Development and application of the methodology for the calculation of average greenhouse gas emissions from the cultivation of rapeseed, wheat, rye, barley and triticale in Estonia

The report was commissioned by the Ministry of the Environment of the Republic of Estonia.

The report has been compiled by: Alar Astover, Merrit Shanskiy and Enn Lauringson. Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences.

www.emu.ee
Eesti Maaülikool
Estonian University of Life Sciences
Põllumajandus- ja keskkonnainstituut
Institute of Agricultural and Environmental Sciences

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Table of contents

1. Introduction

In 2008, the European Parliament and the Council adopted the Renewable Energy Directive (2009/28/EC), which should facilitate the achievement of EU's climate change objectives by 2020: to reduce greenhouse gases (GHG) by 20%, to increase energy efficiency by 20% and to ensure that 20% of energy needs is covered from renewable energy sources.

This Directive establishes a common framework for the promotion of energy from renewable sources. It sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy and for the share of energy from renewable sources in transport. It lays down rules relating to statistical transfers between Member States, joint projects between Member States and with third countries, guarantees of origin, administrative procedures, information and training, and access to the electricity grid for energy from renewable sources. It establishes sustainability criteria for biofuels and bioliquids.

The Member States were to submit a report to the Commission by 31 March 2010 at the latest, providing an overview of typical GHG emissions resulting from the cultivation of agricultural raw materials, and annexing the description of the method and data used to establish the said list to the report. That method should have taken into account topsoil characteristics, climate and expected raw material yields.

The report was commissioned by the Ministry of the Environment to find the average values of GHGs resulting from the cultivation of various agricultural crops in Estonia. The study covered the following crops: rapeseed, rye, wheat, barley and triticale, and the average values of GHG emissions resulting from their cultivation were calculated for each Estonian county. The methodology was based on the Regulation No. 45 of the Ministry of the Environment "Environmental requirements for liquid fuels, sustainability criteria for biofuels, procedure for the monitoring of and reporting on the compliance to environmental requirements, and the methodology for the determination of the reduction of the greenhouse gas emissions resulting from the use of biofuels and bioliquids" and on Annex V of the applicable Directive (2009/28/EC).

2. Methodology

This report covers the development of the methodology that would satisfy Estonian conditions and is based on the instructions to calculate GHG emissions, described in the Directive 2009/28/EC. The methodology forms a basis for the calculation of average GHG emissions from the cultivation of rapeseed, wheat, rye, barley and triticale in Estonian conditions. The work group of the Estonian University of Life Sciences was tasked with the calculation of the emissions (e_{ec}) resulting from the cultivation of the abovementioned crops on a county-by-county basis.

The Directive itself contains little methodological information for the calculation of emissions that result from the cultivation of various crops for making biofuels. Section 6 of chapter C of Annex V of Article 19 of the Directive 2009/28/EC provides the following information in relation to the calculation methodology:

"Emissions from the extraction or cultivation of raw materials, e_{ec}, shall include emissions from the extraction or cultivation process itself; from the collection of raw materials; from waste and leakages; and from the production of chemicals or products used in extraction or cultivation. Capture of CO_2 in the cultivation of raw materials shall be excluded. Certified reductions of greenhouse gas emissions from flaring at oil production sites anywhere in the world shall be deducted. Estimates of emissions from cultivation may be derived from the use of averages calculated for smaller geographical areas than those used in the calculation of the default values, as an alternative to using actual values."

The Directive is clear on the choice of methodologies; co-products shall be distributed and divided by products of proportionally lower heating value. Agricultural crop residues do not presumably have any value and are thus not encumbered with any emissions during the cultivation (Article 19, Annex V, chapter C, sections 17, 18).

"Where a fuel production process produces, in combination, the fuel for which emissions are being calculated and one or more other products (co-products), greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content (determined by lower heating value in the case of co-products other than electricity)."

"Wastes, agricultural crop residues, including straw, bagasse, husks, cobs and nut shells, and residues from processing, including crude glycerine (glycerine that is not refined), shall be considered to have zero life-cycle greenhouse gas emissions up to the process of collection of those materials."

In accordance with the Directive the calculations shall be made per NUT II or smaller regional divisions. Based on NUT II, Estonia is divided into three regions, but as most of the regional statistics have been presented at a more detailed county level this report also includes calculations made per county.

The calculations cover five agricultural crops grown in Estonia: rapeseed, barley, rye, wheat and triticale. In case of wheat the calculations have been made separately for spring wheat and winter wheat. The growth of a crop largely depends on the weather of the growth year and the data from one year might not adequately reflect the yield. Therefore, the results have been determined as the average of three years (2011-2013). Source data on growing areas, harvest, the use of fertilisers and pesticides, and so on, have been primarily received from the Estonian Statistical Office (Table 1). Numerical input has either been found from the databases of the Statistical Office or has been estimated on the basis of research material and expert evaluations. The application rates for fertilisers and pesticides are the average for the whole growing area of a specific crop.

Table 1. Sources for source data

Type of data	**Source**
Average growing area of a crop in 2011-2013 (in hectares)	Estonian Statistical Office
Average total harvest of a crop in 2011-2013 (in tonnes), cereals with moisture content 14% and rapeseed 9%	Estonian Statistical Office
Average yield of a crop in 2011-2013 (t/ha)	Estonian Statistical Office, calculated result of total harvest divided by growing area
Sowing rate in 2011 (kg/ha)	Grain - Estonian Statistical Office, calculated on the basis of the data from 2011; rapeseed - expert evaluation
Average use of mineral fertiliser in 2011-2013 (N, P and K, kg/ha)	Estonian Statistical Office; calculated result of the use of fertilisers divided by the total growing area of a crop; rapeseed equalled to the statistical category of industrial crops; grains differentiated based on expert evaluation
Average use of lime fertiliser in 2011-2013 (kg/ha)	Estonian Statistical Office, calculated result of total lime use divided by total arable land. Only national average value available.
Average use of pesticides in 2011-2013 (kg/ha)	Estonian Statistical Office; Estonian Statistical Office; calculated result of the use of pesticides divided by the total growing area of a crop; rapeseed equalled to the statistical category of industrial crops; grains differentiated based on expert evaluation
Land cultivation methods	Estonian Statistical Office on the basis of the 2010 agricultural census data
Number of livestock units	Estonian Statistical Office on the basis of the 2010 agricultural census data
Number of work operations and fuel consumption depending on the crop and land cultivation method	Synthesis of research material and expert evaluations

In accordance with the Directive 2009/28/EC, the greenhouse gas emission savings from the production and use of transport fuels, biofuels and bioliquids shall be calculated as follows:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}$$

where

E = total emissions from the use of the fuel;

e_{ec} = emissions from the extraction or cultivation of raw materials;

e_l = annualized emissions from carbon stock changes caused by land use change;

e_p = emissions from processing;

e_{td} = emissions from transport and distribution;

e_u = emissions from the fuel in use;

e_{sca} = emission savings from soil carbon accumulation via improved agricultural management;

e_{ccs} = emission savings from carbon capture and geological storage;

e_{ccr} = emission savings from carbon capture and replacement;

e_{ee} = emission savings from excess electricity from co-generation.

