User Manual for
Crop.LCA
A Tool for
Agricultural LCA (Life Cycle Assessment)

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2. Introduction

Crop.LCA is a new open-source adaptable tool to carry out LCA of cropping systems. Crop.LCA can conduct a LCA of cropping systems, using as functional unit the hectare of land, by computing the inventory for energy and 14 substances. The system boundary for the Crop.LCA assessment incorporates all upstream processes of the agricultural phase, field cultivation, including soil GHG emissions, up to farm transport. Crop.LCA carries out the impact assessment for Cumulative Energy Demand (CED) in agreement with Huijbregts et al., (2010), global warming potential (GWP), acidification and eutrophication potential. The main results provided by the tool include estimates of 4 impact categories per year for each crop and the contribution towards the GWP of different processes. The tool is available online and is open source; therefore the code can be modified by the LCA practitioner. The new tool can be used to perform the assessment for either individual crops or for the whole cropping system.

Crop.LCA tool has been coded in R, an open source software (R Development Core Team 2005), and has been conceived as a modular tool with separate functions for different processes: field cultivation, machinery production, transport, maintenance and repair, the production and transport of fertiliser, seed and pesticide, nitrate leaching, soil GHG emissions, soil erosion and soil P loss. Other modules have been designed to compute global warming potential, eutrophication and acidification potential. The input files read by the tool are all .csv (comma separated values) files.

3. How to install the Crop.LCA Tool

a. If not already set up, install R on your computer. Follow the instructions at http://cran.r-project.org/
b. Next download Crop.LCA tool through the below bitbucket link: https://bitbucket.org/croplcateam/crop.lca/overview
c. Save the downloaded folder in the directory of the user's choice which it will be called: your/path/Crop.LCA
d. After the download is finished the main folder structure should appear as follows (Fig. 1):

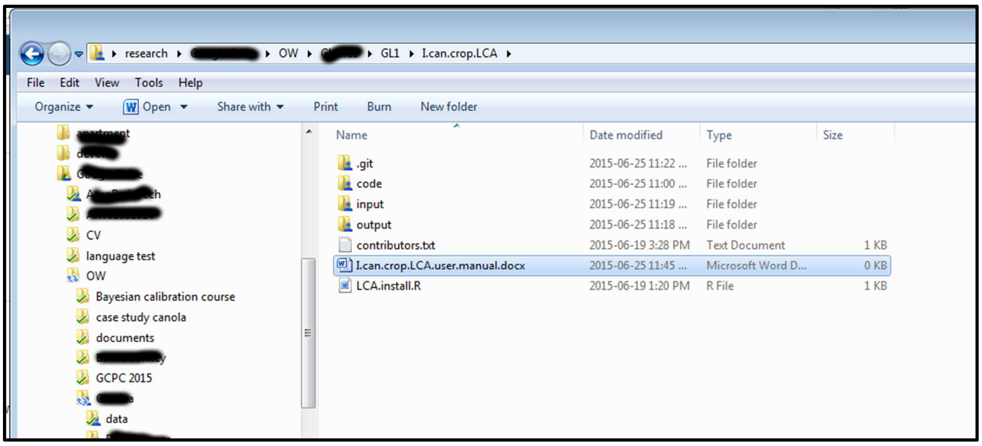


Figure 1 Directory structure of the Crop.LCA tool following installation

e. Launch R and the R prompt will appear similar to the image below (Fig. 2).

Henceforth, when an R command needs to be typed at the R prompt, it will be preceded by the “>” symbol

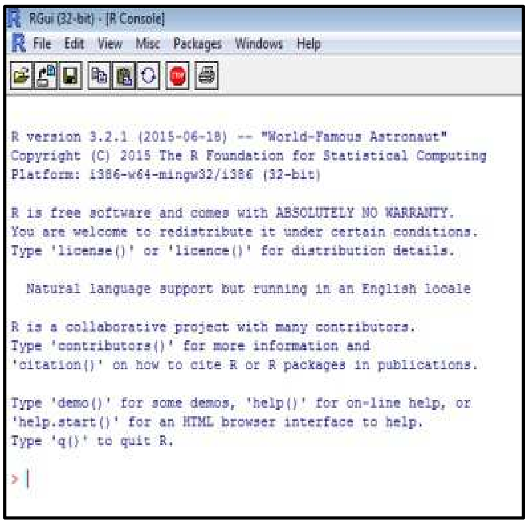


Figure 2 R prompt

f. Typing >getwd(), at the R prompt returns the working directory
g. On a Linux machine Type >setwd(“\your\path\Crop.LCA”) and on a Windows machine type > setwd(“/your/path/Crop.LCA”) to set the working directory to that where Crop.LCA was installed
h. Type >getwd() and the prompt should show:
   [1] "/your/path/Crop.LCA"
   WARNING: Countercheck that the R working directory is correct before going any further.
i. To install the Crop.LCA in the working environment of R, type >source(“LCA.install.R”)
j. In order to keep the R configuration, when you quit R, type >q() the prompt should show:
   Save workspace image? [y/n/c]:
   Press y

4. Running the Crop.LCA tool:

a. Once R has been installed and opened by clicking on the R icon, check that R has the right working directory by typing >getwd(), R should show:
   [1] "/your/path/Crop.LCA"
b. In case it is not the right working directory, follow the procedure described in section 2
c. To run Crop.LCA just type >LCA.ini()

5. Preparing input files

- Crop.LCA requires the following input files (Fig. 3):

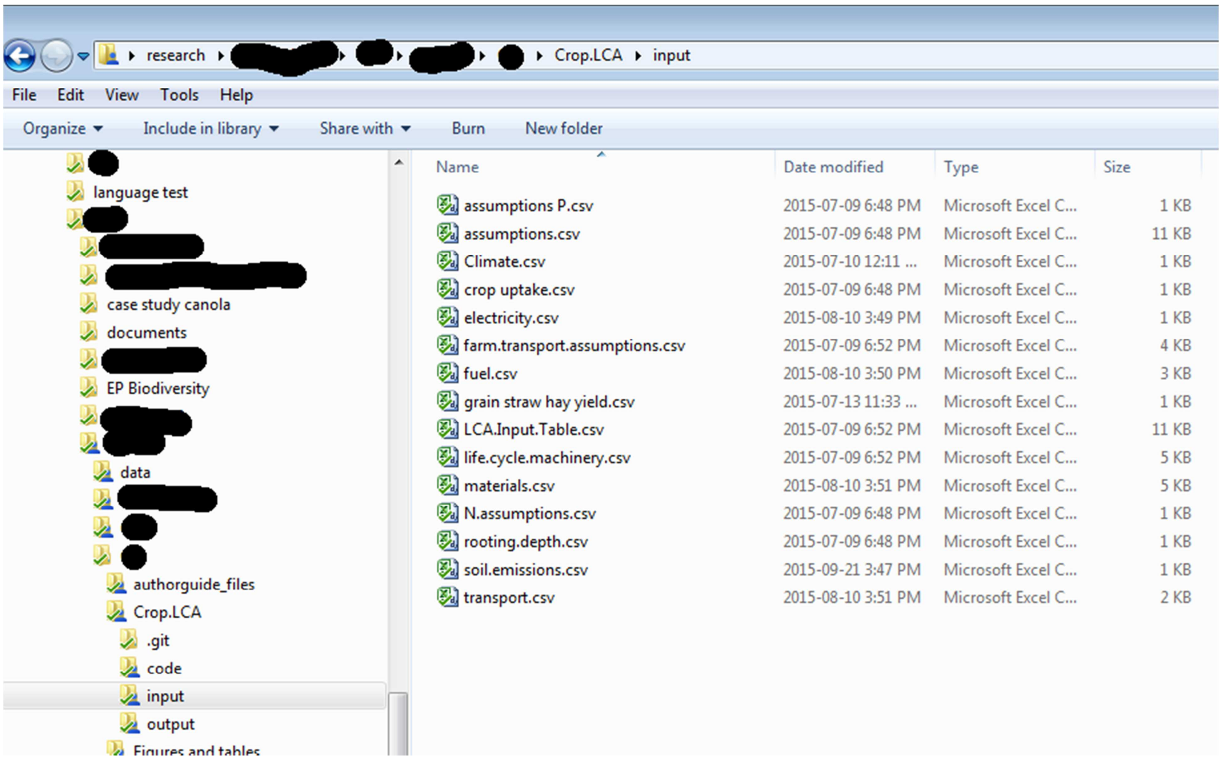


Figure 3 Input file folder of Crop.LCA tool

- The files and their contents are as follows:
  - Assumptions P.csv contains assumptions related to P loss necessary to run the SALCA-P model (Nemecek et al., 2014)
  - Assumptions.csv contains general assumptions for the whole LCA
  - Climate.csv contains rainfall and snowfall necessary to evaluate nitrate leaching with the SQBC model (Nemecek et al., 2014)
  - Crop uptake.csv contains crop N uptake values for different crops necessary to run the SQBC model (Nemecek et al., 2014)
  - Electricity.csv contains the energy consumption and emissions for electricity production at different locations, based on GHGenius ((S&T)2. 2014).
  - Farm.transport.assumptions.csv file contains assumptions related to farm transport of machinery and agricultural product from the farm centre (i.e., location of the main farm facilities including stables, barns, silage pits, and machinery storage facilities) to the field
  - Fuel.csv contains the energy consumption and emissions for fuel production depending on the location according to different sources (Brentrup, 2003; (S&T)2, 2014; USDOE, 2015)
  - Grain straw hay.csv contains values regarding machinery and hand harvested product values for hay, grain yield and residues (straw).
  - LCA.input.table.csv contains all the data regarding crop management and it is the essential file to run Crop.LCA. Improper modification of this file can affect the stability of the programme.
  - Life.cycle.machinery.csv contains statistical data regarding the life cycle of machinery in hours of use on the basis of the ASABE standards (ASABE, 2011a).

