Carbon footprint calculator for European farms: preliminary results of the testing phase

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ABSTRACT

To facilitate the adoption of low-carbon farming practices in Europe, the European Commission developed a carbon calculator that assesses greenhouse gas (GHG) emissions and recommends mitigation actions suitable for each farm. The Carbon Calculator, which quantifies GHG emissions based on international standards for life cycle assessment and carbon footprinting, delivers carbon footprint results both at the farm and product level. To best fine-tune the calculator, a testing phase was conducted by calculating the carbon footprints of 54 farms located in seven European countries that were characterized by a variety of different practices and products. Wide variation was found in the carbon footprints quantified within each product group. This variation can be explained by different levels of input use, crop yields and other farming practices. It was concluded that the calculator can help EU farmers identify actions that could lead to substantial reductions in the carbon footprints of their farms and products.

Keywords: life cycle assessment, agriculture, greenhouse gas emissions, carbon footprint, environmental footprint

1. Introduction

In the European Union (EU-27 Member States), direct emissions of greenhouse gases (GHG) from agriculture accounted for around 10% of total emissions in 2011 (EEA 2013). According to the European Commission's Roadmap 2050, the target is to reduce agricultural GHG emissions by 42 – 49% relative to 1990 levels by 2050 (EC 2011).

To facilitate reducing farm-level GHG emissions, appropriate and context-specific policy instruments are needed. These measures are to be coupled with supporting tools in order to promote low-carbon farming practices. Many farm-level carbon footprint calculators have been developed to provide support to farmers in identifying the main GHG emission sources along with possible reduction strategies. Examples include the Cool Farm Tool (Hillier et al. 2011), CLA CAML Calculator (CLA 2014), Farm Carbon Calculator (FCC 2014) and Cplan Carbon Calculator (Cplan 2014). As a part of the European Commission project on Low-Carbon Farming, a new farm-level carbon calculator was developed. The Carbon Calculator is suitable for the main farming types in the whole EU, and it also generates farm specific mitigation action recommendations.

During the development process of the Carbon Calculator, the tool was tested on 54 farms around Europe. In this paper the preliminary results of the testing phase are presented and the reasons for differences in the results between different farms are investigated.

2. Methods

2.1. Carbon Calculator

The Carbon Calculator quantifies GHG emissions according to international standards and other technical specifications for life cycle assessment (LCA) and carbon footprinting (GHG Protocol 2011; ISO 14040 2006; ISO 14044 2006; ISO/TS 14067 2013) while also striving for alignment with the European Commission's Environmental Footprint methods (EC 2013) and the EnviFood Protocol (Food SCP RT 2013). The tool is designed to be suitable for the most common farm types in the EU-27.

The main elements of the method underpinning the Carbon Calculator are described below. For a broader description of the method, see Bochu *et al.* (2013). The Carbon Calculator has been developed in Microsoft Excel. Visual Basic for Applications (VBA) was used for creating user forms for data entry. Specific skills for using Microsoft Excel spread sheets are not required to operate the calculator. The tool has been designed to be used by farmers or farmers' advisors. The latest version of the Carbon Calculator, the user handbook and the methodology guide are available for free download at http://mars.jrc.ec.europa.eu/mars/Projects/LC-Farming.

2.2. System boundaries, functional units, allocation rules

The system boundaries for the Carbon Calculator extend from cradle to farm gate. Processing of foods at farm is not included in the system boundaries. The GHG emissions included are CO_2, CH_4, N_2O and hydrofluorocarbons (HFC). GHG emission sources considered are: CO_2 emissions from fuel use and burning of crop residues; CH_4 emissions from ruminant enteric fermentation and manure management; N_2O emissions from soils due to use of organic and synthetic N fertilizers; and HFC emissions from leakage of refrigeration gases. In addition, the upstream emissions generated outside of the farm include emissions from the production and transportation of farm inputs, production of buildings and farm machinery, pumping drinking or irrigation water by collective pumping systems, fuel use by contractors for field operations; and N_2O emissions from NH_3 volatilization and from N leaching and runoff are also incorporated. The user of the Carbon Calculator can choose whether direct land use change (LUC) emissions related to purchased feed are included or not.