The main task of this study was to calculate e_{ec}, or the emissions resulting from the cultivation of the abovementioned crops. Emissions from the production of machinery and equipment were not considered.

The greenhouse gases taken into account in the application of the formula are the following: CO_2, N_2O and CH_4. For the purpose of calculating CO_2 equivalence, those gases shall be valued as follows:

CO_2: 1

N_2O: 296

CH_4: 23

The basis for calculating nitrogen emissions from mineral soils was the BioGrace greenhouse gas calculation tool version 4d (BioGrace 2015). This calculation tool is in line with the sustainability criteria of the Renewable Energy Directive (2009/28/EC, RED) which are equally stated in the Fuel Quality Directive (2009/30/EC). The recognition is based on RED Article 18 (4-6) and refers to proving compliance of RED Article 17 (2) and RED Annex V on GHG emission saving. For this calculation IPCC guidelines for National Greenhouse Gas Inventories, Volume 4, Chapter 11 (2006) Tier 1 was used.

When calculating emissions of N_2O from cultivation, both direct and indirect emissions were included. In case of direct emission N in synthetic fertilizers, organic fertilizers (50% from manure input) and crop residues was considered. Emission factor for direct emission was 1%.

Crop residue N was calculated from harvested yield according to default factors presented in IPCC 2006 Chapter 11 Table 11.2. Indirect N_2O emissions are calculated from volatilized NH_3 with emission factor 1% and nitrate leaching with emission factor 0.75%.

N_2O emissions from managed organic soils was decided to not include in calculations. A digitized legacy soil map (1:10,000) provides most spatially precise data on distribution of organic soils. According to study by Agricultural Research Centre (PMK 2012) about 30 thousand hectares of organic soils are currently in agricultural use. Accordingly to survey, conducted in 2011, there was carried out investigation to determine the status of peat soils. For that, 31 test areas were investigated. In conclusion of that 31 test areas 19 were exploited as permanent grasslands (PMK 2012). Field survey of legacy soil map was made mainly in period 1960-1980. Due to the intensive drainage and tillage peat has been partly mineralized and shallow peat soils has been degraded to mineral soils. According to survey by PMK (2012) about 1/3 of agriculturally managed organic soils must be currently reclassified to mineral soils. For current project PMK made special query where digitized soil map was matched with agricultural field layer under investigated crops (oilseed rape, wheat, barley, rye, triticale) in 2015. As national average from total cultivation area of these crops 2.5% was under organic soils. Because of small proportion of organic soils and high uncertainty if these areas used for bioenergy purpose were main argumentation to not include organic soils in emission calculations.

Straw removal from cultivated fields were taken 20% for all cereals and no removal was considered for rapeseed. Dry matter fraction of harvested product was set 86% for cereals and 91% for rapeseed. We considered it necessary to correct the amount of nitrogen provided in the manure. Instead of the default 100% of the manure N input we used 50% of the manure N input (Edwards et al. 2013; Köble 2014). Assessment of N input from manure and its spatial distribution is similar to the method applied in Edwards et al. (2013): Assessing GHG default emissions from biofuels in EU legislation. Main reasons to consider only 50% of the manure input are same as presented by Edwards et al. (2013): uncertainties in the input data and uncertainties when disaggregating county level manure input to the crop and field level. We have no reliable information about manure N applied to the individual crop. To calculate N_2O emissions, each county was awarded the average manure N input based on the burden of livestock units per hectare of agricultural land, taking into account that one livestock unit equals 100 kg N (Daalgard et al. 2012).

We have used national average lime fertilizer use data and applied emission factor 0.12 CO_2-C/kg. There is no statistical data available on liming of agricultural land across counties. There is large uncertainties to disaggregate liming emissions to crop and field or even region level. As the liming improves the nutritional value of many types of topsoil for the plants and increases the efficiency of fertilisers, this practice might actually lead to the reduction of N_20 emissions, which, in turn, would balance the emissions of CO_2 from lime fertilisers.

Emissions related to drying of the harvested yield can vary between years in large extent. In Nordic conditions and depending on the initial humidity of the harvest it could take 5–35 l of fuel oil to dry a tonne of grain (Ahokas 2012). Based on expert opinion we considered in all counties mean moisture content at harvest for cereals 19% and for rapeseed 13%. The energy requirement was assumed to be 5,4 MJ/kg evaporated water (Ahokas 2012). Emission factor 0.09 kg CO_2-eq/MJ for fuel oil was used in calculations.

To convert crop yield to energy we followed BioGrace calculation rules and conversion coefficients. Calorific value (lower heating value) of rapeseed was taken 26.4 MJ per kg of dry matter and 0.5784 MJ biodiesel (FAME - fatty acid methyl ester) is obtained by the industrial conversion of 1 MJ of rapeseed. We used allocation factor 58.6% in conversion rapeseed to FAME biodiesel. In extraction of oil is energy allocation 61.3% and the rest is contained in rapeseed cake. In esterification from oil to biodiesel allocation is 95.7% and rest of the energy is stored in the glycerine.

In case of any type of grain, we have applied in the calculations the values of converting wheat into ethanol: lower heating value of wheat grains is 17 MJ per kg of dry matter and 0.537 MJ ethanol is obtained from 1 MJ of wheat. In conversion of grains to ethanol allocation factor 59.5% was used.

3. Source data

3.1. Growing area and yield of crops

The growing areas of grain and rapeseed vary to a large extent in different counties (Table 3). In some counties (e.g. Hiiumaa), the growing areas of winter wheat and triticale have remained below 100 hectares as a three-year average. The largest grain growing area in Estonia has been sown with wheat, whereas spring wheat forms a slightly larger share than winter wheat. Barley is grown in Estonia on more than a hundred thousand hectares, mainly as cattle feed. Triticale is not a very popular crop so far. The grain with the greatest average yield in three years has been winter wheat (Table 4). The yields of different crops vary to a large extent per county. Grain growing has been the most productive in the counties of Central Estonia. In Hiiu county, the harvest of winter wheat practically failed in the years analysed. The level of yield has a significant influence on the GHG emissions calculated for potential energy production. The results could be harmonised to a certain degree if the analysis covered a longer time span; however, in such a case they would no longer reflect the current situation in production.