- Materials.csv contains data for production of materials (including fertiliser components, pesticides, seed, rubber and steel) based on different sources (Bhatty et al., 1979; Boehmel et al., 2008; Brentrup, 2003; Ceccon et al., 2002; Gasol et al., 2012; Goglio et al., 2012; Hacıseferoğulları et al., 2003; (S&T)2, 2014)
- N.assumptions.csv contains soil characteristics necessary to run the SQBC model (Nemecek et al., 2014).
- Rooting.depth.csv contains rooting depth values necessary to run the SQBC model (Nemecek et al., 2014) from different sources (Dardanelli et al., 1997; Manschadi et al., 1998; Nemecek et al., 2014).
- Soil.emissions.csv contains GHG emissions estimates (e.g., CO_2, N_2O, CH_4). These have to be introduced by the user.
- Transport.csv contains energy consumption and emissions for different modes/means of transport based on data from GHGenius ((S&T)2. 2014).

- ***WARNING:*** All the input files are read by the tool, therefore they cannot be deleted, nor should the column order be modified in any file.
- ***WARNING:*** life.cycle.machinery.csv and farm.transport.assumptions.csv should have the same number of rows, whereas, LCA.input.table.csv should have the number of rows of life.cycle.machinery.csv minus the number of harvest operations with a petrol truck. For instance, the input dataset downloaded from the bitbucket website contains a LCA.Input.Table.csv file with 50 lines and 3 harvest operations with a petrol truck, therefore life.cycle.machinery.csv and farm.transport.assumptions.csv have 53 lines.
- In several tables, there is mentioned NMVOC abbreviation which means non methane volatile organic compounds.
- The following files do not need to be changed unless new crops (i.e. crops currently not considered by Crop.LCA) are assessed: crop.uptake.csv, rooting.depth.csv.
- In all the input file a special declaration convention should be used for crops as shown in Table 1:

Table 1: Declaration convention for different crops which can be analysed by Crop.LCA

Crop	Crop declaration in Crop.LCA
Winter wheat, spring wheat	“Wheat”
Maize, Corn	“Maize”
Faba beans	“Faba beans”
Barley	“Barley”
Alfalfa	“Alfalfa”
Canola, Oilseed rape, Rapeseed	“Rapeseed”

- In the following paragraphs there are a description of the main files and instructions in how to fill and modify them.

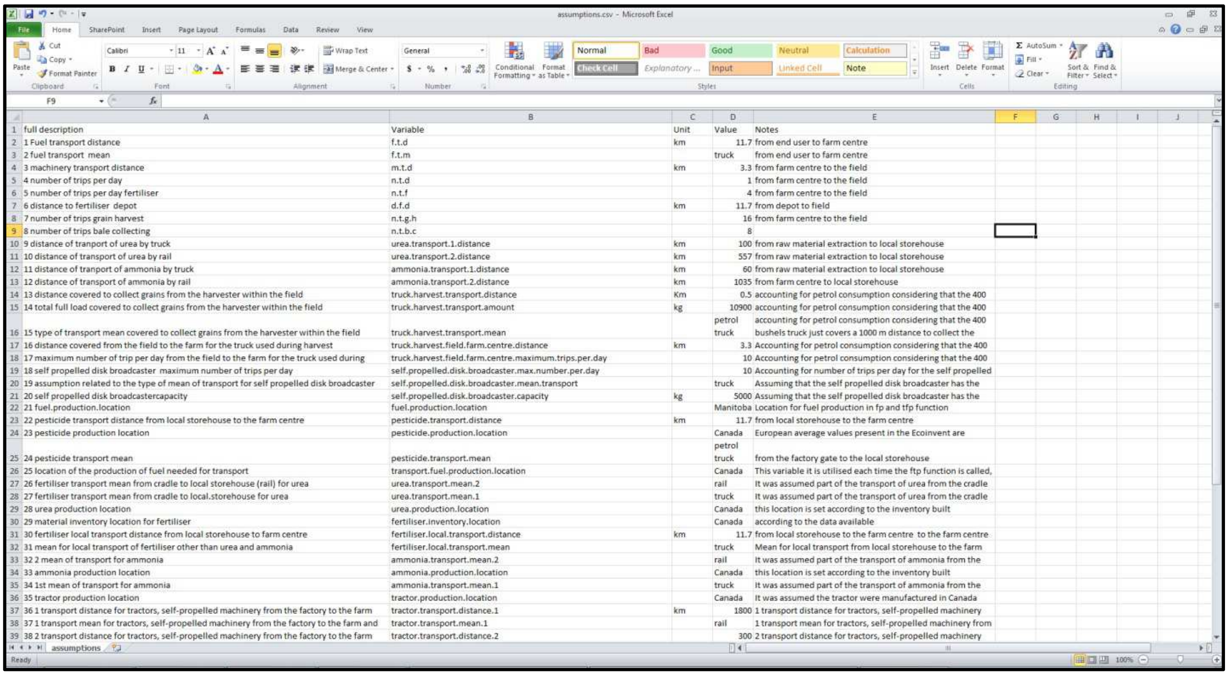
5.1 Assumptions.csv file

Here you can see a snapshot of the assumptions.csv file (Fig. 4):

- Column A contains a full description of the assumption considered
- Column B contains the name of the variable
    - ***WARNING:***

- Column B should be never modified by the user, unless significant change of the code should be carried out
- Some variables refer to the location where a certain process is carried out: this should be present also in other related files. For instance, if f.t.m (fuel transport mode) contains truck, there should be a corresponding line in the transport.csv file containing the character string "truck".

- Column C contains the units
- Column D contains alphanumerical values
  - ***WARNING:*** In Column D:
    - Cells should not contain any spaces
    - The distance given for various transport operations is the one-way distance, the transport functions tf() and tfp() automatically compute the return distance too.
- Column E notes. This column contains some details regarding the assumption variables for the user and it is not read by the tool

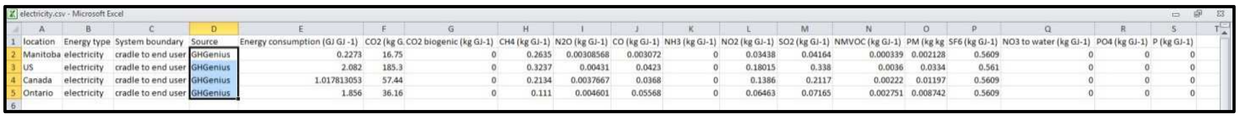


full description	Variable	Unit	Value	Notes
1 Fuel transport distance	f.t.d	km	11.7	from end user to farm centre
2 fuel transport mean	f.t.m		truck	from end user to farm centre
3 machinery transport distance	m.t.d	km	3.3	from farm centre to the field
4 number of trips per day	n.t.d		1	from farm centre to the field
5 number of trips per day fertiliser	n.t.f		4	from farm centre to the field
6 distance to fertiliser depot	d.f.d	km	11.7	from depot to field
7 number of trips grain harvest	n.t.g.h		16	from farm centre to the field
8 number of trips bale collecting	n.t.b.c		8	
9 distance of tranport of urea by truck	urea.transport.1.distance	km	100	from raw material extraction to local storehouse
10 distance of transport of urea by rail	urea.transport.2.distance	km	557	from raw material extraction to local storehouse
11 distance of tranport of ammonia by truck	ammonia.transport.1.distance	km	60	from raw material extraction to local storehouse
12 distance of transport of ammonia by rail	ammonia.transport.2.distance	km	1035	from farm centre to local storehouse
13 distance covered to collect grains from the harvester within the field	truck.harvest.transport.distance	Km	0.5	accounting for petrol consumption considering that the 400
14 total full load covered to collect grains from the harvester within the field	truck.harvest.transport.amount	kg	10900	accounting for petrol consumption considering that the 400
15 type of transport mean covered to collect grains from the harvester within the field	truck.harvest.transport.mean		petrol truck	accounting for petrol consumption considering that the 400 bushels truck just covers a 1000 m distance to collect the
16 distance covered from the field to the farm for the truck used during harvest	truck.harvest.field.farm.centre.distance	km	3.3	Accounting for petrol consumption considering that the 400
17 maximum number of trip per day from the field to the farm for the truck used during	truck.harvest.field.farm.centre.maximum.trips.per.day		10	Accounting for petrol consumption considering that the 400
18 self propelled disk broadcaster maximum number of trips per day	self.propelled.disk.broadcaster.max.number.per.day		10	Accounting for number of trips per day for the self propelled
19 assumption related to the type of mean of transport for self propelled disk broadcaster	self.propelled.disk.broadcaster.mean.transport		truck	Assuming that the self propelled disk broadcaster has the
20 self propelled disk broadcastercapacity	self.propelled.disk.broadcaster.capacity	kg	5000	Assuming that the self propelled disk broadcaster has the
21 fuel.production.location	fuel.production.location		Manitoba	Location for fuel production in fp and tfp function
22 pesticide transport distance from local storehouse to the farm centre	pesticide.transport.distance	km	11.7	from local storehouse to the farm centre
23 pesticide production location	pesticide.production.location		Canada	European average values present in the Ecoinvent are
24 pesticide transport mean	pesticide.transport.mean		petrol truck	from the factory gate to the local storehouse
25 location of the production of fuel needed for transport	transport.fuel.production.location		Canada	This variable it is utilised each time the ftp function is called,
26 fertiliser transport mean from cradle to local storehouse (rail) for urea	urea.transport.mean.2		rail	It was assumed part of the transport of urea from the cradle
27 fertiliser transport mean from cradle to local.storehouse for urea	urea.transport.mean.1		truck	It was assumed part of the transport of urea from the cradle
28 urea production location	urea.production.location		Canada	this location is set according to the inventory built
29 material inventory location for fertiliser	fertiliser.inventory.location		Canada	according to the data available
30 fertiliser local transport distance from local storehouse to farm centre	fertiliser.local.transport.distance	km	11.7	from local storehouse to the farm centre to the farm centre
31 mean for local transport of fertiliser other than urea and ammonia	fertiliser.local.transport.mean		truck	Mean for local transport from local storehouse to the farm
32 2 mean of transport for ammonia	ammonia.transport.mean.2		rail	It was assumed part of the transport of ammonia from the
33 ammonia production location	ammonia.production.location		Canada	this location is set according to the inventory built
34 1st mean of transport for ammonia	ammonia.transport.mean.1		truck	It was assumed part of the transport of ammonia from the
35 tractor production location	tractor.production.location		Canada	It was assumed the tractor were manufactured in Canada
36 1 transport distance for tractors, self-propelled machinery from the factory to the farm	tractor.transport.distance.1	km	1800	1 transport distance for tractors, self-propelled machinery
37 1 transport mean for tractors, self-propelled machinery from the factory to the farm and	tractor.transport.mean.1		rail	1 transport mean for tractors, self-propelled machinery from
38 2 transport distance for tractors, self-propelled machinery from the factory to the farm	tractor.transport.distance.2		300	2 transport distance for tractors, self-propelled machinery

