GREENHOUSE GAS EMISSIONS FROM WHEAT AND RAPE WHEN CULTIVATED AS RAW MATERIALS FOR BIOFUELS IN FINLAND

Calculation in accordance with Article 19(2) of Directive 2009/28/EC of the European Parliament and of the Council

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1 INTRODUCTION

Pursuant to Article 19(2) of Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (RES Directive), Member States had to submit to the Commission by 31 March 2010 a report including a list of those areas on their territory where the typical greenhouse gas emissions from the cultivation of agricultural raw materials could 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 of the Directive. In addition, Member States have to describe the methodology and data used to establish that list. The methods used have to take into account soil characteristics, climate and expected raw material yields. However, changes in carbon stocks caused by changes in land use are not taken into account when calculating the emissions from cultivation; instead, this is included separately in the formula for calculating the total emissions from fuel use.

The allocation between fuel (ethanol, biodiesel) and co-products must be done according to their lower calorific value, regardless of the end use of the co-product. In other words, even if the dregs from ethanol production are used as feed, the allocation must be based on the assumption that the dregs are burned.

The default values for emissions from cultivation include emissions from the cultivation process (emissions from machinery and the use of fertilisers, the N_2O emissions of soil), emissions from the harvesting of the raw material (emissions from machinery) and emissions from the production of chemicals or products used in extraction or cultivation (production of fertilisers and pesticides).

The most likely first-generation biofuels in Finland would be wheat or barley ethanol and rape or turnip rape biodiesel. In this report the emissions from the cultivation of wheat and rape are calculated, as default values are set for them in Annex V of the Directive.

According to Annex V of the Directive the typical greenhouse gas emissions are:

- wheat ethanol	23 g CO_2-equiv./MJ
- rape biodiesel	29 g CO_2-equiv./MJ.

2 SOURCE DATA

2.1 Areas under crops and crop yields

According to the Directive, the report should be based on the areas classified as NUTS level 2 or lower. Finland's NUTS 2 areas are:

- East Finland (Southern Savonia, Northern Savonia, North Karelia, Kainuu)
- South Finland (Uusimaa, Finland Proper, Häme, Southeast Finland)
- West Finland (Satakunta, Pirkanmaa, Central Finland, Southern Ostrobothnia, Ostrobothnia)
- North Finland (Northern Ostrobothnia, Lapland)
- Åland.

Table 1 presents the average crop yields in the NUTS 2 areas. The yields are calculated using the average yields of the Employment and Economic Development Centres in 2009.

Table 1. Average yields of the different crops (kg/ha) by NUTS 2.

Area	Wheat	Rape
East Finland	3 225	-
South Finland	4 110	1 973
West Finland	4 008	1 813
North Finland	3 430	-
Åland	3 920	-

2.2 Seeds

The average amount of seeds sowed is (Virtanen et al. 2009, Lassi & Tulisalo 2009):

- wheat 274 kg/ha

- rape 10 kg/ha

Considering that the seed harvest is about 4 000 kg/ha for wheat and 1 700 kg/ha for rape, the emissions from wheat seeds account for about 7% and those from rape seeds for about 0.5% of the total emissions from cultivation.

2.3 Production and use of fertilisers

Yara is the only producer of fertilisers in Finland, which means that most of the fertilisers used in Finland are Yara's. Catalytic denitrification equipment was installed in Yara's nitric acid plants in 2009 and this has reduced the N_2O emissions from nitric acid production by nearly 90%. This is a decrease of 40-50% in the share of fertiliser production in overall emissions. Yara has guaranteed that the emissions of fertilisers produced in the Nordic countries are under 4 kg CO_2-equiv./kg N. This value has been verified by Det Norske Veritas (DNV). (Yara 2010) The value for fertiliser production used in the calculation is thus 4 kg CO_2-equiv./kg N.

The application rates of fertilisers are based on the authorised fertiliser amounts in the commitment requirements related to environmental aid (Finnish Agency for Rural Affairs 2009). The amounts of nitrogenous fertiliser applied are 100 kg N/ha for wheat and rape.