Table 3. Average growing area of a crop in 2011-2013 (in hectares). Source data: Estonian Statistical Office

County	Rye	Winter wheat	Triticale	Spring wheat	Barley	Rapeseed
Harju	606	2202	612	3584	7321	4907
Hiiu	117	81	45	337	449	272
Ida-Viru	856	1095	64	2301	3845	3013
Jõgeva	740	6431	325	8219	11695	9052
Järva	1044	4699	44	6114	14901	7688
Lääne	338	1645	129	3309	4046	3491
Lääne-Viru	2162	9079	225	9349	18864	13453
Põlva	750	2955	97	4199	6741	4889
Pärnu	759	2620	383	6091	7682	5177
Rapla	638	2204	373	4081	7219	5304
Saare	318	648	643	1669	2591	1668
Tartu	2699	9566	545	7351	12839	11463
Valga	504	2128	288	3255	3686	3580
Viljandi	1987	5876	553	9134	13383	10010
Võru	382	2494	109	2908	4574	3461
Total	13900	53723	4436	71901	119838	87427

Table 4. Average yield of a crop in 2011-2013 (t/ha). Total harvest divided by growing area. Source data: Estonian Statistical Office

County	Rye	Winter wheat	Triticale	Spring wheat	Barley	Rapeseed
Harju	2,287	3,562	3,851	2,858	2,916	1,667
Hiiu	2,493	0,646	1,948	1,559	1,835	1,504
Ida-Viru	2,248	3,873	5,292	3,027	3,092	1,999
Jõgeva	3,789	3,985	3,642	3,465	3,151	2,082
Järva	3,399	3,709	3,786	3,175	2,913	1,692
Lääne	2,471	3,142	2,879	2,379	2,255	1,420
Lääne-Viru	2,608	3,768	2,982	3,231	3,123	1,971
Põlva	2,020	3,394	4,134	3,041	3,139	1,808
Pärnu	2,674	2,715	3,031	2,722	2,338	1,461
Rapla	2,697	3,473	4,268	2,506	2,601	1,714
Saare	2,091	2,939	1,975	2,246	2,450	1,549
Tartu	2,504	4,228	4,486	3,472	3,351	2,018
Valga	2,259	3,345	4,416	2,927	3,084	1,669
Viljandi	2,844	3,620	3,611	3,185	3,206	1,783
Võru	1,975	3,040	3,945	2,873	3,151	1,649
Average	2,638	3,680	3,550	3,053	2,990	1,815

3.2. Seeds

The seeding rates for grain were acquired from the data published by the Statistical Office for 2011 (Table 5). After consultations with agricultural producers and experts we took 4 kg/ha as the seeding rate for rapeseed. Following emission values were taken in account: seeds of rapeseed 0.73 kg CO2-eq/kg (BioGrace 2015), seeds of rye 0.38 kg CO2-eq/kg (Ecoinvent 2.2 2010), seeds of wheat 0.28 kg CO2-eq/kg (BioGrace 2015) and other cereals were equalled with wheat.

Table 5. Seeding rate, calculated on the basis of the 2011 data from the Statistical Office

Crop	Seeding rate, kg/ha
Winter and spring wheat	235
Rye	182
Triticale	228
Barley	208

3.3. Use of fertilisers

Average application rates for mineral fertilisers by county were found based on the source data from the Statistical Office as a three-year average. For grain, the statistics database contains consolidated data on fertiliser use. To distinguish fertiliser application rates by types of grain we applied the following coefficients to the average: barley 1.0, wheat 1.2 and rye/triticale 0.75. These relative coefficients follow most often used recommendations for fertilising rates and are in compliance with earlier data about the use of fertilisers for different crops in Estonia.

Rapeseed is fertilised more intensely than grain (Tables 6 and 7). Counties show great variation in their rates, the lowest rates are in use in Hiiumaa, the largest ones in Jõgeva County.

In order to calculate the emissions resulting from the production of mineral fertilisers we used the following factors: 2.9 kg CO_2/kg N (Erlingson 2009 from Ahlgren et al. 2011); 0.71 kg CO_2/kg P and 0.46 kg CO_2/kg K (LowCVP 2004).

Lime fertilisers were used 28030 tons annually in 2011-2013 (Estonian Statistical Office). National average lime fertilizer rate for total arable land is 45 kg/ha. Data of regional distribution of liming is not available. Thus we used this uniform lime rate for all counties. Emission coefficient was 0.12 kg CO_2-eq/kg.

Table 6. The average use of mineral fertilisers for rapeseed in 2011-2013 (kg/ha). Source data: Estonian Statistical Office

County	N	P	K
Harju	85	6	17
Hiiu	74	8	27
Ida-Viru	90	9	21
Jõgeva	96	10	28
Järva	92	9	31
Lääne	84	8	21
Lääne-Viru	98	9	28
Põlva	98	9	32
Pärnu	69	7	21
Rapla	88	6	19
Saare	78	7	21
Tartu	100	8	29
Valga	117	8	28
Viljandi	98	12	31
Võru	92	11	34
Average	94	9	27

Table 7. The average use of mineral fertilisers for wheat, barley, rye and triticale in 2011-2013 (kg/ha). Source data: Estonian Statistical Office

County	Spring and winter wheat			Barley			Rye and triticale		
	N	P	K	N	P	K	N	P	K
Harju	75	4	10	63	3	8	47	2	6
Hiiu	33	5	9	27	4	7	21	3	6
Ida-Viru	74	6	17	61	5	14	46	4	10
Jõgeva	87	10	27	72	8	23	54	6	17
Järva	81	6	20	68	5	16	51	4	12
Lääne	65	5	11	54	4	10	41	3	7
Lääne-Viru	81	7	20	67	6	16	50	4	12
Põlva	65	7	19	54	6	16	41	4	12
Pärnu	59	8	20	49	7	16	37	5	12
Rapla	56	5	12	47	4	10	35	3	8
Saare	41	3	7	34	2	6	26	2	5
Tartu	85	7	21	71	6	18	53	4	13
Valga	72	8	24	60	7	20	45	5	15
Viljandi	76	8	21	64	7	18	48	5	13
Võru	65	7	17	54	6	15	40	4	11
Average	74	7	19	62	6	16	46	4	12

Livestock intensity in 2010 according agricultural census (Estonian Statistical Office) was basis to calculate average manure N load to agricultural land (Table 8). We considered that one livestock unit equals 100 kg N (Daalgard et al. 2012).

Table 8. The average livestock intensity (livestock units per hectar of agricultural land) in 2010 and calculated manure N load (kg/ha).

County	LU/ha	N, kg/ha
Harju	0.47	47
Hiiu	0.26	26
Ida-Viru	0.17	17
Jõgeva	0.43	43
Järva	0.33	33
Lääne	0.19	19
Lääne-Viru	0.34	34
Põlva	0.30	30
Pärnu	0.26	26
Rapla	0.26	26
Saare	0.41	41
Tartu	0.23	23
Valga	0.30	30
Viljandi	0.49	49
Võru	0.24	24
Average	0.33	33

3.4. Plant protection products

Average application rates for plant protection products by county were found based on the source data from the Statistical Office as a three-year average (Table 9). The average application rate for grain was differentiated by type of grain with the help of the following relative coefficients: wheat 1.1, barley 0.9 and rye/triticale 0.8. For rapeseed, normally more pesticides are used than for grain.

When calculating emissions, we followed the data by Olesen et al. (2004), according to which the emissions related to the production of one kg of chemical plant protection product is 4.92 kg CO_2, 0.00018 CH_4 and 0.0015 N_2O. Similar indicators have been used for calculation in both Finland and Sweden.

