kg P2O5 $ha^{-1}r^{-1}$	56	0	180	34

K_2O Dosage	Kg K_2O $ha^{-1}r^{-1}$	91	0	245	50
CaO Dosage	Kg CaO $ha^{-1}r^{-1}$	178	0	2000	-
Pesticide dosage	Kg s.a. $ha^{-1}r^{-1}$	1.8	0	9.2	1.2
Sowing standard	Kg $ha^{-1}r^{-1}$	3.4	1.8	6.3	6.0
Field N_2O emissions	Kg N_2O $ha^{-1}r^{-1}$	3.08	1.00	5.31	3.11

*JRC Excel file with input data relevant to calculating default GHG emissions from biofuels according to RE Directive Methodology (http://re.jrc.ec.europa.eu/biof/html/input_data_ghg.htm)

Table 20. Agricultural emissions of greenhouse gasses for winter rape cultivation

Voivodship	Agricultural emissions in CO_2 eq MJ^{-1}	
	estimated	eefault
Dolnośląskie	24.60	29
Kujawsko-Pomorskie	25.59	29
Lubelskie	24.65	29
Lubuskie	22.19	29
Łódzkie	24.40	29
Małopolskie	25.43	29
Mazowieckie	24.09	29
Opolskie	25.79	29
Podkarpackie	21.32	29
Podlaskie	28.25	29
Pomorskie	26.56	29
Śląskie	25.54	29
Świętokrzyskie	24.08	29
Warmińsko-Mazurskie	24.02	29
Wielkopolskie	21.79	29
Zachodnio-Pomorskie	23.74	29

6. Coal sequestration in soils as a result of agricultural technology improvement involving different amounts of post-harvest residues being ploughed under in the traditional tillage system, reduced tillage system and no till farming system.

Ploughing post-harvest residues in the traditional tillage system results in increased sequestration of coal in soils, its amount depending on the climate, type of soil and the amount of post-harvest residues incorporated into the soil. Increments were expressed in relation to a production technology in which all the post-harvest residues are collected from the field (Table 26).

Table 26. Coal sequestration increments in tillage system depending on climate, type of soil and the amount of post-harvest residues incorporated, as opposed to the tillage system involving the collection of the whole amount of post-harvest residues (Mg $ha^{-1}r^{-1}$)

Amount of post-harvest residues	Cold and moist climate		
	1	2	3
Average	0,31	0,23	0,37
Huge excluding manure	0,68	0,51	0,87
Huge including manure	1,59	1,19	1,92

Soils: 1.High clay activity mineral soils 2. Sandy 3. Spodic

Farms producing raw materials intended for bio-fuel production do not breed animals as a rule, this is why coal sequestration as a result of incorporating post-harvest residues in average or high amounts without manure shall be the most appropriate for them.

Simplification of cultivation by means of partial reduction of tillage increases the volumes of coal sequestered in soils as opposed to traditional tillage system (Table 27)

Table 27. Coal sequestration increments in soil in reduced tillage system depending on climate, soil type and amount of post-harvest residues incorporated as opposed to traditional tillagesystem involving the collection of the whole of post-harvest residues from the field (Mg $ha^{-1}r^{-1}$)

Amount of post-harvest residues	Cold and moist climate		
	1	2	3
Average	0,61	0,41	0,74
Huge excluding manure	1,01	0,76	1,23

The estimations concerning emissions in the life cycle shall be influenced not only by increased coal sequestration in the soil but also by savings of fuel resulting from partial tillage reduction.

In no till farming system further increase of coal sequestration may be achieved (Table 28). However, fertilization with manure is not recommended in this system due to the fact that manure cannot be sufficiently covered by soil.

However, estimations of GHG emissions in bio-fuel life cycle and emissions reductions take account not only of coal sequestration increments, but also increase of N_2O emissions related with supplying the soil with certain amounts of nitrogen originating from post-harvest residues. Increase of coal sequestration in soil reduces emissions in bio-fuel life cycle and increases emission reductions, while increase of N_2O gives a reverse effect. Thus, the estimations are resultants of those antagonistic impacts.

Table 28. Coal sequestration increments in soil in the system of no till farming in relation to climate, soil type and amount of post-harvest residues supplied to the soil as opposed to traditional tillage system involving the collection of the whole amount of post-harvest residues (Mg $ha^{-1}r^{-1}$)

Amount of post-harvest residues	Cold and moist climate		
	1	2	3
Average	0,84	0,63	1,02
Huge without manure	1,11	0,95	1,54

7. GHG Emissions and emissions reductions in the full cycle of bio-fuel production in farming systems including and excluding agricultural technology improvement

Estimates of agricultural emissions of GHG, emissions in the life cycle of bio-ethanol from wheat and maize (technological fuel- natural gas, steam boiler) and emission reductions were made by means of using average parameters which characterize agricultural technologies of the crops' production in the voivodships. Analogous estimates for rape were made for the production path in which Biograce does not require the determination of technological fuel.