2.4 Production and use of pesticides

The emissions from the production of pesticides are (Ahlgren et al. 2009):

- 4.92 kg CO_2/kg

- 0.00018 kg CH_4/kg

- 0.0015 kg N_2O /kg

The application rates of pesticides are based on the growth programmes of Agrimarket (2009) and the crop cultivation guide of K-maatalous (2010), because farmers are expected to follow these recommendations. It is assumed that the pesticide application rate is 2 kg/ha. The pesticides available and their application rates may change in the future, but as the emissions from pesticide use are marginal, this will not have much effect on overall emissions.

2.5 Machinery

The report focuses on traditional cultivation, which includes tillage (ploughing and harrowing), sowing, fertilising, the application of pesticides, threshing and crop transport. The fuel consumption data for each phase are based on Mikkola and Ahokas (2010).

2.7 Transport

When calculating the emissions from fertiliser transport, it is estimated that the distance covered is 200 km. It is also assumed that the fertilisers are transported from the place of production to the place of use with a full trailer combination truck that is fully loaded (40 tonnes) but empty when returning. The emission data are from the LIISA database of the Technical Research Centre of Finland (VTT). Fertilisers must be transported to Åland by ship, but this has not been taken into account here, because the emissions from transport are insignificant.

2.8 Direct and indirect N_2O emissions

Nitrous oxide is released from the soil as a result of nitrification and denitrification processes caused by microbial activity. The strength of these processes and the formation and release of nitrous oxide depend on many factors, such as the amount and chemical form of the nitrogen, the oxygen state of the soil, the pH, the moisture content, the temperature and the amount of soluble carbon. According to the IPCC's instructions, the direct and indirect N_2O emissions from the increased input of nitrogen should be taken into account when assessing the N_2O emissions from agricultural land (Pipatti et al. 2000).

Direct N_2O emissions from the soil consist of the N_2O emissions from fertiliser use and crop residues. The emissions from fertiliser use are calculated using equation 1 (IPCC 2006).

$$N_2O_{fert} = N_{fert} \bullet EF \bullet \frac{44}{28} \qquad (1)$$

where N_{fert} is the amount of nitrogen used (kg)
EF is the emission factor (0.01 kg N_2O-N/kg N).

When calculating the N_2O emissions of crop residues, account must be taken of both the above-ground and underground biomass (roots) (IPCC 2006). The emissions from crop residues are calculated using equation 2:

$$N_2O_{\text{crop residue}} = (m_{straw} \cdot N_{straw} + m_{roots} \cdot N_{roots}) \cdot EF \cdot \frac{44}{28} \quad (2)$$

where
m_{straw} is the amount of above-ground biomass (kg)
N_{straw} is the nitrogen content of the above-ground biomass (%)
m_{roots} is the amount of underground biomass (kg)
N_{roots} is the nitrogen content of the underground biomass (%)
EF is the emission factor (0.01 kg N_2O-N/kg N).

The above-ground biomass of a crop is calculated using the harvest index (HI). The harvest index means the ratio of the dry matter of the quantities cropped to the total above-ground biomass. The harvest index of wheat is 0.45 and of rape 0.35 (Pahkala et al. 2009). The underground biomass of wheat and rape is 22% of the above-ground biomass (Ahlgren et al. 2009).

Indirect N_2O emissions consist of the evaporation and leaching of nitrogen caused by fertiliser use and are calculated using equation 3.

$$N_2O_{\text{indirect}} = (N_{fert} \cdot Frac_{GASF} \cdot EF_{GASF} + N_{fert} \cdot Frac_{LEACH} \cdot EF_{LEACH}) \cdot \frac{44}{28} \quad (3)$$

where
$Frac_{GASF}$ is the volatile part of the nitrogen (0.1)
EF_{GASF} is the emission factor for the volatile part (0.01 kg N_2O-N/kg N).
$Frac_{LEACH}$ is the leaching part of the nitrogen (0.15)
EF_{LEACH} is the emission factor for the leaching part (0.0075 kg N_2O-N/kg N).

The calculation uses the factors in the IPCC 2006 instructions except for the leaching part of the nitrogen, which is based on the national greenhouse gas inventory, which describes Finland's situation better (Statistics Finland 2009).