Table 9. The average use of plant protection products for rapeseed, wheat, barley, rye and triticale in 2011-2013 (kg/ha). Source data: Estonian Statistical Office

County	Rapeseed	Wheat	Barley	Rye and triticale
Harju	2.1	2.0	1.6	1.5
Hiiu	2.2	1.4	1.1	1.0
Ida-Viru	2.6	1.5	1.2	1.1
Jõgeva	2.9	1.7	1.4	1.3
Järva	2.6	2.6	2.1	1.9
Lääne	2.6	1.7	1.4	1.3
Lääne-Viru	2.1	2.1	1.7	1.5
Põlva	2.2	1.4	1.2	1.1
Pärnu	1.5	1.6	1.3	1.1
Rapla	2.2	1.9	1.6	1.4
Saare	1.8	1.3	1.1	0.9
Tartu	2.4	2.0	1.6	1.4
Valga	1.5	1.6	1.3	1.2
Viljandi	2.7	1.8	1.4	1.3
Võru	1.4	0.7	0.6	0.5
Average	2.3	1.8	1.5	1.3

3.5. Machine operations, soil tillage methods and fuel consumption

The charts for machine operations were compiled for three methods of soil tillage: ploughing-based, minimised and direct seeding method (Tables 10–12).

Table 10. Number of work operations in case of ploughing-based soil tillage

Work operation	Winter wheat	Spring wheat	Rye	Triticale	Barley	Rapeseed
Ploughing	1	1	1	1	1	1
Soil preparation	2	3	2	2	3	3
Sowing	1	1	1	1	1	1
Harrowing during growth	1	0	0	0	0	0
Fertilising during growth	2	2	2	2	1	1
Plant protection	3	2	1	1	1	2
Harvesting	1	1	1	1	1	1
Stubble ploughing		1			1	1

Table 11. Number of work operations in case of shallow tillage or minimised soil tillage

Work operation	Winter wheat	Spring wheat	Rye	Triticale	Barley	Rapeseed
Soil preparation	1	1	1	1	1	1
Sowing	1	1	1	1	1	1
Fertilising during growth	2	2	2	2	1	1
Plant protection	3	2	1	1	1	2
Harvesting	1	1	1	1	1	1
Stubble ploughing		1			1	1

Table 12. Number of work operations in case of direct seeding

Work operation	Winter wheat	Spring wheat	Rye	Triticale	Barley	Rapeseed
Direct drilling	1	1	1	1	1	1
Fertilising	2	2	2	2	1	1
Plant protection	3	3	3	3	3	3
Harvesting	1	1	1	1	1	1

Distribution of soil tillage methods by county was determined based on the Statistical Office data from the 2010 agricultural census (Table 13). Since in Hiiu and Ida-Viru Counties the samples of minimised soil tillage and direct seeding were too small for publication, the data for the said counties is based on the smallest possible share of the respective tillage method (6% for minimised tillage and 3% for direct seeding). The proportions of these tillage practices were applied to all the crops without further distinction.

Table 13. Soil tillage methods in 2010. Source data: Estonian Statistical Office, Agricultural Census 2010.

County	Ploughing	Minimised soil tillage	Direct seeding
Harju	61	22	17
Hiiu	91	6	3
Ida-Viru	91	6	3
Jõgeva	79	12	9
Järva	72	21	7
Lääne	74	20	5
Lääne-Viru	73	19	9
Põlva	72	18	10
Pärnu	67	25	8
Rapla	74	16	10
Saare	77	20	3
Tartu	76	15	9
Valga	77	15	8
Viljandi	64	26	10
Võru	89	6	5
Average	73	18	9

Based on the average fuel consumption of each work operation (Ahokas et al 2012; Kallas et al 2006; Viil, Tamm 2011), the average consumption of diesel fuel per hectare was calculated for the three soil preparation methods and for each crop (Tables 14–16). In all the cases the average fuel consumption of 3 l/ha for transport was also taken into account. No distinction in fuel consumption was made between counties because it would not have served any purpose as there were no direct source data for this and since the types of topsoil may vary greatly within the borders of a county.

Table 14. Fuel consumption in case of ploughing-based soil preparation (l/ha)

Work operation	Winter wheat	Spring wheat	Rye	Triticale	Barley	Rapeseed
Ploughing	15	15	15	15	15	15
Soil preparation	6.6	11.6	6.6	6.6	11.6	11.6
Sowing	7	7	7	7	7	7
Harrowing during growth	5	0	0	0	0	0
Fertilising during growth	6.2	6.2	6.2	6.2	3.1	3.1
Plant protection	6	4	2	2	2	4
Harvesting	15.6	15.6	15.6	15.6	15.6	20
Stubble ploughing		7			7	7
Total	61.4	66.4	52.4	52.4	61.3	67.7

Table 15. Fuel consumption in case of minimised soil preparation (l/ha)

Work operation	Winter wheat	Spring wheat	Rye	Triticale	Barley	Rapeseed
Soil preparation	7	7	7	7	7	7
Sowing	7	7	7	7	7	7
Fertilising during growth	6.2	6.2	6.2	6.2	3.1	3.1
Plant protection	6	4	2	2	2	4
Harvesting	15.6	15.6	15.6	15.6	15.6	20
Stubble ploughing		7			7	7
Total	41.8	46.8	37.8	37.8	41.7	48.1

Table 16. Fuel consumption in case of direct drilling (l/ha)

Direct drilling	Winter wheat	Spring wheat	Rye	Triticale	Barley	Rapeseed
Direct drilling	7	7	7	7	7	7
Fertilising	6.2	6.2	6.2	6.2	3.1	3.1
Plant protection	6	4	2	2	2	4
Harvesting	15.6	15.6	15.6	15.6	15.6	20
Total	35.2	35.2	35.2	35.2	32.1	36.1

In our calculations we assumed that for each litre of diesel fuel used (burnt in the engine) the emission is 2.6 kg CO_2 (Lindgren et al 2002).

4. Results

4.1. Direct and indirect emissions of N_2O

If there are excessive stores of mineral nitrogen in the topsoil then in certain conditions microorganisms are capable of producing nitrous oxide. The amount of mineral nitrogen to be converted into nitrous oxide depends on several factors, such as the initial form of nitrogen, the source of organic matter, temperature, soil humidity and the presence of oxygen (Gödde, Conrad, 2000; Ahlgren et al. 2011). Excess nitrogen in cultivated soil can cause the nitrogen to leach into ground water or to wash out. When a certain share of nitrogen is leached and washed out, it presumably becomes a volatile oxide, which causes indirect emissions.

Nitrous oxide emissions from cultivated land have not been measured extensively in Estonia. There are some research results available on the measurements of nitrogen emissions from swamps and drained areas. At the same time, internationally published research papers indicate that there are great variations in measurements, leading to limited repeatability of statistical results from different studies because different parameters have been used, as described by Ahlgren et al. (2011), to compare the ratio between nitrous oxide and assimilated nitrogen.