Figure 4 Lay-out of the assumptions.csv file

5.2 Electricity.csv file

The electricity.csv file looks like as shown in Fig. 5:



location	Energy type	System boundary	Source	Energy consumption (GJ GJ -1)	CO2 (kg G	CO2 biogenic (kg GJ-1)	CH4 (kg GJ-1)	N2O (kg GJ-1)	CO (kg GJ-1)	NH3 (kg GJ-1)	NO2 (kg GJ-1)	SO2 (kg GJ-1)	NMVOC (kg GJ-1)	PM (kg kg	SF6 (kg GJ-1)	NO3 to water (kg GJ-1)	PO4 (kg GJ-1)	P (kg GJ-1)
Manitoba	electricity	cradle to end user	GHGenius	0.2273	16.75	0	0.2635	0.00308568	0.003072	0	0.03438	0.04164	0.000339	0.002128	0.5609	0	0	0
US	electricity	cradle to end user	GHGenius	2.082	185.3	0	0.3237	0.00431	0.0423	0	0.18015	0.338	0.0036	0.0334	0.561	0	0	0
Canada	electricity	cradle to end user	GHGenius	1.017813053	57.44	0	0.2134	0.0037667	0.0368	0	0.1386	0.2117	0.00222	0.01197	0.5609	0	0	0
Ontario	electricity	cradle to end user	GHGenius	1.856	36.16	0	0.111	0.004601	0.05568	0	0.06463	0.07165	0.002751	0.008742	0.5609	0	0	0

Figure 5 Appearance of the electricity.csv file (NMVOC: non methane volatile organic compounds; SF6: Sulphur hexafluoride; PM Particulate matter)

- Column A indicates where the electricity is produced. The country name should be put with the first letter capitalized. If the electricity production occurs in the US, the cell should contain “US”.
- Column B indicates the energy
- type, and is not read by the tool
- Column C gives the system boundary
- Column D gives the energy consumption per GJ of energy consumed
- Columns E-S contains emissions of different substances per GJ of electrical energy consumed
- Values in this file can be changed as long as there are no empty spaces in the cell.

5.3 Farm.transport.assumptions.csv

The file appears as in figure 6

- ***WARNING:*** the farm.transport.assumptions.csv file should have the same number of rows as the life.cycle.machinery.csv file, whereas the LCA.Input.Table.csv should have the number of rows as life.cycle.machinery.csv minus the number of harvest operations with petrol truck. For instance, the input dataset downloaded from the bitbucket website contains a LCA.Input.Table.csv file with 50 lines and 3 harvest operations with a petrol truck, therefore life.cycle.machinery.csv and farm.transport.assumptions.csv have 53 lines.
- ***WARNING:*** Columns A-C should have the same format as the LCA.Input.Table.csv file
- Column A contains the year of assessment. The same year of assessment should be given in the following files: Climate.csv, grain straw hay yield.csv, LCA.Input.Table.csv, life.cycle.machinery.csv, soil.GHG.emissions.csv.
- ***WARNING:*** If the crop life cycle covers two separate years, for instance 2006-2007, the harvest year should be written in column A (e.g, 2007).
- Column B: contains the plot identification which corresponds to the cropping system assessed. For instance, if the LCA involves two rotations ((2) Canola-Wheat-Barley and Canola-Wheat-Wheat (3)), the cell should contain “2”, “3”, “2+3” or “All”. The cell must not contain spaces after the plot letter or plot number. For instance “2 “ is not correct, while “2” is correct.
    - Multiple plots can be indicated with the expression “2+3”, when the transport occurs for both plot 2 and 3, or “All” indicating that the field operation is carried out for all the plots present.
- Column C: crop type for assessment. This column should have the same format of column C in the LCA.Input.Table.csv file with “Faba beans”, written in this way. The first letter of each crop should be capitalized (e.g. “Maize”, not maize, wheat as “Wheat”, barley as “Barley”, Canola and rapeseed as “Rapeseed”, alfalfa as “Alfalfa”). See Table 1.
- Column D: Crop management operations. This column should be the same as column D of LCA.input.table.csv
- Column E: operating machinery. This column should be the same as column E of the LCA.input.table.csv, except for harvest operations.
- Column F contains the distance in km for farm transport from the field to the farm centre for one single transport operation.

- Column G contains the frequency per day that the operation can potentially carried out. This value can be assessed on the basis of expert opinion.

Year	Plot	Crop	Crop.management.operation	operating machinery	Distance to field (km)	Number of trips per day
2006	2	Maize	Disk harrowing	Disk harrow	3.3	1
2006	2	Maize	Herbicide treatment	Sprayer self propelled	6.43	10
2006	2	Maize	harrowing	heavy harrow with straight spring tine	3.3	1
2006	2	Maize	harrowing	heavy harrow with straight spring tine	3.3	1
2006	2	Maize	Seeding+ fertiliser application	seeding drill + aircart	3.3	5
2006	2	Maize	fertiliser application	self propelled disk broadcaster	11.7	5
2006	2	Maize	harrowing	straight spring tine harrow	3.3	1
2006	2	Maize	Herbicide treatment	Sprayer self propelled	6.43	10
2006	2	Maize	harvesting	combined harvester+265 Petrol truck 10.9 t full load	3.3	1
2006	2	Maize	harvesting	combined harvester+265 Petrol truck 10.9 t full load	3.3	10
2006	2	Maize	Mulching	flail mower	3.3	1
2006	3	Alfalfa	seeding	mechanical seed drill	3.3	5
2006	3	Alfalfa	mowing	rotary mowing	3.3	1
2006	3	Alfalfa	mowing	rotary mowing	3.3	1
2006	3	Alfalfa	weeding	Sprayer self propelled	6.43	10
2006	3	Alfalfa	mowing	rotary mowing	3.3	1
2007	3	Alfalfa	cutting	Swather	3.3	1
2007	3	Alfalfa	windrowing	tractor*windrower	3.3	1
2007	3	Alfalfa	baling	baler	3.3	1
2007	3	Alfalfa	bale collecting	tractor + 10t trailer	3.3	10
2007	3	Alfalfa	cutting	haybine	3.3	1
2007	3	Alfalfa	windrowing	Windrower	3.3	1
2007	3	Alfalfa	baling	baler	3.3	1
2007	3	Alfalfa	bale collecting	tractor + 10t trailer	3.3	10