Changes in carbon stocks in soils (management practices and land use changes) and in farmland features (natural infrastructure), as well as GHG emissions avoided through the production of renewable energy (whether used on the farm or sold) are quantified but reported separately from other GHG emission results. In addition, the carbon calculator delivers results in terms of direct primary energy use, water use and the nitrogen balance of the farm.

The Carbon Calculator quantifies emissions from the whole farm during a year (or production season). Results are presented on the basis of two different functional units, i.e. (i) the utilized agricultural area (UAA) of the farm (tCO_2-eq/ha UAA) and (ii) a ton of each of up to five main products. In the case of livestock meat production, the functional unit is a ton of carcass live weight. If the farm produces more than five products, the remaining products are allocated to a sixth category named "other products".

In the Carbon Calculator, the production data are entered separately for each crop and livestock type and, in most cases, the inputs can be directly attributed to specific products. In some cases the user has to allocate environmental loads between different products. Regarding the use of fuels in farm machinery (excluding machinery use for crop production), electricity, buildings and other materials used as production inputs (e.g. plastics), the user has to allocate the energy inputs between the products of the farm. Fuel used for field operations is directly attributed to the corresponding crops. The user has to indicate whether each crop is used for feed at the farm or sold out.

In the case of co-products (e.g. milk and meat or eggs and meat) physical allocation based on protein content is used. Meat output is determined based on the weight of the animals sold during the assessment period. The emissions of the whole cattle herd during the assessment period are fully allocated to the products (meat, milk or eggs) delivered by the farm during the assessment period. If the farm does not sell any animals during the assessment period, the carbon footprint of meat is not measured by the Carbon Calculator and all emissions are allocated to the milk sold. Indeed, this is a weakness of the current Calculator that will have to be remedied in its next version.

Two options for the end of life management of exported manure are included: manure is spread on another farmland or treated as residue. If manure is spread on another farm, the farm inventory is credited for the avoided emissions from nitrogen-based fertilizer production calculated as an equal amount of nitrogen from mineral fertilizers. If manure is managed as residue, the emissions from its management are included in the carbon footprint of the farm. In both cases, the emissions from transportation of manure are included.

2.3. Data for emission factors

The IPCC (2006) Tier 2 methodology is used for i) CH_4 emissions from enteric fermentation, manure storage, manure application and manure deposited on pasture land; ii) N_2O emissions from manure storage and application and N fertilizer use; and iii) changes in carbon stocks. The emissions for production and transportation of mineral fertilizers are based on Weiss and Leip (2012), Wood and Cowie (2004), ADEME (2012), GESTIM (2010) and Brentrup and Palliere (2008). For purchased feedstuff the user can choose between two datasets: data based on Weiss and Leip (2012) include LUC emissions whereas data based on ADEME (2012) do not include

LUC emissions. Data from ADEME (2012) is also used for seeds, buildings, machinery, plastics and collective irrigation. Data from the European Life Cycle Data System (ELCD) (2001) are used for electricity and fuels.

2.4. Mitigation and sequestration actions

The Carbon Calculator includes 16 GHG mitigation actions. The actions were selected based on the mitigation potential and practicality of implementation by the farmers. The tool calculates the mitigation costs/savings for six mitigation actions.

2.5. Farm data

Data for the Carbon Calculator were collected from 54 farms in seven European countries, including 20 farms in Spain, 19 in the United Kingdom, 6 in the Netherlands, 4 in Italy, 2 in Germany, 2 in Poland and 1 in Slovenia. The data included 43 conventional, 8 organic, 2 integrated and 1 conservation farm. The study regions were chosen on the basis of their suitability to represent a wide range of environmental zones. The data were collected as a part of a survey that studied the farmers' willingness to use the carbon calculator (except the data from Italy) (Elbersen et al. 2013). A tutorial for the Carbon Calculator was shown to farmers before they were requested to complete a survey regarding their willingness to use the tool. The farmers were subsequently queried as to their willingness to provide farm data for the Carbon Calculator. In total, 170 farmers were approached in eight EU countries (i.e. Denmark, Germany, Spain, Netherlands, Poland, Slovenia, Sweden and United Kingdom) as part of the survey. Of these, 50 farmers provided data for the Carbon Calculator. In addition, data from 4 Italian farms were collected at a later stage.