As we can see from a Swedish report on the same topic, an alternative method is recommended to calculate nitrous oxide emissions. This alternative method is grounded in a series of nitrous oxide measurements from agricultural land, which are relevant to Swedish conditions. The method makes use of extensive, mostly international source data. Calculations using this method show that the nitrous oxide emissions correspond to 4.1±2.5 and 5.0±7.2 kg N_2O/ha and year for fertilisation with less than, and more than, 100 kg N/ha and year respectively.

In connection to the increased growing area of grain in Estonia in the past few years the use of fertilisers and plant protection products has also grown. In general, the N_2O calculations indicate that the largest quantity of emissions results from the cultivation of rapeseed (Table 22), while in case of wheat, barley and other grain the emitted amount is smaller (Tables 18–21).

Table 18. Direct and indirect emissions of N_2O from the growing of barley per county

County	Total emission from the soil kg N_2O ha^{-1}	Direct N_2O emission	Indirect N_2O emission: leaching	Indirect N_2O emission: deposition in atmosphere
Harju	2.36	1.78	0.41	0.17
Hiiu	1.21	0.93	0.20	0.08
Ida-Viru	2.01	1.54	0.35	0.13
Jõgeva	2.51	1.92	0.42	0.17
Järva	2.28	1.73	0.39	0.16
Lääne	1.76	1.35	0.30	0.11
Lääne-Viru	2.31	1.76	0.39	0.16
Põlva	2.00	1.52	0.35	0.13
Pärnu	1.74	1.32	0.30	0.13
Rapla	1.73	1.32	0.30	0.11
Saare	1.60	1.22	0.27	0.11
Tartu	2.31	1.76	0.39	0.16
Valga	2.12	1.62	0.36	0.14
Viljandi	2.44	1.85	0.41	0.17
Võru	1.93	1.48	0.33	0.13
Average	2.17	1.65	0.38	0.14

Table 19. Direct and indirect emissions of N_2O from the growing of rye per county

County	Total emission from the soil kg N_2O ha^{-1}	Direct N_2O emission	Indirect N_2O emission: leaching	Indirect N_2O emission: deposition in atmosphere
Harju	1.89	1.41	0.31	0.16
Hiiu	1.13	0.86	0.19	0.08
Ida-Viru	1.52	1.16	0.27	0.09
Jõgeva	2.14	1.62	0.36	0.16
Järva	1.92	1.46	0.33	0.13
Lääne	1.48	1.14	0.25	0.09
Lääne-Viru	1.84	1.38	0.31	0.13
Põlva	1.54	1.16	0.27	0.11
Pärnu	1.48	1.13	0.25	0.09
Rapla	1.45	1.10	0.25	0.09
Saare	1.34	1.01	0.22	0.11
Tartu	1.78	1.35	0.30	0.13
Valga	1.65	1.24	0.28	0.13
Viljandi	2.00	1.49	0.35	0.16
Võru	1.45	1.10	0.25	0.09
Average	1.73	1.30	0.30	0.13

Table 20. Direct and indirect emissions of N_2O from the growing of triticale per county

County	Total emission from the soil kg N_2O ha^{-1}	Direct N_2O emission	Indirect N_2O emission: leaching	Indirect N_2O emission: deposition in atmosphere
Harju	2.07	1.57	0.35	0.16
Hiiu	1.07	0.80	0.19	0.08
Ida-Viru	1.89	1.47	0.33	0.09
Jõgeva	2.12	1.60	0.36	0.16
Järva	1.96	1.50	0.33	0.13
Lääne	1.52	1.16	0.27	0.09
Lääne-Viru	1.87	1.43	0.31	0.13
Põlva	1.78	1.37	0.30	0.11
Pärnu	1.52	1.16	0.27	0.09
Rapla	1.62	1.24	0.28	0.09
Saare	1.32	1.00	0.21	0.11
Tartu	2.00	1.52	0.35	0.13
Valga	1.89	1.43	0.33	0.13
Viljandi	2.09	1.57	0.36	0.16
Võru	1.67	1.29	0.28	0.09
Average	1.84	1.40	0.31	0.13

Table 21. Direct and indirect emissions of N_2O from the growing of wheat per county

County	Total emission from the soil kg N_2O ha^{-1}	Direct N_2O emission	Indirect N_2O emission: leaching	Indirect N_2O emission: deposition in atmosphere
Harju	2.72	2.07	0.46	0.19
Hiiu	1.29	0.97	0.22	0.09
Ida-Viru	2.39	1.84	0.41	0.14
Jõgeva	3.00	2.28	0.52	0.20
Järva	2.70	2.06	0.47	0.17
Lääne	2.11	1.60	0.36	0.14
Lääne-Viru	2.75	2.09	0.47	0.19
Põlva	2.31	1.76	0.39	0.16
Pärnu	2.06	1.56	0.36	0.14
Rapla	2.03	1.55	0.35	0.13
Saare	1.79	1.35	0.31	0.13
Tartu	2.78	2.12	0.49	0.17
Valga	2.44	1.86	0.42	0.16
Viljandi	2.80	2.12	0.47	0.20
Võru	2.20	1.68	0.38	0.14
Average	2.55	1.94	0.44	0.17

Table 22. Direct and indirect emissions of N_2O from the growing of rapeseed per county

County	Total emission from the soil kg N_2O ha^{-1}	Direct N_2O emission	Indirect N_2O emission: leaching	Indirect N_2O emission: deposition in atmosphere
Harju	2.92	2.22	0.50	0.20
Hiiu	2.39	1.82	0.41	0.16
Ida-Viru	2.83	2.17	0.49	0.17
Jõgeva	3.25	2.48	0.55	0.22
Järva	2.91	2.22	0.50	0.19
Lääne	2.50	1.92	0.42	0.16
Lääne-Viru	3.16	2.42	0.54	0.20
Põlva	3.05	2.33	0.52	0.20
Pärnu	2.28	1.73	0.39	0.16
Rapla	2.77	2.13	0.47	0.17
Saare	2.66	2.01	0.46	0.19
Tartu	3.11	2.39	0.53	0.19
Valga	3.39	2.58	0.58	0.24
Viljandi	3.27	2.48	0.55	0.24
Võru	2.80	2.12	0.49	0.19
Average	3.00	2.28	0.52	0.20

4.2. Rapeseed into biodiesel

In the EU Directive (2009/28/EC), the default greenhouse gas emissions of biodiesel made from rapeseed are 29 g CO_2/MJ. Estonian average emission is 33 g CO_2/MJ. Depending on the county, this figure varies between 29 and 41 g CO_2/MJ (Table 23). Emissions are largest in Harju county with high proportion of organic soils and in the areas with low rapeseed yield – Lääne and Valga counties. In case of all the analysed crops, the largest share of GHGs is made up of N_2O emissions (Figure 1). In case of rapeseed cultivation, the share of nitrogen fertiliser is 19% and the share of fuel is 12%. The importance of other sources is negligible.