Figure 6 Structure of the Farm.transport.assumptions.csv file

5.4 Fuel.csv file

The fuel.csv file is similar to the electricity file and it appears as shown in Fig. 7:

location	Fuel	System boundary	Source	HHV (GJ k	Energy consumption (GJ k	CO2 (kg kg-1)	CO2 biogenic (kg kg-	CH4 (kg kg-1)
Manitoba	diesel	cradle to end user	Brentrup et al. 2004, (	0.04577	0.01496679	1.0060246	0	0.006238451
Manitoba	lubricatin	cradle to end user	Brentrup et al. 2004, (	0.04554	0.010515186	0.6744474	0	0.0056925
Manitoba	natural ga	cradle to end user	Brentrup et al. 2004, (	0.05223	0.006314607	0.35955132	0	0.008106096
Manitoba	coal	cradle to end user	Brentrup et al. 2004, (	0.02397	0.000322157	0.10050621	0	0.00066325
Manitoba	petrol	cradle to end user	Brentrup et al. 2004, (	0.04654	0.014073696	0.963378	0	0.00625963
US	coal	cradle to end user	GHGgenius, GREET	0.02397	0.0004794	1.884042	0	0.10302306
US	fuel oil	cradle to end user	GHGenius, GREET	0.04554	0.008306496	0.5815458	0	0.008953164
Canada	diesel	cradle to end user	GHGenius, GREET	0.04577	0.013058181	0.8334717	0	0.007199621
Canada	Coking co	cradle to end user	GHGenius, GREET	0.02397	0.000529737	0.11038185	0	0.001668791
Canada	fuel oil	cradle to end user	GHGenius, GREET	0.04554	0.007937622	0.5155128	0	0.00653499
Canada	natural ga	cradle to end user	GHGenius, GREET	0.05223	0.007557681	0.43909761	0	0.0083568
Canada	lubricatin	cradle to end user	GHGenius, GREET	0.04554	0.007937622	0.5155128	0	0.00653499

location	N2O (kg kg-1)	CO (kg kg-	NH3 (kg k	NO2 (kg k	SO2 (kg kg	NMVOC (kg kg-1)	PM (kg kg	SF6 (kg kg	NO3 to w	PO4 (kg k	P (kg kg-1)
Manitoba	0.0000277	0.000618	0	0.002655	0.002747	0.000199557	0.000172	0	0	0	0
Manitoba	0.0000124	0.000372	0	0.002052	0.001702	0.0000167	8.76E-05	0	0	0	0
Manitoba	0.0000102	0.000294	0	0.002181	0.000375	0.00017262	1.83E-05	0	0	0	0
Manitoba	0.00000349	4.74E-05	0	3.56E-05	1.98E-05	0.00000713	8.83E-06	0	0	0	0
Manitoba	0.0000355	0.000666	0	0.002587	0.002617	0.001247272	0.000195	0	0	0	0
US	0.10302306	0.103023	0	0.103023	0.103023	0.10302306	0.103023	0	0	0	0
US	0.0000225	0.000822	0	0.001959	0.001388	0.000199602	0.000929	0	0	0	0
Canada	0.0000321	0.000803	0	0.002497	0.0031	0.000224822	0.000217	0	0	0	0
Canada	0.00000413	8.41E-05	0	0.000425	4.44E-05	0.000013603	1.68E-05	0	0	0	0
Canada	1.67E-05	0.497297	0	0.001899	0.001523	0.000181887	9.07E-05	0	0	0	0
Canada	1.12E-05	0.000347	0	0.002378	0.000536	0.00018082	3.12E-05	0	0	0	0
Canada	1.67E-05	0.497297	0	0.001899	0.001523	0.000181887	9.07E-05	0	0	0	0

Figure 7 Lay-out of the fuel.csv file (NMVOC: non methane volatile organic compounds; SF6: Sulphur hexafluoride; PM: Particulate matter)

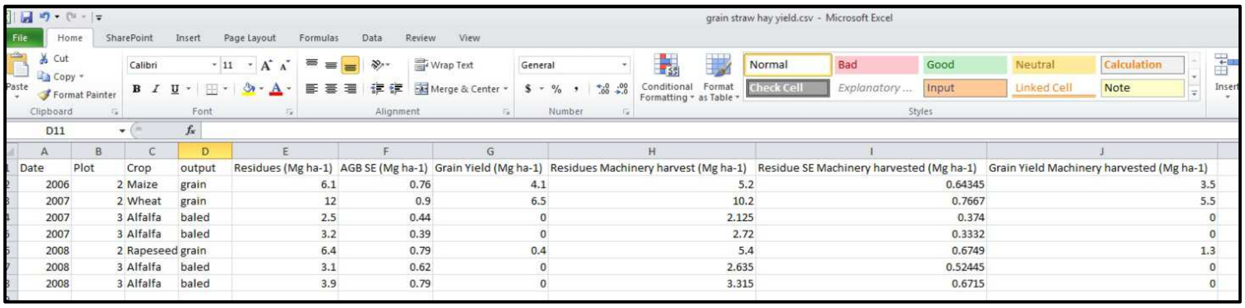
- Column A: location where the fuel is purchased and utilised
  - ***WARNING:*** the location should have the same format as in the sample file with no spaces and the first letter capitalized. However for production processes in the United States of America, the cell should simply contain "US".
- Column B: type of fuel
  - ***WARNING:*** in this column the fuel names should have the same format as in the sample file with no spaces
- Column C: system boundary
- Column D: Source

- Column E: High heating value in GJ per kg of fuel
- Column F: Energy consumption in GJ per kg of fuel
- Column G-T: Emissions per kg of fuel
- This file should be only modified when new locations have been assessed or for new fuels are added

5.5 Grain straw hay yield.csv file

The grain straw hay yield.csv contains essential data from the cropping systems assessed. The most important columns are columns A-C, column H and column J. These columns are actually read by the tool. Indeed only machinery harvested yield is considered due to the fact that this is the actual yield collected by machinery during field operations. The grain straw hay yield.csv file has the structure shown in Figure 8.

- Column A: year
    - ***WARNING:*** The year should have the same format as the LCA.input.table.csv, life.cycle.machinery, farm.transport.csv



Date	Plot	Crop	output	Residues (Mg ha-1)	AGB SE (Mg ha-1)	Grain Yield (Mg ha-1)	Residues Machinery harvest (Mg ha-1)	Residue SE Machinery harvested (Mg ha-1)	Grain Yield Machinery harvested (Mg ha-1)
2006	2	Maize	grain	6.1	0.76	4.1	5.2	0.64345	3.5
2007	2	Wheat	grain	12	0.9	6.5	10.2	0.7667	5.5
2007	3	Alfalfa	baled	2.5	0.44	0	2.125	0.374	0
2007	3	Alfalfa	baled	3.2	0.39	0	2.72	0.3332	0
2008	2	Rapeseed	grain	6.4	0.79	0.4	5.4	0.6749	1.3
2008	3	Alfalfa	baled	3.1	0.62	0	2.635	0.52445	0
2008	3	Alfalfa	baled	3.9	0.79	0	3.315	0.6715	0

Figure 8 Structure of the grain straw hay yield.csv file

-
    - ***WARNING:*** If the crop life cycle covers two separate years, for instance 2006-2007, the harvest year should be written in column A (e.g, 2007)
- Column B: Plot
    - ***WARNING:*** The plot should have the same format as the LCA.input.table.csv.
- Column C: Crop type for assessment
    - ***WARNING:*** Column C should have the same format as the LCA.Input.Table.csv, life.cycle.machinery.csv, farm.transport.csv files with “Faba beans”, written in this way. The first letter of each crop should be capitalized (e.g. “Maize”, not maize, wheat as “Wheat”, barley as “Barley”, Canola and rapeseed as “Rapeseed”, alfalfa as “Alfalfa”). See table 1.
- Column D: output. This column clarifies which output is considered and whether it is baled or not
- Column E-G: Residues, Standard errors of residues and grain yield in Mg of oven dried biomass per ha. This data are not considered by the tool because the tool only considers the mechanical harvest yield.
- Column H-J: Residues, standard error of residue and grain yield in Mg of oven dried biomass per ha with mechanical harvest yield. Column H and column J are read by the Crop.LCA tool.

5.6 LCA.input.table.csv file

The LCA.input.table.csv is the essential file of the Crop.LCA tool. It contains all the details regarding machinery operations (Figure 9, 10).

	A	B	C	D	E	F	G	H	I	J	K	
1	Year	Plot	Crop	Crop management operation	Tractor power (hp)	Machinery weight (kg)	Operating machine	Weight of the operating machine (kg)	working speed (km h-1)	Working width (m)	type of pesticide	Amount
2	2006	2	Maize	Disk harrowing	240	13381	Disk harrow	5443	8	8.53		
3	2006	2	Maize	Chemical weeding	310	14061	Sprayer self propelled		20	27.4	herbicide	1.7*0.54
4	2006	2	Maize	harrowing	239.2 KW	14099	heavy harrow with straight spring tine	7778	10	9.14		
5	2006	2	Maize	harrowing	239.2 KW	14099	heavy harrow with straight spring tine	7778	10	9.14		
6	2006	2	Maize	Seeding+ fertiliser application	239.2 KW	14099	seeding drill	5443	6.5	9.14		
7	2006	2	Maize	fertiliser application	405	4535	self propelled disk broadcaster	907	16.1	24.3		
8	2006	2	Maize	harrowing	240	13381	straight spring tine harrow	3401	12	21.3		
9	2006	2	Maize	Chemical weeding	310	14061	Sprayer self propelled		20	27.4	herbicide	1.7*0.54
10	2006	2	Maize	harvesting	340 (P 265)	17237+(3855)	combined harvester+265 Petrol truck 10.9 t full load	2722	6.88 ha h-1	9.144		
11	2006	2	Maize	Mulching	240	13381	flail mower	2993	6.4	4.57		
12	2006	3	Alfalfa	seeding	189	7801	mechanical seed drill	1067	7	3		
13	2006	3	Alfalfa	mowing	189	7801	rotary mowing	3325	7	4.5		
14	2006	3	Alfalfa	mowing	189	7801	rotary mowing	3325	7	4.5		
15	2006	3	Alfalfa	Chemical weeding	310	14061	Sprayer self propelled		20	27.4	herbicide	0.043*0.7
16	2006	3	Alfalfa	mowing	189	7801	rotary mowing	3325	7	4.5		
17	2007	3	Alfalfa	cutting	108	3290	Swather	2041	7	7.62		
18	2007	3	Alfalfa	windrowing	101	5670	tractor and windrower	613	11.3	2.6		
19	2007	3	Alfalfa	baling	101	5670	baler	2290	8	(1.9 pick up front)		
20	2007	3	Alfalfa	bale collecting	101	5670	tractor + 10t trailer 1200+(1000)		4 ha h-1			
21	2007	3	Alfalfa	cutting	108	3290	Swather	2041	7	7.62		
22	2007	3	Alfalfa	windrowing	101	5670	tractor and windrower	613	11.3	2.6		
23	2007	3	Alfalfa	baling	101	5670	baler	2290	8	(1.9 pick up front)		
24	2007	3	Alfalfa	bale collecting	101	5670	tractor + 10t trailer 1200+(1000)		4 ha h-1			
25	2007	2	Wheat	cultivating	239.2 KW	14099	heavy harrow with straight spring tine	7778	10	9.14		
26	2007	2	Wheat	harrowing	240	13381	straight spring tine harrow	3401	12	21.3		
				seeding and								