3. Results

The three main sources of GHG emissions from livestock farms were enteric fermentation, N_2O emissions from soils and manure management. The main emission sources on crop farms included fertilizer production, N_2O emissions from soils and machinery manufacturing (Table 1). The sources with lowest contribution in both farm types were fuels manufacturing and transportation and other inputs (e.g. seeds, pesticides and plastics), and purchased feedstuff for the livestock farms.

The results of the carbon footprint of products show that the median values are close to the reference values found in literature (Table 2), even though the range between minimum and maximum values is wide. The wide range of the results, especially in livestock sectors, is explained by the allocation technique used, which attributes all of the emission of the cattle produced during the assessment period to the livestock product output produced during the assessment period. The high emissions in some crop farms can be explained by high levels of nitrogen fertilizers used on those farms.

Due to insufficient number of samples from organic farms, it was not possible to statistically evaluate the differences between carbon footprints of organic and conventional farms. The results of milk and barley were selected for further analysis as they represent the most common livestock and crop products in the dataset (Table 3). Wilcoxon non-parametric test for sample pairs showed significant difference in the carbon footprint results of milk between the UK and Italy ($W = 6$, $p= 0.022$) and Italy and Spain ($W = 12$, $p = 0.034$) whereas no significant differences were found between the other countries.

In the case of barley production, the statistical difference was tested only between Spain and the UK due to the small sample size in Poland. Significant differences in the carbon footprint results of barley production were not found between Spain and the UK.

Spearman's rank test was used for testing the correlation between nitrogen balance of the farm and carbon footprint results of milk and barley. Significant correlation was not found between nitrogen balance (nitrogen inputs – nitrogen outputs) and carbon footprint of milk production. In the case of barley, statistically significant moderate positive correlation was found between nitrogen balance and carbon footprint ($r = 0.596$, $p = 0.032$).

Table 1. Results of the sources of greenhouse gas emissions from livestock and crop farms.

Emission source	Livestock farms (N=41) % of total emissions	Median ($kgCO_2/ha$)	Variation Coefficient	Crop farms (N=13) % of total emissions	Median ($kgCO_2/ha$)	Variation Coefficient
GHG emissions from direct activities	**87**	**5960**	**1.0**	**43**	**895**	**0.5**
Enteric fermentation	54	3697	1.0	-	-	-
N_2O emissions from soils	18	1256	1.2	32	663	2.1
Manure management	12	797	1.3	-	-	-
Machinery fuel use	4	246	0.9	11	229	0.4
GHG emissions from indirect activities	**13**	**852**	**1.2**	**57**	**1166**	**0.8**
Purchased feedstuff	0.1	4	2.2	-	-	-
Purchased animals	1	60	2.4	-	-	-
Fertilizer production	6	411	0.9	33	682	0.6
Electricity use	3	205	1.4	1	5	2.9
Irrigation	0	6	3.6	-	-	-
Machinery manufacturing	2	109	1.1	20	407	1.4
Farm buildings	0.2	11	2.5	-	-	-
Fuels manufacturing and transportation	0.5	31	0.9	1	28	0.43
Other inputs (seeds, pesticides, plastics)	0.5	17	1.4	2	44	0.79
Total GHG emissions		**6812**	**1.0**		**2061**	**0.55**

Table 2. Carbon footprint results (tCO_2-eq per 1000 kg of crops or 1000 kg of live weight of animals) when land use change related emissions are not included

Product	**N**	**Median**	**Min**	**Max**	**Reference**	**Source**
Barley	15	0.5	0.3	1.4	0.3-0.7	a, b
Wheat	13	0.4	0.2	1.4	0.3-0.8	a, b
Sugar beet	5	0.4	0.1	2.7	0.2	a
Rape seed	7	1.0	0.1	4.0	1.0-1.7	a, b
Milk	27	1.0	0.5	1.8	1.1-1.8	a, b, c
Dairy meat	22	6.2	2.2	14	3.3-4.5	d
Beef	15	18	2.9	77	3.3-47.8	a, b, c, d
Sheep	7	22	13	69	3.5-51.8	a, b, c, d
Pork	5	6.7	2.1	7.7	2.3-6.2	a, b, c, d

a Nielsen et al. (2003)
b Williams et al. (2006)
c Leip et al. (2010)
d Nijdam et al. (2012)