2.9 Yield and allocation

The ethanol yield of wheat is 7.45 MJ/kg of wheat (Virtanen et al. 2009). However, the ethanol yield may be slightly higher in the future - 7.93 MJ/kg of wheat - owing to improved technologies and chemicals. The starch wheat varieties that may be cultivated in the future will further increase the ethanol yield of wheat. The biodiesel yield of rape depends on the pressing process (hot or cold pressing). According to Bernesson et al. (2004), the biodiesel yield is 15.11 MJ/kg of rape in industrial-scale biodiesel production.

Allocation must be carried out according to the calorific value of the end products. Dregs are a co-product of ethanol production. Their calorific value according to Bernesson et al. (2006) is 19.51 MJ/kg of dry matter. Thus 60.8% of the emissions from the cultivation of wheat are allocated to ethanol, with about 1 kg of dregs per kg of ethanol being produced (Virtanen et al. 2009, Ahlgren et al. 2009). Co-products of biodiesel production include rapeseed cake and glycerol. In large-scale production of biodiesel, 64.4% of the emissions from the cultivation of rape are allocated to biodiesel (Bernesson et al. 2004).

3 RESULTS

The tables below show the emissions from the cultivation of wheat and rape in the NUTS 2 areas. The calculation is based on the average crop yield in each area.

3.1 Wheat ethanol

Table 2 presents the emissions from the cultivation of wheat in the NUTS 2 areas.

Table 2: Emissions from the cultivation of wheat in the NUTS 2 areas.

	East Finland	South Finland	West Finland	North Finland	Åland
Fertiliser production	9.25	7.46	7.65	8.94	7.82
Pesticide production	0.25	0.20	0.21	0.21	0.21
Seeds	2.16	1.74	1.78	2.05	1.82
Transport	0.29	0.23	0.24	0.27	0.24
Machinery	5.06	3.97	4.07	4.76	4.16
Direct N_2O emissions	13.60	11.22	11.44	12.94	11.64
Indirect N_2O emissions	2.35	1.84	1.89	2.21	1.93
Total	**32.96**	**26.67**	**27.28**	**31.42**	**27.83**

Only bread wheat is grown in Finland at present, but according to the JRC's report (2007) if wheat were grown as a raw material for ethanol it would be possible to achieve a yield 13.5% higher than for bread wheat with the same fertiliser amounts. The conditions for receiving environmental aid restrict the use of nitrogen fertiliser, meaning that bread wheat growers are forced to accept low yields. Professional farmers in Finland could well produce yields of over 6 000 kg/ha, but then the protein content of wheat would be too low for baking (Peltonen 2010) and the wheat would be better suited as raw material for ethanol. At present no starch wheat varieties are cultivated in Finland, but this would certainly change if the production of ethanol from wheat became more widespread. However, it is very difficult to estimate potential yield levels, so at this stage calculations must be based on the present yields of bread wheat.

3.2 Rape biodiesel

Table 3 presents the emissions from the cultivation of rape in the NUTS 2 areas.

Table 3. Emissions from the cultivation of rape in the NUTS 2 areas.

	South Finland	West Finland
Fertiliser production	8.64	9.40
Production and use of lime	3.46	3.76
Pesticide production	0.23	0.25
Seeds	0.14	0.15
Transport	0.18	0.19
Machinery	4.60	5.00

Direct N_2O emissions	13.39	13.90
Indirect N_2O emissions	2.13	2.32
Total	**32.77**	**34.99**

5 SUMMARY

Pursuant to Article 19(2) of Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (RES Directive), Member States had to submit to the Commission by 31 March 2010 a report including a list of those areas on their territory where the typical greenhouse gas emissions from the cultivation of agricultural raw materials could 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 of the Directive. The values are

- wheat ethanol 23 g CO_2-equiv./MJ
- rape biodiesel 29 g CO_2-equiv./MJ.

The emissions from cultivation in the NUTS 2 areas were calculated for wheat and rape, because default values are set for these in the Directive.

The default value of 23 g CO_2-equiv./MJ for wheat in part D of Annex V of Directive 2009/28/EC is exceeded in all NUTS 2 areas.

The default value of 29 g CO_2-equiv./MJ for rape in part D of Annex V of Directive 2009/28/EC is exceeded in all NUTS 2 areas.