Figure 9 Columns A-K of LCA.Input.Table.csv file

L	M	N	O	P	Q
Amount of product (l ha-1) by concentration of active ingredient (kg l-1) (adjusted considering the total amount of product and the actual amount of active ingredient applied	Fertiliser amount (kg ha-1)	Composition and nutrient content	Date	Notes	Amount of seed (kg ha-1)
				CAT 45 (240hp) 6.6L 6-cylinder diesel, 22700 lbs	
1.7*0.54			13th June 2006	JD R4038 sprayer (310hp) 6-cylinder 9.0 L diseal, 90 FT boom, 3800 L spray capacity, 31000 lbs without spray liquid	
				Based on Summer superchisels 28ft, CAT MT765 (320hp) 8.8L 6-cylinder diesel engine, 29500 lbs	
				Based on Summer superchisels 28ft, CAT MT765 (320hp) 8.8L 6-cylinder diesel engine, 29500 lbs	
	180	NPKS 32-25-10-10, urea 46-0-0-0, (NH4)H2PO4 11-52-0-0, KCl 0-0-60-0,		KCl 0-0-60 Viterra: Urea NH4H2PO4 11-52-0 KCl 0-0-60 (NH4)2SO4 20.5-0-0-24, 74,130 seeds/ha	74130 seed ha-1
	112	Urea 46%	17th May 2006	SpreadMagna 100 10 mph 6191 kg fertiliser capacity	
				On the basis of the 300hp 350F DRW 4*2 with a spreadmagna mount spreader	
1.7*0.54			13th June 2006	JD R4038 sprayer (310hp) 6-cylinder 9.0 L diseal, 90 FT boom, 3800 L spray capacity, 31000 lbs without spray liquid	
			6th october 2006	Cat Lexion 470	
			25th October 2006	CAT 45 (240hp) 6.6L 6-cylinder diesel, 22700 lbs, Balzer 2500 25ft corn shredder 6600 lbs	
			28th May 2008	90% alfalfa (Medicago sativa L. ???Gala??? preinoculated) and 10% timothy grass (Phleum pretense LIs there any seedbed preparation tillage before planting? Brillion drill SS10 pull type 4.735 bushels load, 2481 lbs; Tractor model 6190R	12.5
			14th July 2008	John Deere 956	
			14th July 2008	John Deere 956	
0.043*0.7			25th July 2008	JD R4038 sprayer (310hp) 6-cylinder 9.0 L diseal, 90 FT boom, 3800 L spray capacity, 31000 lbs without spray liquid, 0.35% WW imazamox and imazethapyr; Odissey 43 g ha-1	
			14th August and 20tl	John Deere 956 rotary mower	

Figure 10 Columns L-Q of the LCA.Input.Table.csv file

- ***WARNING:*** the farm.transport.assumptions.csv file should have the same number of rows as the life.cycle.machinery.csv file, whereas LCA.input.Table.csv should have the number of rows as life.cycle.machinery.csv minus the number of harvest operations with a petrol truck. For instance, the input dataset downloaded from the bitbucket website contains a LCA.Input.Table.csv file with 50 lines and 3 harvest operations with a petrol truck, therefore life.cycle.machinery.csv and farm.transport.assumptions.csv have 53 lines.
- ***WARNING:*** For baling operations:
  - o The baling operation should be separated for each plot. For instance if plot 2 and 3 are baled: the cells in column B should contain “2” and “3” not “2+3”
  - o If a crop is baled more than once per year (for instance in the case of Alfalfa which can be cut and baled 2-3 times), the baling operations for the fodder crop should be listed sequentially and not be interrupted by the baling operations of other crops. Fig . 11 shows the correct sequence for baling operations when a crop is baled more than once per year, as compared to Fig. 12 which shows the incorrect sequence.

LCA.Input.Table..xlsx - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	
1	Year	Plot	Crop	Crop management operation	Tractor power (hp)	Machinery	Operating machine	Weight of the operating machine (kg)	working speed (km h-1)	Working width (m)	type of pesticide	Amount of product (l ha-1) by concentration of active ingredient (kg l-1) (ac
2	2007	3	Alfalfa	cutting	108	3290	Swather	2041	7	7.62		
3	2007	3	Alfalfa	windrowing	101	5670	tractor and windrower	613	11.3	2.6		
4	2007	3	Alfalfa	baling	101	5670	baler	2290		8 (1.9 pick up front)		
5	2007	3	Alfalfa	bale collecting	101	5670	tractor + 10t trailer	1200+(1000)	4 ha h-1			
6	2007	3	Alfalfa	cutting	108	3290	Swather	2041	7	7.62		
7	2007	3	Alfalfa	windrowing	101	5670	tractor and windrower	613	11.3	2.6		
8	2007	3	Alfalfa	baling	101	5670	baler	2290		8 (1.9 pick up front)		
9	2007	3	Alfalfa	bale collecting	101	5670	tractor + 10t trailer	1200+(1000)	4 ha h-1			
10	2007	2	Wheat	baling	101	5670	baler	2290		8 (1.9 pick up front)		
11	2007	2	Wheat	bale collecting	101	5670	tractor +10t trailer +front loader	1200+(1000)	4 ha h-1			

Figure 11 Correct sequence of baling operations for alfalfa and wheat

LCA.Input.Table..xlsx - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	
1	Year	Plot	Crop	Crop management operation	Tractor power (hp)	Machinery	Operating machine	Weight of the operating machine (kg)	working speed (km h-1)	Working width (m)	type of pesticide	Amount of product (l ha-1) by concentration of active ingredient (kg l-1) (ac
2	2007	3	Alfalfa	cutting	108	3290	Swather	2041	7	7.62		
3	2007	3	Alfalfa	windrowing	101	5670	tractor and windrower	613	11.3	2.6		
4	2007	3	Alfalfa	baling	101	5670	baler	2290		8 (1.9 pick up front)		
5	2007	3	Alfalfa	bale collecting	101	5670	tractor + 10t trailer	1200+(1000)	4 ha h-1			
6	2007	2	Wheat	baling	101	5670	baler	2290		8 (1.9 pick up front)		
7	2007	2	Wheat	bale collecting	101	5670	tractor +10t trailer +front loader	1200+(1000)	4 ha h-1			
8	2007	3	Alfalfa	cutting	108	3290	Swather	2041	7	7.62		
9	2007	3	Alfalfa	windrowing	101	5670	tractor and windrower	613	11.3	2.6		
10	2007	3	Alfalfa	baling	101	5670	baler	2290		8 (1.9 pick up front)		
11	2007	3	Alfalfa	bale collecting	101	5670	tractor + 10t trailer	1200+(1000)	4 ha h-1			

Figure 12 Incorrect sequence of baling operation for alfalfa and wheat

- Each line in this file represents a machinery operation with a tractor or a self-propelled machine. For harvest operation there is the option of having two powered machines of which one is the combine harvester while the other is a petrol truck with 10.9t full load capacity. The inventory values for the latter are established according to GHGenius integrated with a survey of truck manufacturers ((S&T)2. 2014). To add a new field operation, a line has to be added and filled.
- Column A: Year
  - o ***WARNING:*** The year should have the same format as the LCA.input.table.csv, life.cycle.machinery.csv, farm.transport.csv
  - o ***WARNING:*** If the crop life cycle covers two separate years, for instance 2006-2007, the harvest year should be used (e.g., 2007)
- Column B: Plot
  - o ***WARNING:*** The plot should have the same format as the LCA.input.table.csv.
  - o Column B contains the plot identification which corresponds to the cropping system assessed. For instance, if the LCA involves two rotations ((2) Canola-Wheat-Barley and Canola-Wheat-Wheat 3), the cell should contain “2”, “3”, “2+3” or “All”. The cell must not contain spaces after the plot letter or plot number. For instance “2 “ is not correct, while “2” is correct.