It was found that the results of emission sources for milk and barley production in the inventory correspond closely to the results found in literature for average emissions of milk production in EU and barley production in the UK (Table 4). These results exclude land use change emissions related to purchased feed production. In the case of milk production, the main difference between the median and the reference value was in fertilizer production. This could be explained by the relatively high number of conventional farms in our database that used only manure as fertilizer. The relatively low contribution of capital goods such as buildings and machinery to the overall carbon footprint of milk may be explained by the incomplete submission of data from some farms. Often, it was found out that farmers are seemingly likely to collect little information on capital goods. Comprehensive assessments are difficult without using default data. In the case of barley, the largest difference in the median and reference values was in N_2O emissions from soils. This could be explained by high variation in the nitrogen balances in our dataset.

Table 3. Descriptive statistics of the carbon footprint results of milk and barley production (tCO_2-eq/t).

Country	Number of farms	Min	Max	Average	Median	Standard Deviation	Variation Coefficient
Milk							
Italy	4	1.27	1.55	1.37	1.34	0.13	0.09
Netherlands	4	0.80	1.62	1.07	0.92	0.38	0.36
Spain	3	0.76	0.95	0.84	0.81	0.10	0.12
United Kingdom	14	0.73	1.41	1.03	1.00	0.23	0.22
Barley							
Poland	2	0.24	0.40	0.32	0.32	0.11	0.34
Spain	6	0.43	1.41	0.67	0.49	0.39	0.58
United Kingdom	5	0.42	1.14	0.75	0.73	0.33	0.44

Table 4. Preliminary results of the sources of greenhouse gas emissions from milk and barley production (in kg CO_2-eq/1000 kg milk or barley, N = number of farms).

	Milk (N=25)				**Barley (N=13)**			
Emission source	**Min**	**Max**	**Median**	**Reference value[a]**	**Min**	**Max**	**Median**	**Reference value[b]**
Enteric fermentation	363	842	479	519	-	-	-	-
N_2O emissions from soils	24	491	140	218	114	538	248	178
Manure management	34	358	107	111	-	-	-	-
Machinery fuel use	3.7	112	15	40	27	179	58	51
Purchased feedstuff	0	493	31	50	-	-	-	-
Fertilizer production	0	110	36	136	87	719	170	128
Electricity use	2.8	84	27	50	0	50	6	10
Buildings and machinery	0.2	35	7	80	7	81	19	17
Other inputs (seeds, pesticides, plastics)	0.2	10	3.6	0	0	52	18	12
Total GHG emissions	**733**	**1615**	**985**	**1208**	**259**	**1410**	**485**	**396**

[a] Leip et al. (2010)

[b] Williams et al. (2006)

The most common mitigation actions recommended by the Carbon Calculator were agroforestry, biogas production, and reduction of methane from enteric fermentation (Table 5). The most effective mitigation actions in terms of the median mitigation potential (as % of total farm emissions reduced) included use of no-tillage, improvement of the nitrogen fertilizer balance and biogas production.

The current version of the Carbon Calculator estimates the costs/savings of some of the mitigation actions. In nearly all cases, the Carbon Calculator showed savings gained by implementing the mitigation actions (Table 6). However, these results do not include possible investment costs, but represent only the changes in the input costs.

Table 5. Preliminary results of the mitigation actions recommended to the farms in the dataset (in % of total farm-level emissions reduced).

Mitigation Action	Number of farms	Median	Variation Coefficient
No-tillage	16	9.5	0.87
Adjust N fertilizer balance	16	9.2	1.1
Biogas production	37	8.6	0.77
Agroforestry	45	6.9	1.2
Soils covered all the year	13	5.3	0.64
Reduce methane from enteric fermentation	32	4.8	0.42
Implementation of hedges and other landscape elements	15	4.2	0.60
Introduction of legumes in the rotation	27	3.0	0.82
Change in slurry management system: cover/crust	1	1.9	-
Wood boiler	2	1.8	0.31
Reduce engines fuel consumption (test and eco driving)	10	1.3	0.56
Solar panel on suitable buildings	0	-	-
Introduction of legumes in grasslands	0	-	-
Avoid burning residues	0	-	-
Reduction of electricity consumption of the milking system	0	-	-
Heat water with solar panel	0	-	-