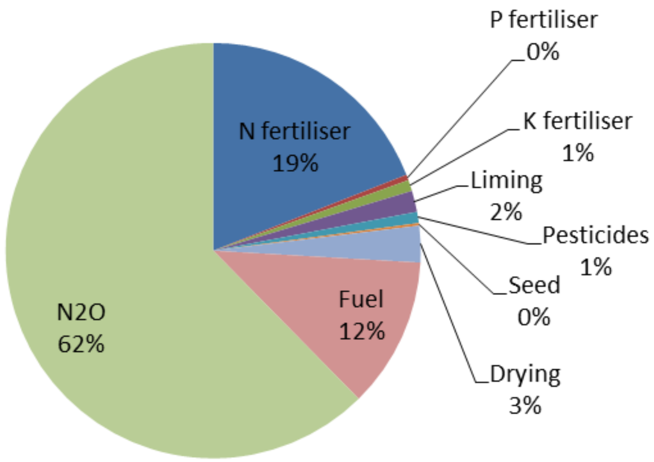

Figure 1. Distribution of sources of greenhouse gas emissions (based on CO_2 equivalent) upon the cultivation of rapeseed as the Estonian average

Table 23. The emissions of greenhouse gases upon the cultivation of rapeseed (g CO2eq/$MJ_{biodiesel}$)

County	Emission g $CO_2eq/MJ_{biodiesel}$	Emission, kg CO_2eq/ha Mineral fertiliser N	P	K	Liming	Plant protection	Seeds	Drying	Fuel	N_2O	Total
Harju	34	246	4	8	24	11	3	37	159	865	1356
Hiiu	33	215	6	13	24	12	3	34	178	707	1191
Ida-Viru	29	262	6	10	24	14	3	45	178	837	1378
Jõgeva	31	277	7	13	24	16	3	47	170	963	1519
Järva	35	266	7	14	24	14	3	38	168	861	1394
Lääne	37	245	6	10	24	14	3	32	169	740	1241
Lääne-Viru	32	284	6	13	24	11	3	44	167	935	1487
Põlva	34	283	6	15	24	12	3	40	167	902	1452
Pärnu	32	199	5	10	24	8	3	33	165	674	1120
Rapla	33	256	5	9	24	12	3	38	168	819	1332
Saare	35	227	5	10	24	10	3	35	171	786	1270
Tartu	31	289	6	13	24	13	3	45	169	921	1482
Valga	41	340	6	13	24	8	3	37	170	1005	1605
Viljandi	36	284	9	14	24	14	3	40	162	967	1517
Võru	35	267	8	16	24	7	3	37	177	828	1366
Average	33	271	6	12	24	12	3	41	167	888	1425

4.3. Spring wheat into ethanol

In the EU Directive (2009/28/EC), the default greenhouse gas emissions of ethanol made from wheat are 23 g CO_2/MJ. Average emission of 34 g CO_2/MJ, which results from the cultivation of spring wheat, exceeds the specified default value (Table 24). In the case of cereals seeds are forming about 5% of emissions (Figure 2).

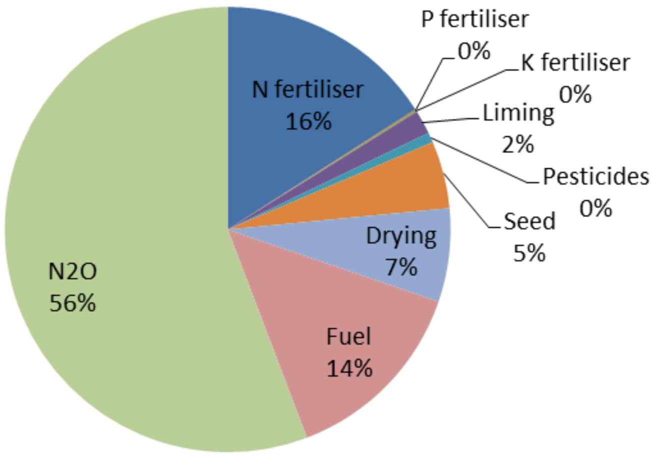

Figure 2. Distribution of sources of greenhouse gas emissions (based on CO_2 equivalent) upon the cultivation of spring wheat as the Estonian average

Table 24. The emissions of greenhouse gases upon the cultivation of spring wheat (g CO_2eq/$MJ_{ethanol}$)

County	Emission g CO_2eq/$MJ_{ethanol}$	Emission, kg CO_2eq/ha Mineral fertiliser N	P	K	Liming	Plant protection	Seeds	Drying	Fuel	N_2O	Total
Harju	37	218	11	28	24	11	66	86	159	805	1406
Hiiu	44	95	13	26	24	7	66	47	237	381	896
Ida-Viru	35	214	16	49	24	8	66	91	237	707	1411
Jõgeva	36	251	29	79	24	9	66	104	206	888	1657
Järva	36	235	18	57	24	14	66	95	188	800	1497
Lääne	39	189	14	33	24	9	66	71	193	623	1223
Lääne-Viru	35	234	20	57	24	11	66	97	189	814	1512
Põlva	33	189	20	54	24	8	66	91	188	684	1324
Pärnu	34	170	24	57	24	8	66	82	174	609	1214
Rapla	36	163	13	35	24	10	66	75	193	600	1179
Saare	35	119	8	22	24	7	66	67	200	530	1042
Tartu	34	247	21	62	24	11	66	104	197	823	1554
Valga	37	208	24	71	24	9	66	88	201	721	1411
Viljandi	36	221	23	62	24	9	66	96	167	828	1495
Võru	35	187	20	51	24	4	66	86	233	651	1322
Average	34	215	1	2	24	10	66	92	189	754	1351

4.4. Winter wheat into ethanol

The average emissions of the cultivation of winter wheat are 28 g CO_2/MJ (Table 25). In most of the counties, this figure stays in the range between 25 and 32 g CO_2/MJ. The figure for Hiiu County is extraordinarily high in the observed period because of the small yield. The largest part of the emissions resulting from the cultivation of winter wheat consists of N_2O emission (Figure 3).