        - ***WARNING:*** For baling operations, the plot should be kept separate. For instance, "2+3" is not correct, while "2" and "3" in two separate cells is correct.
    - Multiple plots can be indicated with the expression "2+3", when the transport occurs for both plot 2 and 3, or "All" indicating that the field operation is carried out for all the plots present.
- Column C: Crop type for assessment
    - ***WARNING:*** Column C should have the same format as the LCA.Input.Table.csv, life.cycle.machinery.csv, farm.transport.csv files with "Faba beans", written in this way. The first letter of each crop should be capitalized (e.g. "Maize", not maize, wheat as "Wheat", barley as "Barley", Canola as "Rapeseed", alfalfa as "Alfalfa"). See Table 1.
- Column D: crop management operation
    - ***WARNING:*** The format should be exactly the same as in the sample file. The cell should not contain any space at the end of the string. For instance:
        - Seeding should be written "seeding" or "Seeding" for each seeding operation.
        - For herbicide treatment the expression "Chemical weeding" should be used.
        - For Pesticide treatments the word "Pesticide" should be contained in the cell.
        - For fertiliser applications the expression "Fertiliser" or "fertiliser" should be used.
        - For harvest the expression "Harvest" or "harvest" should be used.
        - For baling the expression "Baling" or "baling" should be used.
- Column E: Tractor, self-propelled, harvester and truck power expressed in hp.
    - ***WARNING:*** The presence of the character string "KW" allows the automatic conversion of the value present from KW to hp
    - ***WARNING:*** the presence of a "+" correspond to a new power related to a new machine. This would happen only when in column G there is the expression "Petrol" or "petrol" and in column D "harvest" or "Harvest"
- Column F: Machinery weight in kg. This is the weight of the machinery (e.g., tractor, self-propelled, truck and harvester) used during field operation
- Column G: Operating machinery.
    - ***WARNING:*** If the expression "Petrol" or "petrol" in this column and in column D there is the "Harvest", "harvest", "Harvesting" or "harvesting", the Crop.LCA tool would consider two powered machines.
- Column H: Weight of the operating machine in kg. The tool is able to handle up to three operating machines for each line of the LCA.Input.Table.csv file. The tool considers trailers and headers of combine harvesters as operating machines.
    - ***WARNING:*** The expression "1200+1000" indicates there were two machines with different weights (1200 kg, 1000 kg)
    - ***WARNING:*** A machinery life time in column G-I of the life.cycle.machinery.csv should correspond for each machinery weight. The order of appearance in the LCA.Input.Table.csv and life.cycle.machinery.csv files should be the same.
- Column I: working speed in km h^{-1}.
    - ***WARNING:*** The expression "ha h-1" in this column indicates the effective field capacity. The presence of this expression makes the tool consider the effective field capacity instead. In that case, column J can be left empty.

- Column J: Working width of the machine in m.
    - ***WARNING:*** This cell can be left empty in case the corresponding column I cell contains the expression "ha h-1".
    - ***WARNING:*** For baling, the effective field capacity is calculated as a function of the amount of biomass to be baled, in accordance to expert opinion.
- Column K: Type of pesticide or active ingredient. This column is read when the expression "Chemical weeding" or "Pesticide" is present in column D.
    - ***WARNING:*** The format of the column K cell should be similar to the column B in the materials.csv file
- Column L: Amount of product (l ha^{-1}) by concentration of active ingredient (kg l^{-1}) (adjusted considering the total amount of product and the actual amount of active ingredient applied). The first value represents the amount of product per ha (l ha^{-1}) and the second value represents the concentration of the active ingredient (kg l^{-1}). For instance, if 1.5 of a herbicide is spread over 1 ha and the active ingredient has a concentration of 0.5 kg l^{-1}, column L should contain "1.5*0.5". This column is read when the expression "weeding" or "Pesticide" is present in column D.
- Column M: Total fertiliser amount in kg ha^{-1}. This column is read when column D contains the expression "Fertiliser" or "fertiliser"
    - ***WARNING:*** by adding the expression "160+20", two separate fertilisers (not a compound fertiliser) are spread during the same fertiliser application. For instance, 160 kg ha^{-1} of ammonia are applied in the same machinery operation with 20 kg ha^{-1} of liquid ammonium polyphosphate ([NH4PO4]n) during seeding.
- Column N: Composition and nutrient content. In this cell, the composition of the fertiliser should be stated. The different component listed in this cell should have the same format as in column B of the material.csv file. This column is read when column D contains the expression "Fertiliser" or "fertiliser".
    - ***WARNING:*** To add two separate fertilisers added together, after duly modifying column N, the two fertilizers together with their nutrient concentration should be listed as follows:

      "NH3 82.4% [NH4PO4]n 10-34-0-0"

    - ***WARNING:*** To add a mixed fertiliser the user should first list the type of fertiliser (e.g., NPKS or NP), then the general nutrient content (e.g., "32-25-10-10"), then the name and composition of each nutrient component (e.g., "urea 46-0-0-0, (NH4)H2PO4 11-52-0-0, KCl 0-0-60-0, (NH4)2SO4, 20.5-0-0-24"). Therefore, in the case of this example, column N should appear as follows:

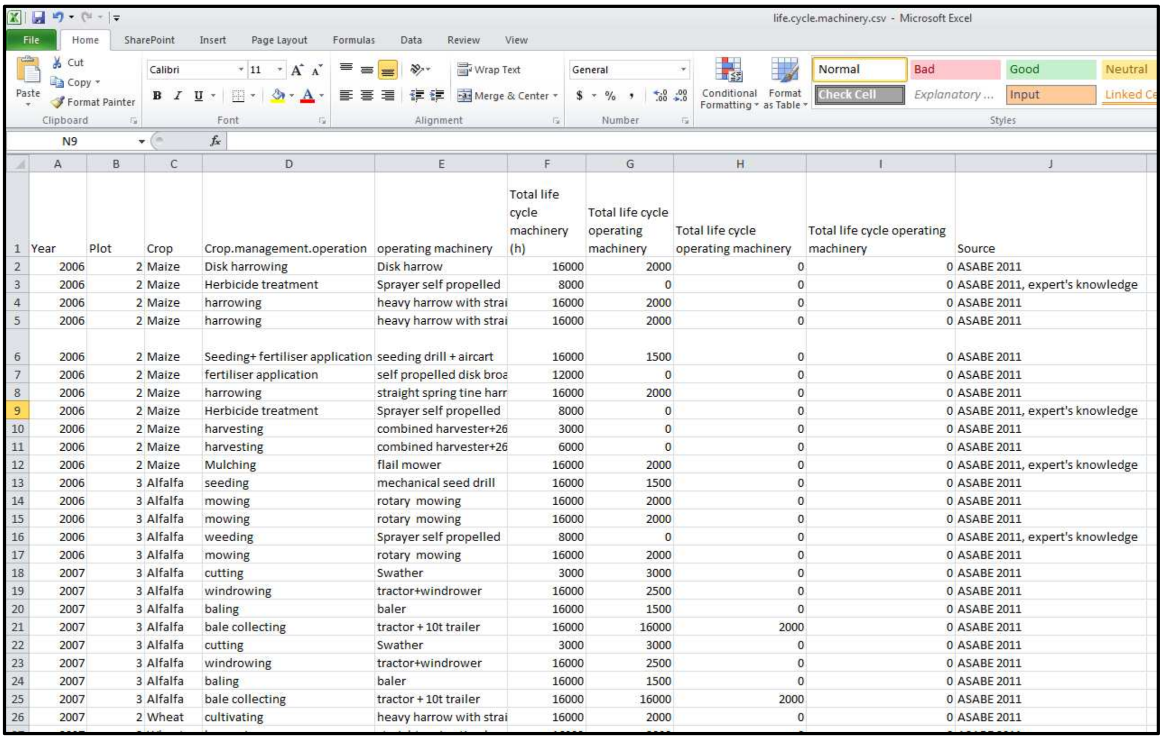
      "NPKS 32-25-10-10, urea 46-0-0-0, (NH4)H2PO4 11-52-0-0, KCl 0-0-60-0, (NH4)2SO4, 20.5-0-0-24"

- ***WARNING:*** The nutrient component and the name of the fertilizers should have the exact format as they appear in column B of the materials.csv file
- Column O: Date. This column is not read by the Crop.LCA tool
- Column P: Notes. This column is not read by the Crop.LCA tool
- Column Q: Amount of seed in kg per ha.
    - ***WARNING:*** If there is the word “seeds” and in column C there is the expression “maize”, the Crop.LCA computes the impact related to seed production considering the number of seeds per ha

5.7 Life.cycle.machinery.csv file

The life.cycle.machinery.csv file contains essential data necessary to compute the impact of production, transport, maintenance and repairs of the machinery and has the structure shown in Figure 13.

- ***WARNING:*** the farm.transport.assumptions.csv file should have the same number of rows as the life.cycle.machinery.csv file, whereas LCA.input.table.csv should have the number of rows as