The calculation also contains many uncertainties, such as the very significant uncertainty in respect of N_2O emissions from the soil. Furthermore, changes in carbon stocks caused by changes in land use are not taken into account when calculating the emissions from cultivation, because this is included separately in the formula for calculating the total emissions of fuel use. Besides, the carbon stocks of the soil are also affected by cultivation in itself, but this is not taken into account in this calculation, because the Directive does not specify whether this should be done and many uncertainty factors are involved here, too.

SOURCES

Agrimarket 2009. Kasvuohjelmat. Available at: http://www.agrimarket.fi/main.cfm?iO=118

Ahlgren, S., Hansson, P-A., Kimming, M., Aronsson, P. & Lundkvist, H. 2009. Greenhouse gas emissions from cultivation of agricultural crops for biofuels and production of biogas from manure. 2009-09-08, Revised version. Dnr SLU ua 12-4067/08.

Bernesson, S., Nilsson, D. & Hansson, P-A. 2004. A limited LCA comparing large- and medium-scale production of rape methyl esther (RME) under Swedish conditions. Biomass and Bioenergy 26 (2004) 545-559.

Bernesson, S., Nilsson, D. & Hansson, P-A. 2006. A limited LCA comparing large- and small-scale production of ethanol for heavy engines under Swedish condition. Biomass and Bioenergy 30 (2006) 46-57.

IPCC 2006. Guidelines for National Greenhouse Gas Inventories. Chapter 11. N2O Emissions from Managed Soils, and CO2 Emissions from Lime and Urea Application. Volume 4: Agriculture, Forestry and Other Land Use. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf

JRC 2007. Well-to-Wheel Analysis of Future Automotive Fuels and Powertrains in the European Context. WELL-to-TANK Report. Version 2c, March 2007. Available at: http://ies.jrc.ec.europa.eu/WTW

K-maatalous 2010. Viljelyopas. K-maatalouden viljelyohjelma. Available at: http://www.k-maatalous.fi/palvelut/asiakkuus/Documents/Viljelyopas_suomi.pdf

Lassi, K. & Tulisalo, U. 2009. Viljelytekniikka. Öljykasvinviljelijän opas. Available at: http://www.agronet.fi/rypsi2000/viljelytekniikka.htm

Agency for Rural Affairs 2009. Maatalouden ympäristötuen sitoumusehdot 2009. Euroopan maa seudun kehittämisen maatalousrahasto. Available at: http://www.mavi.fi/attachments/mavi/ymparistotuki/5FKLsan7m/Ymparistotuen_sitoumusehdot_2009.pdf

Mikkola, H. & Ahokas, J. 2010. Suomalaisten peltokasvien energiatase ja nettoenergia Saatavissa: http://www.smts.fi/jul2010/esite2010/091.pdf

Pahkala, K., Hakala, K., Kontturi, M. & Niemeläinen, O. 2009. Peltobiomassat globaalina energianlähteenä. Maa- ja elintarviketalous 137.

Peltonen, J. 2010. Ympäristösäännöt estävät myllyvehnän viljelyn. Maatilan Pellervo. February 2010.

Pipatti, R., Tuhkanen, S., Mälkiä, P. & Pietilä, R. 2000. Maatalouden kasvihuonekaasupäästöt sekä päästöjen vähentämisen mahdollisuudet ja kustannustehokkuus. VTT julkaisuja 841. Espoo 2000.

Statistics Finland 2009. Greenhouse Gas Emissions in Finland 1990-2007. National Inventory Report under the UNFCCC and the Kyoto Protocol. 8 April 2009.

Tike 2010. Matilda tietopalvelu. Peltokasvitilastot. . Available at: http://www.maataloustilastot.fi/tilasto/4

Virtanen, Y., Usva, K., Silvenius, F., Sinkko, T., Nurmi, P., Kauppinen, T. & Nousiainen, J. 2009. Peltoenergian tuotantojärjestelmien ympäristövaikutukset. Peltobioenergia-hankkeen loppuraportti.

Yara 2010. Hiilijalanjälki. Lannoituksen ilmastovaikutuksen parantaminen. Yara International 2010.
Available at: http://www.yara.fi/doc/31441Carbon%20footprint_Fi_web.pdf