Calculations were made for four farming systems: tillage involving the collection of the whole amount of post-harvest residues, tillage of all the amount of post-harvest residues, reduced tillage with leaving the whole amount of post-harvest residues on the field, and no till farming system with leaving the whole amount of post-harvest residues on the field. Coal sequestration increments in soil made of high clay activity mineral were adopted at the following levels: comparative tillage system – 0 t C $ha^{-1}r^{-1}$, tillage involving post-harvest residues being ploughed under– 0,31 t $C^{-1}r^{-1}$, reduced tillage system with leaving post-harvest residues in the field – 0,61 t $ha^{-1}r^{-1}$ and no till farming system with leaving post-harvest residues on the field – 0,84 t C $ha^{-1}r^{-1}$. Estimated amounts included: field emissions of N_2O (kg N_2O $h^{-1}r^{-1}$) in ploughing system (N_2O_p) and with improved agricultural technology (N2O_pa), GHG emissions (g CO eq $ha^{-1}r^{-1}$);

agricultural (ER), total in life cycle (ET), total in live cycle taking account of allocation (EA) and emission reduction in relation to conventional fuel (OE) expressed in %.

Results obtained for wheat, maize and rape have been presented in Tables 29, 30 and 31.

In the case of wheat, GHG emission reductions in traditional tillage system account on average for 36% for voivodships for the production path with the use of natural gas as technological fuel (Table 29). Thus, they exceed by 1% only the requirement for emission reductions, which shall have been set for 35% as of 1 April 2013. If we calculated emission reductions for the production path for undefined fuel, they would be below the obligatory value of 35%. An achievement of 50% emission reduction as of 2017 shall require a production of raw materials in the system of reduced tillage (average value of reduction for voivodships 50%) or better in no till farming system (average value of reduction for voivodships 56%) in order for a safe compliance with the required standard. Even if the raw material is produced in no till farming system, it shall not guarantee a 60% emission reduction, which will have been required from new installations as of 2018. Where the fulfilment of standards of wheat production path is impossible – a need shall arise to use maize for bio-ethanol production. This plant provides for greater emission reductions than wheat (Table 30). In the case of this raw material emissions reductions shall, in the majority of voivodships, exceed the value of 50% even if maize is produced in traditional tillage system. This creates an opportunity of setting such proportions of wheat and maize, that the requirement of emission reductions be fulfilled, as the production plants shall be accountable for total raw material (in mass balance) rather than for emissions for particular raw material assortments. If maize is cultivated in systems with improved agricultural technology , emission reductions shall significantly exceed 50% (Table 30).

In the case of rape cultivated in traditional tillage system, emission reductions shall range between 40-47%, which ensures the fulfilment of the required 35% emission reduction requirement (Table 31). For the purpose of safe compliance with the standard of 50% reduction, the raw material should originate from reduced tillage farming system or no till farming system of production. New installations should process raw materials cultivated in no till farming system (Table 31).

Table 29. Variability of the volume of GHG emissions in the life cycle of biofuels made of wheat depending on agricultural technology improvement