	A	B	C	D	E	F	G	H	I	J
1	Year	Plot	Crop	Crop.management.operation	operating machinery	Total life cycle machinery (h)	Total life cycle operating machinery	Total life cycle operating machinery	Total life cycle operating machinery	Source
2	2006	2	Maize	Disk harrowing	Disk harrow	16000	2000	0	0	ASABE 2011
3	2006	2	Maize	Herbicide treatment	Sprayer self propelled	8000	0	0	0	ASABE 2011, expert's knowledge
4	2006	2	Maize	harrowing	heavy harrow with strai	16000	2000	0	0	ASABE 2011
5	2006	2	Maize	harrowing	heavy harrow with strai	16000	2000	0	0	ASABE 2011
6	2006	2	Maize	Seeding+ fertiliser application	seeding drill + aircart	16000	1500	0	0	ASABE 2011
7	2006	2	Maize	fertiliser application	self propelled disk broa	12000	0	0	0	ASABE 2011
8	2006	2	Maize	harrowing	straight spring tine harr	16000	2000	0	0	ASABE 2011
9	2006	2	Maize	Herbicide treatment	Sprayer self propelled	8000	0	0	0	ASABE 2011, expert's knowledge
10	2006	2	Maize	harvesting	combined harvester+26	3000	0	0	0	ASABE 2011
11	2006	2	Maize	harvesting	combined harvester+26	6000	0	0	0	ASABE 2011
12	2006	2	Maize	Mulching	flail mower	16000	2000	0	0	ASABE 2011, expert's knowledge
13	2006	3	Alfalfa	seeding	mechanical seed drill	16000	1500	0	0	ASABE 2011
14	2006	3	Alfalfa	mowing	rotary mowing	16000	2000	0	0	ASABE 2011
15	2006	3	Alfalfa	mowing	rotary mowing	16000	2000	0	0	ASABE 2011
16	2006	3	Alfalfa	weeding	Sprayer self propelled	8000	0	0	0	ASABE 2011, expert's knowledge
17	2006	3	Alfalfa	mowing	rotary mowing	16000	2000	0	0	ASABE 2011
18	2007	3	Alfalfa	cutting	Swather	3000	3000	0	0	ASABE 2011
19	2007	3	Alfalfa	windrowing	tractor+windrower	16000	2500	0	0	ASABE 2011
20	2007	3	Alfalfa	baling	baler	16000	1500	0	0	ASABE 2011
21	2007	3	Alfalfa	bale collecting	tractor + 10t trailer	16000	16000	2000	0	ASABE 2011
22	2007	3	Alfalfa	cutting	Swather	3000	3000	0	0	ASABE 2011
23	2007	3	Alfalfa	windrowing	tractor+windrower	16000	2500	0	0	ASABE 2011
24	2007	3	Alfalfa	baling	baler	16000	1500	0	0	ASABE 2011
25	2007	3	Alfalfa	bale collecting	tractor + 10t trailer	16000	16000	2000	0	ASABE 2011
26	2007	2	Wheat	cultivating	heavy harrow with strai	16000	2000	0	0	ASABE 2011

Figure 13 Structure of the life.cycle.machinery.csv

life.cycle.machinery.csv minus the number of harvest operations with petrol truck. For instance, the input dataset downloaded from the bitbucket website contains a LCA.Input.Table.csv file with

50 lines and 3 harvest operations with a petrol truck, therefore life.cycle.machinery.csv and farm.transport.assumptions.csv have 53 lines.

- Column A: Year
  - ***WARNING:*** The year should have the same format as the LCA.input.table.csv, life.cycle.machinery.csv, farm.transport.csv
  - ***WARNING:*** If the crop life cycle covers two separate years, for instance 2006-2007, the harvest year should be written in column A (e.g, 2007)
- Column B: Plot
  - ***WARNING:*** The plot should have the same format as the LCA.input.table.csv.
  - Column B: contains the plot identification which corresponds to the cropping system assessed. For instance, if the LCA involves two rotations ((2) Canola-Wheat-Barley and Canola-Wheat-Wheat 3), the cell should contain “2”, “3”, “2+3” or “All”. The cell must not contain spaces after the plot letter or plot number. For instance “2 “ is not correct, while “2” is correct.
  - Multiple plots can be indicated with the expression “2+3”, when the transport occurs for both plot 2 and 3, or “All” indicating that the field operation is carried out for all the plots present.

- Column C: Crop type for assessment

  - ***WARNING:*** Column C should have the same format as the LCA.Input.Table.csv, life.cycle.machinery.csv, farm.transport.csv files with “Faba beans”, written in this way. The first letter of each crop should be capitalized (e.g. “Maize”, not maize, wheat as “Wheat”, barley as “Barley”, Canola as “Rapeseed”, alfalfa as “Alfalfa”). See table 1.

- Column D: crop management operation
  - ***WARNING:*** The format should be exactly the same as in the sample file. The cell should not contain any space at the end of the string. For instance:
    - Seeding should be written “seeding” or “Seeding” for each seeding operation.
    - For herbicide treatment the expression “Chemical weeding” should be used.
    - For Pesticide treatments the word “Pesticide” should be contained in the cell.
    - For fertiliser applications the expression “Fertiliser” or “fertiliser” should be used.
    - For harvest the expression “Harvest” or “harvest” should be used.
    - For baling the expression “Baling” or “baling” should be used.
- Column E: Operating machinery.
  - ***WARNING:*** It should have the same format as column G in the LCA.Input.Table.csv file
  - ***WARNING:*** If the expression “Petrol” or “petrol” is found in this column and “Harvest”, “harvest”, “Harvesting” or “harvesting” is found in column D, the Crop.LCA tool would consider two operating machines.
- Column F: Total life cycle machinery (h). This indicates the total life cycle time expressed in h of powered machines (tractors, self-propelled machines, truck and combined harvesters).
- Column G-I: Total life cycle machinery (h). This indicates the total life cycle time expressed in h of each operating machine, including combine harvester headers and trailers.

- *WARNING:* A machinery life time in column G-I of the life.cycle.machinery.csv should correspond for each machinery weight in column H of the LCA.Input.Table.csv file. The order of appearance in the LCA.Input.Table.csv file and life.cycle.machinery.csv file should be the same.

- Column J: source. This column is not read by the Crop.LCA tool. It contains the source of data for the total life time of the machinery. For the machinery utilised in this sample file, the main source is the ASABE standards (ASABE, 2011a, 2011b).

5.8 Materials.csv file

The materials.csv file has the structure shown in Figure 14:

materials.csv - Microsoft Excel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	location	Material	System boundary	Source	Energy consumpt	CO2 (kg kg-1)	CO2 biogenic (kg	CH4 (kg kg-1	N2O (kg k	CO (kg kg-	NH3 (kg k	NO2 (kg k	SO2 (kg kg	NMVOC (kg kg-1)	PM (kg kg	SF6 (kg kg-1)	NO3 to water (kg kg-1)	PO4 (kg kg-1)	P (kg kg-1)
2	Canada	tractor manufactu	factory gate to factory gate	GHGenius	0.00627	0.473	0	0.000695	1.16E-05	0.000283	0	0.00118	0.000641	0.00403	0.00299	0	0	0	0
3	Canada	tractor raw materi	cradle to factory gate	GHGenius	0.0641	3.28	0	0.00579	6.58E-05	0.0126	0	0.00594	0.0104	0.0000363	0.00226	0	0	0	0
4	Canada	tractor tank produ	cradle to factory gate	GHGenius	0.0337	1.702	0	0.00438	5.65E-05	0.00111	0	0.00327	0.00209	0.0000994	0.000908	0	0	0	0
5	Canada	tractor manufactu	cradle to factory gate	GHGenius	0.00285	0.276	0	0.000421	0.00274	0.00434	0	0.00115	0.000196	0.000047	0.00004	0	0	0	0
6	Canada	steel	cradle to factory gate	GHGenius	0.036731284	0.837018289	0	0.00545346	4.06E-05	0.000599	0	0.002707	0.002692	0.000291056	0.001049341	0.003741203	0	0	0
7	Canada	rubber	cradle to factory gate	GHGenius	0.106953026	3.020626176	0	0.00432174	1.63E-05	0.000685	0	0.003586	0.004441	0.006063235	0.000483314	0.0005609	0	0	0
8	Canada	herbicide	cradle to regional storehouse	Brentrup et al. 2003, G	0.050794415	3.099307139	0	0.02503755	0.000144	0.413696	0	0.00933	0.009379	0.000646532	0.000599778	0.01037665	0	0	0
9	Canada	fungicide	cradle to regional storehouse	Brentrup et al. 2003, G	0.036244508	2.21024973	0	0.0181044	0.000102	0.249307	0	0.006705	0.006242	0.000463935	0.000401057	0.0072917	0	0	0
10	Canada	insecticide	cradle to regional storehouse	Brentrup et al. 2003, G	0.103320461	6.242545818	0	0.05072875	0.000299	1.466721	0	0.01903	0.019701	0.001243261	0.001206916	0.02596967	0	0	0
11	Canada	(NH4)H2PO4	cradle to regional storehouse	Brentrup et al. 2003, a	0.024883728	1.534762236	0	0.01465422	0.000113	0.042425	0.001985	0.012266	0.081386	0.000407591	0.006449862	3.26E-03	0	0	7.39E-05
12	Canada	KCl	cradle to regional storehouse	Brentrup et al. 2003, G	0.002248885	0.150242117	0	0.00093953	1.55E-05	0.001889	0	0.000758	0.00024	4.11E-05	3.20E-05	0	0	0	0
13	Canada	(NH4)2SO4	cradle to regional storehouse	Audsley et al. 1997 as	0.008489866	1.852435564	0	0.00052316	0.016041	0.000302	0.013	0.014574	0.000298	6.61E-05	6.76E-05	0.00E+00	0.00022	0	0
14	Canada	CO(NH2)2	cradle to factory gate	Sheehan et al., 1998,	0.04766558	0.628966091	0.001012008	0.0068299	1.71E-05	0.001899	0.001256	0.001793	0.000635	0.000544243	0.001673221	2.73E-09	0.00000154	0.00000469	1.69E-07
15	Canada	NH3	cradle to factory gate	Sheehan et al., 1998, E	0.076218111	2.305777857	0.001226454	0.01046664	0.000025	0.000921	0.000802	0.002904	0.000858	0.000890861	0.000210337	4.69E-09	0.00000174	0.00000677	2.83E-07
16	Canada	Alfalfa seed	cradle to regional storehouse	Brentrup et al. 2003, C	0.014066144	0.271845064	0	0.00107977	1.72E-05	0.017297	0	0.000684	0.000372	5.21E-05	3.82E-05	0.000291668	0	0	0
17	Canada	Maize seed	cradle to regional storehouse	Brentrup 2003, Goglio	0.018739757	0.270269268	0	0.00106218	1.71E-05	0.01675	0	0.000679	0.000367	0.0000517	0.0000379	0.000286	0	0	0
18	Canada	Faba beans seed	cradle to regional storehouse	Brentrup 2003, Hacise	0.022909757	0.270269268	0	0.00106218	1.71E-05	0.01675	0	0.000679	0.000367	0.000051661	3.79E-05	0.000286059	0	0	0
19	Canada	Wheat seed	cradle to regional storehouse	Brentrup 2003, and en	0.021066144	0.271845064	0	0.00107977	1.72E-05	0.017297	0	0.000684	0.000372	0.0000521	0.0000382	0.000291668	0	0	0
20	Canada	Barley seed	cradle to regional storehouse	Brentrup 2003, and en	0.021516597	0.268904825	0	0.00104716	1.70E-05	0.016422	0	0.000674	0.000364	5.13E-05	3.77E-05	0.00028	0	0	0
21	Canada	Rapeseed seed	cradle to regional storehouse	Brentrup 2003, and en	0.022508944	0.313880504	0	0.00151823	1.91E-05	0.028129	0	0.000836	0.000489	0.0000616	0.0000449	0.000476765	0	0	0