Table 6. Preliminary results of the greenhouse gas mitigation costs/savings

Mitigation action		Mitigation savings (Euro/ha)		
	N	Median	Min	Max
Adjust N fertilizer use	19	93	3.1	1000
Soils covered all the year	14	62	-7.2	1200
Use of wood boiler	5	33	4.0	75
Heat water with solar energy	1	9.6	9.6	9.6
Reduce tractor fuel use	19	8.7	1.7	65

4. Discussion

The preliminary results show that the Carbon Calculator generates carbon footprint results that are close to the reference values found in literature. However, the variation in the results was wide. In the case of livestock meat, the variation can be explained by the allocation method used for allocating emissions to the end product. For instance, in the case of beef, all emissions related to raising the beef cattle are allocated to the meat sold in that year. Assuming a situation when only a relatively small quantity of animals is slaughtered compared to the total number of animals raised in a certain year, the meat produced receives a relatively high apparent carbon footprint. Therefore, the allocation of the impacts to the livestock products does not reflect reality, and thus, caution is needed when the results are compared with other farms or within the same farm between different years.

In the case of crop products, some large carbon footprint preliminary results were explained by high level of nitrogen fertilizer used on those farms. The detailed results of barley production showed that the emissions of fertilizer production varied between 87 and 719 kg CO_2-eq/t barley, and the N_2O emission from soils varied between 114 and 538 kg CO_2-eq/t barley.

The data presented in this paper did not include LUC emissions related to purchased feed production. It has been shown that inclusion of LUC emissions can triple or even quadruple the carbon footprint of livestock products produced in Europe, especially when imported soybean feed is used (Weiss and Leip 2012). We found the same effect in our data when we tested the impact of the choice of purchased feed emission data on the results (data not shown).

The results produced by the Carbon Calculator have to be interpreted with caution. Due to the attributional LCA approach used, the tool does not capture possible impacts associated with indirect effects, such as substitution effect, indirect land use change, income effect, secondary effects, market-clearing price and quantity adjustments. For instance, the emissions of a farm and its products may be reduced by extensification (reduced inputs and reduced yields). However, this may lead in increased production somewhere else, assuming that consumption quantities remain at the same level. Therefore, the impact of the mitigation actions can only be judged when changes in the production patterns and outputs quantities at the farm do not induce market-level changes in production and consumption.

The results presented in this paper showed that mitigation actions recommended by the Carbon Calculator can help farmers to reduce costs while also reducing GHG emissions. This is also supported by literature. For example, MacLeod et al. (2010) showed that, in particular, mitigation actions related to improved nitrogen use efficiency can reduce costs.

In addition to GHG emissions, the Carbon Calculator reports direct energy and water use, and nitrogen balance. To avoid burden shifting from climate change to other environmental impacts, future versions of the tool the scope should be extended to include a broader range of impact categories.

5. Conclusion

This paper showed that the Carbon Calculator generates results that are comparable with results from literature. The Carbon Calculator can also help farmers identify mitigation actions that reduce input costs while decreasing GHG emissions. Due to the methodological choices related to allocation for livestock emissions, comparisons of the results between different farms should be undertaken with caution. In the case of livestock farms, the current version of the tool is best suited for comparing carbon footprint results of one farm within different years if the farm has the same number of animals and animals sold in each year. Further improvements to the tool are required before it can be used for benchmarking purposes.

Other improvement possibilities for the Calculator include harmonization of its underpinning methodology with the European Commission Organizational Environmental Footprint guidelines (EC 2013), including addition of more environmental impact categories. Further harmonization can also be sought against the forthcoming guidelines on environmental assessment of feed and livestock developed in the context of the FAO-led Livestock Environmental Assessment and Performance (LEAP) Partnership. There is also room for adding more mitigation actions, providing uncertainty assessments and providing cost/saving estimates for each mitigation action.

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This paper is from:

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

LCA Food 2014

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

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ISBN: 978-0-9882145-7-6