Voivodship	N_2O emissions		Traditional tillage system				Tillage + post-harvest residues				Reduced tillage + post-harvest residues				No till system + post-harvest residues			
	N_2O_p	N_2O_pa	ER	ET	EA	OE	ER	ET	EA	OE	ER	ET	EA	OE	ER	ET	EA	OE
DLN	2,92	3,37	22,1	88,7	53,4	**36**	23,8	84,9	48,5	**42**	23,8	78,5	42,0	**50**	23,8	73,6	37,1	**56**
KUJ	3,50	4,00	22,9	90,1	54,2	**35**	24,6	87,0	50,0	**40**	24,6	81,3	44,3	**47**	24,6	76,9	39,9	**52**
LUB	2,73	3,15	22,0	88,5	53,3	**36**	23,6	84,4	48,1	**43**	23,6	77,0	41,4	**51**	23,6	72,6	36,3	**57**
LUS	2,68	3,15	21,8	88,2	53,1	**37**	23,6	84,5	48,2	**43**	23,6	77,9	41,6	**50**	23,6	72,9	36,6	**56**
LOD	2,28	2,67	20,9	86,6	52,2	**38**	22,5	82,0	46,4	**45**	22,5	74,8	39,2	**53**	22,5	69,3	33,7	**60**
MAL	2,70	3,12	22,5	89,5	53,9	**36**	24,2	85,2	48,4	**42**	24,2	78,3	41,5	**50**	24,2	73,0	36,2	**57**
MAZ	2,94	3,37	22,6	89,5	53,9	**36**	24,2	85,6	48,9	**42**	24,2	79,2	42,5	**49**	24,2	74,3	37,6	**55**
OPL	3,09	3,39	23,0	90,3	54,3	**35**	24,2	85,6	48,9	**42**	24,2	79,2	42,5	**49**	24,2	74,3	37,6	**55**
PDK	1,93	2,31	19,4	84,2	50,7	**39**	21,1	79,3	44,7	**47**	21,1	71,9	37,2	**56**	21,1	66,1	31,5	**55**
PDL	2,44	2,83	22,2	88,9	53,5	**36**	23,9	84,1	47,6	**43**	23,9	76,8	40,3	**52**	23,9	71,2	34,7	**59**
POM	2,84	3,15	22,8	89,9	54,1	**35**	24,0	85,1	48,5	**42**	24,0	78,6	42,0	**50**	24,0	73,6	37,0	**56**
SLS	2,92	3,34	22,5	89,4	53,8	**36**	24,1	85,3	48,6	**42**	24,1	78,7	42,0	**50**	24,0	73,7	37,0	**56**
SWT	2,24	2,63	21,0	86,9	52,3	**38**	22,7	82,2	46,5	**44**	22,7	75,0	39,3	**53**	22,7	69,3	33,8	**55**
WAM	2,61	3,01	22,7	89,7	54,0	**36**	24,3	85,2	48,4	**42**	24,3	78,1	41,3	**51**	24,3	72,7	35,9	**57**
WLP	2,64	3,07	21,8	88,1	53,1	**37**	23,4	84,1	47,9	**43**	23,4	77,5	41,3	**51**	23,4	72,5	36,3	**57**
ZAP	3,22	3,68	22,7	89,8	54,0	**36**	24,4	86,2	49,3	**41**	24,4	80,1	43,2	**48**	24,4	75,3	38,5	**54**

Table 30. Variability of the volume of GHG emissions in the life cycle of bio-ethanol made of maize depending on agricultural technology improvement

Voivodship	N_2O emissions		Traditional tillage system				Tillage + post-harvest residues				Reduced tillage + post-harvest residues				No till system + post-harvest residues			
	N_2O_p	N_2O_pa	ER	ET	EA	OE	ER	ET	EA	OE	ER	ET	EA	OE	ER	ET	EA	OE
DLN	3,01	3,45	14,7	68,3	38,0	**55**	15,8	65,5	34,3	**59**	15,81	60,9	29,7	**65**	15,81	57,4	26,2	**69**
KUJ	2,91	3,30	16,0	70,6	39,2	**53**	16,8	55,8	34,8	**58**	16,8	61,7	29,7	**65**	16,8	57,8	25,8	**69**
LUB	2,82	3,21	15,8	70,3	39,1	**53**	16,9	66,9	34,8	**58**	16,9	61,7	29,6	**65**	16,9	57,7	25,6	**69**
LUS	2,30	2,65	15,1	69,0	38,4	**54**	16,3	65,2	33,7	**60**	16,3	59,5	28,0	**67**	16,3	55,2	23,6	**72**
LOD	2,33	2,67	15,0	68,8	38,3	**54**	16,1	64,7	33,3	**60**	16,1	58,9	27,5	**67**	16,1	54,5	23,1	**72**
MAL	2,44	2,81	14,6	68,0	37,9	**55**	15,7	64,4	33,3	**60**	15,7	59,0	27,9	**67**	15,7	54,8	23,7	**72**
MAZ	2,88	3,29	15,3	69,3	38,5	**54**	16,3	66,2	34,5	**59**	16,3	61,3	29,6	**65**	16,3	57,5	25,9	**69**
OPL	2,85	3,25	16,2	70,9	39,4	**53**	17,3	67,6	35,1	**58**	17,3	62,3	29,9	**64**	17,3	58,3	25,8	**69**
PDK	2,64	3,05	14,7	68,2	3,79	**55**	15,7	65,1	34,0	**59**	15,7	60,3	29,1	**65**	15,7	56,6	25,4	**70**
PDL	1,90	2,19	16,8	72,2	40,1	**43**	17,9	66,8	33,9	**60**	17,9	59,7	26,7	**68**	17,9	54,3	21,3	**75**
POM	2,46	2,74	21,1	80,0	44,4	**47**	22,2	74,7	38,2	**54**	22,2	67,7	31,2	**63**	22,2	62,3	25,8	**69**
SLS	3,26	3,65	16,6	71,7	39,9	**52**	17,6	68,6	35,9	**57**	17,6	63,8	31,1	**63**	17,6	60,1	27,5	**67**
SWT	2,39	2,71	17,0	72,4	40,3	**52**	18,1	67,9	34,8	**58**	18,1	61,5	28,4	**66**	18,1	56,7	23,6	**72**
WAM	3,39	3,68	25,1	87,3	48,4	**42**	26,2	82,1	42,3	**50**	26,2	75,2	35,4	**58**	26,2	69,9	30,1	**64**
WLP	2,64	3,04	15,0	68,9	38,3	**54**	16,1	65,7	34,2	**59**	16,1	60,6	29,2	**65**	16,1	56,8	25,3	**70**
ZAP	2,71	3,00	20,2	78,2	43,4	**48**	21,2	73,1	37,4	**55**	21,2	66,3	30,6	**63**	21,2	61,0	25,3	**70**