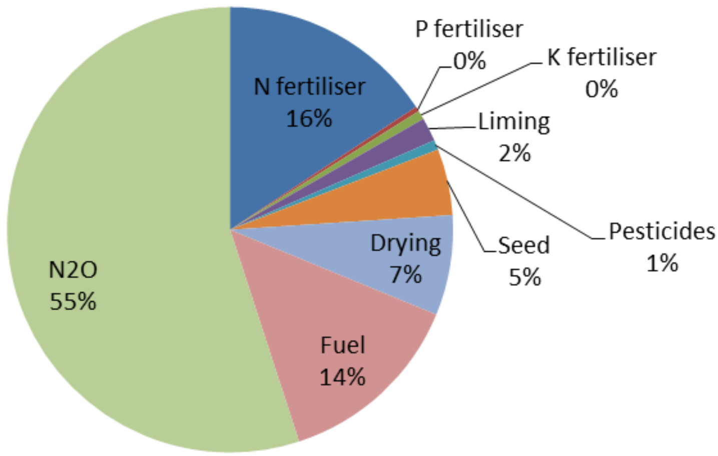

Figure 3. Distribution of sources of greenhouse gas emissions (based on CO_2 equivalent) upon the cultivation of winter wheat as the Estonian average

Table 25. The emissions of greenhouse gases upon the cultivation of winter wheat (g CO_2eq/$MJ_{ethanol}$)

County	Emission g CO_2eq/$MJ_{ethanol}$	Emission, kg CO_2eq/ha									
		Mineral fertiliser			Liming	Plant protection	Seeds	Drying	Fuel	N_2O	Total
		N	P	K							
Harju	29	218	3	4	24	11	66	94	159	805	1383
Hiiu	101	95	3	4	24	7	66	41	237	381	859
Ida-Viru	27	214	4	8	24	8	66	99	237	707	1366
Jõgeva	30	251	7	13	24	9	66	111	206	888	1575
Järva	29	235	4	9	24	14	66	102	188	800	1443
Lääne	29	189	3	5	24	9	66	79	193	623	1192
Lääne-Viru	29	234	5	9	24	11	66	105	189	814	1456
Põlva	28	189	5	9	24	8	66	96	188	684	1267
Pärnu	32	170	6	9	24	8	66	82	174	609	1148
Rapla	25	163	3	6	24	10	66	85	193	600	1150
Saare	26	119	2	3	24	7	66	73	200	530	1024
Tartu	27	247	5	10	24	11	66	117	197	823	1499
Valga	30	208	6	11	24	9	66	93	201	721	1338
Viljandi	30	221	6	10	24	9	66	101	167	828	1431
Võru	32	187	5	8	24	4	66	88	233	651	1266
Average	28	215	5	9	24	10	66	100	189	754	1370

4.5. Rye into ethanol

The average emissions of the cultivation of rye are 30 g CO_2/MJ (Table 26). As compared to other types of grain the share of N_2O emissions is a bit smaller and the share of fuel is a bit bigger in the case of rye (Figure 4).

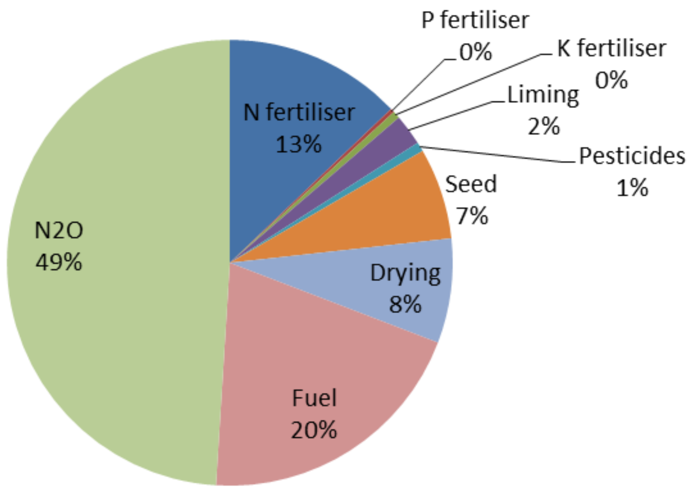

Figure 4. Distribution of sources of greenhouse gas emissions (based on CO_2 equivalent) upon the cultivation of rye as the Estonian average

Table 26. The emissions of greenhouse gases upon the cultivation of rye (g $CO_2eq/MJ_{ethanol}$)

County	Emission	Emission, kg CO_2eq/ha									
		Mineral fertiliser			Liming	Plant protection	Seeds	Drying	Fuel	N_2O	Total
	g $CO_2eq/MJ_{ethanol}$										
		N	P	K							
Harju	35	136	2	3	24	8	69	69	177	558	1045
Hiiu	25	60	2	3	24	5	69	75	264	335	836
Ida-Viru	34	134	3	5	24	6	69	67	264	451	1022
Jõgeva	25	157	4	8	24	7	69	114	229	633	1244
Järva	25	147	3	6	24	10	69	102	210	567	1137
Lääne	29	118	2	3	24	7	69	74	216	437	950
Lääne-Viru	32	146	3	6	24	8	69	78	210	544	1089
Põlva	36	118	3	5	24	6	69	61	210	456	951
Pärnu	26	106	4	6	24	6	69	80	194	437	926
Rapla	26	102	2	3	24	7	69	81	215	428	931
Saare	31	74	1	2	24	5	69	63	223	395	857
Tartu	33	154	3	6	24	8	69	75	219	526	1084
Valga	34	130	4	7	24	6	69	68	224	488	1020
Viljandi	30	138	4	6	24	7	69	85	186	591	1109
Võru	37	117	3	5	24	3	69	59	259	428	967
Average	30	134	3	6	24	7	69	79	211	512	1044

4.6. Triticale into ethanol

The emissions from triticale cultivation are 23 g CO_2/MJ on average (Table 27), this equals with the default value specified in the Directive for wheat. The largest share of emissions comprises N_2O and fuel (Figure 5).

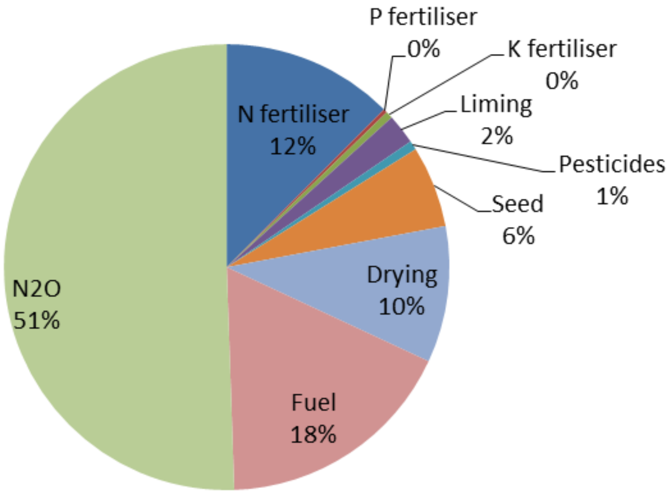

Figure 5. Distribution of sources of greenhouse gas emissions (based on CO_2 equivalent) upon the cultivation of triticale as the Estonian average

Table 27. The emissions of greenhouse gases upon the cultivation of triticale (g CO2eq/$MJ_{ethanol}$)

County	Emission g CO_2eq/$MJ_{ethanol}$	Emission, kg CO_2eq/ha									
		Mineral fertiliser			Liming	Plant protection	Seeds	Drying	Fuel	N_2O	Total
		N	P	K							
Harju	22	136	2	3	24	8	64	116	159	614	1124
Hiiu	30	60	2	3	24	5	64	58	237	316	768
Ida-Viru	17	134	3	5	24	6	64	159	237	558	1188
Jõgeva	25	157	4	8	24	7	64	109	206	628	1206
Järva	23	147	3	6	24	10	64	114	188	581	1136
Lääne	25	118	2	3	24	7	64	86	193	451	949
Lääne-Viru	27	146	3	6	24	8	64	89	189	554	1082
Põlva	19	118	3	5	24	6	64	124	188	526	1057
Pärnu	23	106	4	6	24	6	64	91	174	451	925
Rapla	18	102	2	3	24	7	64	128	193	479	1002
Saare	31	74	1	2	24	5	64	59	200	391	820
Tartu	20	154	3	6	24	8	64	135	197	591	1180
Valga	19	130	4	7	24	6	64	132	201	558	1126
Viljandi	24	138	4	6	24	7	64	108	167	619	1136
Võru	20	117	3	5	24	3	64	118	233	493	1059
Average	23	134	3	6	24	7	64	106	189	544	1077

4.7. Barley into ethanol

The average emissions of greenhouse gases upon the cultivation of barley are 30 g CO_2/MJ (Table 28). This figure is the lowest in Tartu County and the highest in Lääne County. The greatest share of the emissions consists of N_2O, followed by fuel and nitrogen fertilisers (Figure 6).