Table 31. Variability of the volume of GHG emissions in the life cycle of bio-diesel made of rape depending on agricultural technology improvement

Voivodship	N_2O emissions		Traditional tillage system				Tillage + post-harvest residues				Reduced tillage + post-harvest residues				No till system + post-harvest residues			
	N_2O_p	N_2O_pa	ER	ET	EA	OE	ER	ET	EA	OE	ER	ET	EA	OE	ER	ET	EA	OE
DLN	3,13	3,59	24,1	67,8	47,1	**44**	25,9	64,1	42,2	**50**	25,9	57,6	35,7	**57**	25,9	52,6	30,7	**63**
KUJ	3,39	3,86	25,1	69,5	48,1	**43**	2,69	65,9	43,3	**48**	26,9	59,6	37,0	**56**	26,9	54,7	32,1	**62**
LUB	3,06	3,52	24,3	68,1	47,3	**44**	26,1	64,3	42,2	**50**	26,1	57,6	35,5	**58**	26,1	52,5	30,4	**64**
LUS	2,89	3,43	22,0	64,2	45,0	**46**	24,0	61,0	10,5	**52**	24,0	54,8	34,2	**59**	24,0	50,0	29,4	**65**
LOD	2,73	3,14	22,4	68,2	47,4	**43**	26,1	63,6	41,5	**50**	26,1	56,2	34,1	**59**	26,1	50,5	28,4	**66**
MAL	3,17	3,63	24,8	69,0	47,8	**43**	26,6	65,1	42,7	**49**	26,6	58,4	36,0	**57**	26,6	53,3	30,9	**63**
MAZ	3.06	3,53	23,6	66,9	46,6	**33**	25,4	63,2	41,7	**50**	25,4	56,7	35,1	**58**	25,4	51,7	30,1	**64**
OPL	2,99	3,41	25,1	69,5	48,1	**43**	26,8	65,2	42,6	**49**	26,8	58,2	35,6	**57**	26,8	52,9	30,3	**64**
PDK	2,58	3,04	20,6	61,7	43,6	**48**	22,3	58,0	38,6	**54**	22,3	51,4	32,0	**62**	22,3	46,4	27,0	**68**
PDL	3,08	3,49	27,1	72,8	50,0	**40**	28,8	68,2	44,2	**47**	28,8	60,8	36,9	**56**	28,8	55,2	31,3	**63**
POM	3,40	3,88	25,9	70,9	48,9	**42**	27,7	67,3	44,1	**47**	27,7	61,0	37,8	**55**	27,7	56,1	32,9	**61**
SLS	3,03	34,9	25,1	69,5	48,1	**43**	27,0	65,5	42,9	**49**	27,0	58,7	36,0	**57**	27,0	53,4	30,7	**63**
SWT	3,10	3,56	24,6	68,6	47,6	**43**	26,4	64,8	42,6	**49**	26,4	58,3	36,0	**57**	26,4	53,2	31,0	**63**
WAM	3,24	3,73	23,8	67,6	47,0	**44**	25,8	64,1	42,3	**49**	25,8	57,9	36,1	**57**	25,8	53,2	31,4	**63**
WLP	2,94	3,45	21,5	63,3	44,5	**47**	23,3	60,1	40,1	**52**	23,3	54,1	34,0	**59**	23,3	49,5	29,4	**65**
ZAP	3,05	3,55	22,8	65,6	45,8	**45**	24,59	62,2	41,2	**51**	24,6	56,0	35,0	**58**	24,6	51,3	30,2	**64**

8. Annexes including input data for estimations and the results of estimations of agricultural emissions of GHG

Estimations for farms:

Annex 5.1 Wheat Annex 5.1_wheat.xls

Annex 5.2 Triticale Annex 5.2_triticale.xls

Annex 5.3 Maize Annex 5.3_Maize.xls

Annex 5.4 Rye Annex 5.4_Rye.xls

Annex 5.5 Rape Annex 5.5_Rape.xls

Sample questionnaires:

Annex 5.6 Sample questionnaire for production technology inventory in farms as used in 2010 Annex 5.6_Questionnaire.xls

Annex 5.7 Sample simplified questionnaire for collecting data in other years Annex 5.7 Simplified_questionnaire.xls