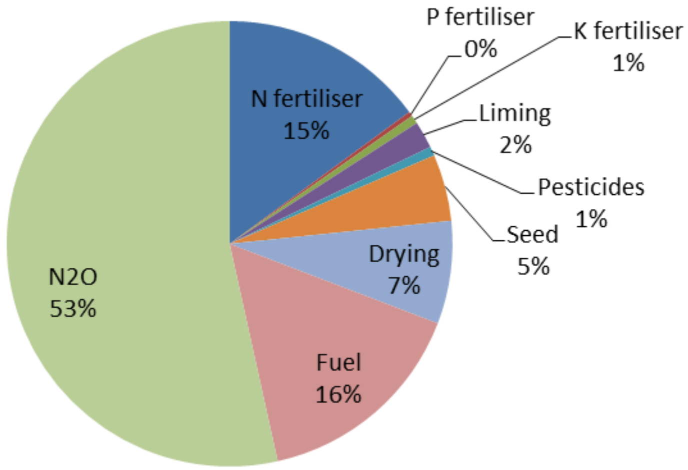

Figure 6. Distribution of sources of greenhouse gas emissions (based on CO_2 equivalent) upon the cultivation of barley as the Estonian average

Table 28. The emissions of greenhouse gases upon the cultivation of barley (g CO2eq/MJ$_{ethanol}$)

County	Emission g CO_2eq/MJ$_{ethanol}$	Emission, kg CO_2eq/ha									
		Mineral fertiliser			Liming	Plant protection	Seeds	Drying	Fuel	N_2O	Total
		N	P	K							
Harju	32	182	2	4	24	9	58	87	159	698	1222
Hiiu	34	79	3	3	24	6	58	55	237	358	823
Ida-Viru	26	178	3	6	24	7	58	93	237	456	1061
Jõgeva	33	209	6	10	24	8	58	95	206	744	1359
Järva	33	196	4	8	24	11	58	87	188	674	1250
Lääne	35	158	3	4	24	8	58	68	193	521	1036
Lääne-Viru	31	195	4	8	24	9	58	94	189	684	1264
Põlva	27	158	4	7	24	6	58	94	188	591	1130
Pärnu	33	142	5	8	24	7	58	70	174	516	1003
Rapla	30	135	3	5	24	8	58	78	193	512	1016
Saare	29	99	2	3	24	6	58	73	200	474	939
Tartu	29	206	4	8	24	9	58	101	197	684	1289
Valga	29	173	5	9	24	7	58	93	201	628	1198
Viljandi	30	184	5	8	24	8	58	96	167	721	1270
Võru	28	156	4	7	24	3	58	95	233	572	1151
Average	30	179	4	7	24	8	58	90	189	642	1201

4.8. Emissions of greenhouse gases per grain and rapeseed yield

The results of GHG emissions per energy unit (CO2eq/MJ in sections 4.2-4.7) largely depend on the technology used to convert the harvest into diesel fuel or ethanol. The direct share of cultivation in the formation of emissions could be better characterised by expressing emission burden per yield unit (e.g. CO_2eq/t of dry matter). Per one tonne of grain, spring wheat has the largest and triticale has the smallest GHG emissions among Estonian average indicators (Table 29). Upon the cultivation of rapeseed, the emissions stay within 758–1057 kg CO_2eq/t, depending on the county.

Table 29. Emissions of greenhouse gases upon the cultivation of grain and rapeseed (kg CO_2eq/t of dry matter)

County	Rye	Winter wheat	Triticale	Spring wheat	Barley	Rapeseed
Harju	531	451	339	572	487	894
Hiiu	390	1546	458	668	521	870
Ida-Viru	529	410	261	542	399	758
Jõgeva	382	459	385	556	502	802
Järva	389	452	349	548	499	905
Lääne	447	441	383	598	534	960
Lääne-Viru	485	449	422	544	471	829
Põlva	548	434	297	506	418	882
Pärnu	403	492	355	518	499	842
Rapla	401	385	273	547	454	854
Saare	476	405	483	540	446	901
Tartu	503	412	306	520	447	807
Valga	525	465	296	560	452	1057
Viljandi	453	460	366	546	461	935
Võru	570	484	312	535	425	910
Average	460	433	353	514	467	863

Conclusion

The objective of the report was to find the average values of GHGs resulting from the cultivation of various agricultural crops in Estonia. Calculations were made for rapeseed, rye, wheat, barley and triticale. The average values of GHG emissions accompanying the cultivation of these crops were determined by county. The methodology was developed based on the Regulation No. 45 of the Ministry of the Environment "Environmental requirements for liquid fuels, sustainability criteria for biofuels, procedure for the monitoring of and reporting on the compliance to environmental requirements, and the methodology for the determination of the reduction of the greenhouse gas emissions resulting from the use of biofuels and bioliquids" and on the guidelines of the Directive 2009/28/EC. Source data necessary for calculations was received from the Estonian Statistical Office, mainly as the average of three years (2011-2013), and partially from expert evaluations.

In the EU Directive (2009/28/EC), the default greenhouse gas emissions of biodiesel made from rapeseed are 29 g CO_2/MJ. The Estonian average actual emission value is 33 g CO_2/MJ. In the Directive, the default greenhouse gas emissions of ethanol made from wheat are 23 g CO_2/MJ. Emissions accompanying the cultivation of analysed grain were calculated per energy unit received during conversion into ethanol. The actual emission values as the Estonian average are as follows, depending on the type of grain: spring wheat 34 g CO_2/MJ, winter wheat 28 g CO_2/MJ, rye 30 g CO_2/MJ, triticale 23 g CO_2/MJ and barley 30 g CO_2/MJ. Greenhouse gas emissions resulting from the cultivation as expressed per dry matter yield are as follows: rapeseed 863 kg CO_2/t, spring wheat 514 kg CO_2/t, winter wheat 433 kg CO_2/t, rye 460 kg CO_2/t, triticale 353 kg CO_2/t and barley 476 kg CO_2/t.

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