Figure 14 Structure of the materials.csv (NMVOC: non methane organic compounds; SF6 Sulphur hexafluoride; PM: Particulate matter)

- *WARNING:* This file should contain the same materials listed for different operations in the LCA.Input.Table.csv. The materials should be spelled in the same way as in the LCA.Input.Table.csv
- Column A: location.
  - *WARNING:* The location should have the same format as in the assumptions.csv file.
- Column B: Material.
  - *WARNING:* The material should be formatted as in the LCA.Input.Table.csv. The only exception is for seed production, in that the name of the crop should be spelled capitalizing the first letter in the following way "Faba beans" followed by term "seed". For instance column B should contain "Faba beans seed" for faba beans or "Wheat seed" for wheat.
- Column C: System boundary
- Column D: Source
- Column E: Energy consumptions in GJ per kg
- Column F-S: Emissions of different substance in kg per kg of material produced.

5.9 Soil.emissions.csv file

The soil.GHG.emissions.csv contains data on soil GHG emissions that the user has to provide in order to consider them in the inventory and the final LCA of the cropping system. The soil.GHG.emissions.csv file appears as shown in Figure 15.

- Column A: Year

- o ***WARNING:*** The year should have the same format as the LCA.input.table.csv, life.cycle.machinery.csv, farm.transport.csv

- o ***WARNING:*** If the crop life cycle covers two separate years, for instance 2006-2007, the harvest year should be written in column A (e.g., 2007)

- Column B: Plot identification which corresponds to the cropping system assessed.

  - o ***WARNING:*** The plot should have the same format as the LCA.input.table.csv.

Year	Plot	Crop	Soil CO2 emissions (kg ha-1 y-1)	Soil CH4 emissions (kg ha-1 y-1)	Soil N2O emissions (kg ha-1 y-1)	Soil NH3 volatilisation (kg ha-1 y-1)
2006	2	Maize	0	0	5.307497155	0
2006	3	Alfalfa	0	0	3.30615721	0
2007	2	Wheat	0	0	6.333771761	0
2007	3	Alfalfa	0	0	0.477797695	0
2008	2	Rapeseed	0	0	6.166085817	0
2008	3	Alfalfa	0	0	0.824256525	0

Figure 15 Lay-out of the soil.emissions.csv file

- Column C: Crop type for assessment
  - o ***WARNING:*** Column C should have the same format as the LCA.Input.Table.csv, life.cycle.machinery.csv, farm.transport.csv files with “Faba beans”, written in this way. The first letter of each crop should be capitalized (e.g. “Maize”, not maize, wheat as “Wheat”, barley as “Barley”, Canola and rapeseed as “Rapeseed”, alfalfa as “Alfalfa”). See table 1.
- Column D: Soil CO_2 emissions in kg per ha per year
- Column E: Soil CH_4 emissions in kg per ha per year
- Column F: Soil N_2O emissions in kg per ha per year
- Column G: Soil NH_3 volatilisation in kg per ha per year

5.10 Transport.csv file

The transport.csv contains data necessary to compute the impact of transport of different goods upstream and downstream of the cropping system analysed. The transport.csv file is shown in Figure 16:

Mean	Notes	Diesel consumption (	Gasoline cons	CO2 (kg km-1 kg-1)	CO2 bioge	CH4 (kg kr	N2O (kg k	CO (kg km	NH3 (kg k	NO2 (kg k	SO2 (kg kr	NMVOC (k	PM (kg kr	SF6 (kg kr	NO3 to w	PO4 (kg kg	P (kg kg-1)
truck	20t, wheel to wheel	0.0000451	0	0.000147	0	1.93E-08	6.27E-09	3.79E-08	0	6.34E-08	1.76E-08	1.94E-08	8E-09	0	0	0	0
petrol truck	20t, wheel to wheel	0	0.00014104	0.000526	0	6.15E-08	2.01E-08	2.53E-07	0	1.81E-07	5.16E-08	1.06E-07	1.93E-08	0	0	0	0
rail	wheel to wheel	0.00000481	0	0.0000166	0	3.17E-09	6.28E-09	4.03E-08	0	2.56E-07	1.35E-08	6.19E-09	8.63E-09	0	0	0	0
marine bulk freight	200Kt C5 does not indicate Diesel but heavy fuel oil consumption, wheel to wheel	0.00000132	0	0.00000514	0	1.30E-09	1.45E-10	1.17E-08	0	1.09E-07	1.14E-09	1.82E-09	2.47E-09	0	0	0	0
marine cargo freight	15000t, wheel to wheel	0.00000461	0	0.0000182	0	4.62E-09	5.14E-10	4.15E-08	0	3.85E-07	4E-09	1.34E-08	8.76E-09	0	0	0	0

Figure 16 Lay-out of the transport.csv file (NMVOC: non methane organic compounds; SF6: Sulphur hexafluoride; PM: Particulate matter)

- Column A: Mean of transport
  - o ***WARNING:*** The format of this column should be exactly the same as in the column D of the assumptions.csv file
  - o ***WARNING:*** row 5 indicates value for a marine bulk freight using fuel oil as fuel, therefore for this row the value refers to heavy fuel consumption
- Column B: Notes

- Column C: Diesel consumption in kg km^{-1} per kg of goods transported.
- Column D: Gasoline consumption in kg km^{-1} per kg of goods transported.
- Column E-R: Emissions in kg km^{-1} per kg of goods transported.

6. Output files

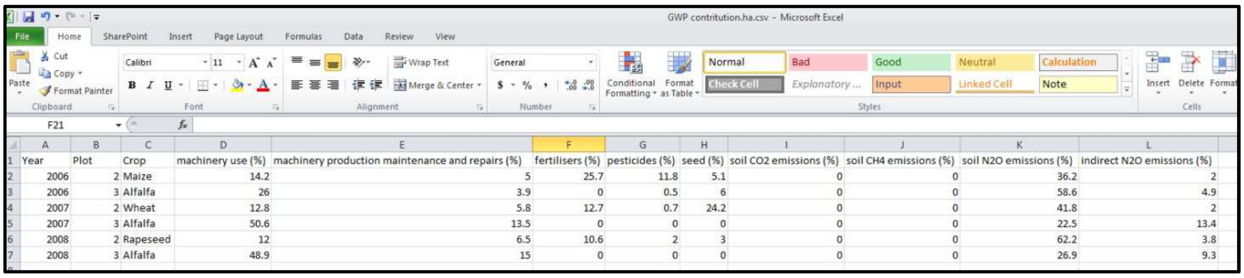
The output files are distinguished between intermediate and final outputs:

- The final output are contained in the \output directory and are the following:
  - GWP contribution.ha.csv, this file contains the contributions of different processes on the Global Warming Potential of the cropping systems
  - LCA.results.ha.csv, this file contains the overall results on an annual basis of the LCA for the impact categories considered (i.e. CED, GWP, acidification potential and eutrophication potential)
  - Nitrate.leaching.csv contains the results for nitrate leaching estimated using the SQBC model (Nemecek et al., 2014).
  - P.loss.csv contains values for the annual loss of phosphorus estimated using the SALCA-P model (Nemecek et al., 2014)
  - soil.erosion.csv contains values for soil erosion on an annual basis computed using the USLE (Universal Soil Loss Equation) (Faist Emmenegger et al., 2009; Nemecek et al., 2014; Stone and Hilborn, 2012)
  - year.fertilisers.inventory.csv contains the life cycle inventory on year basis for fertilizer production and transport up to the farm centre or the field depending on the fertilizer
  - year.inventory.csv contains the life cycle inventory on an annual basis for the full system analysed
  - year.machinery.production.maintenance.rapairs.inventory.csv contains the life cycle inventory on an annual basis for machinery production, transport, maintenance and repairs up to the farm centre
  - year.machinery.use.inventory.csv contains the life cycle inventory for the use of machinery on an annual basis
  - year.pesticides.csv contains the life cycle inventory for pesticide production and transport up to the farm centre on an annual basis
  - year.seed.inventory.csv contains the life cycle inventory for seed production and transport up to the farm centre on an annual basis
- The intermediate results are present in the main Crop.LCA folder and they are the following:
  - cultivation.fuel.transport.fuel.consumptions.csv contains the fuel consumption of the transport of the fuel used during field cultivation. The table shows the value in kg ha^{-1}
  - farm.transport.fuel.transport.csv contains fuel and energy consumption, and emissions of the transport of fuel used during farm transport. The file contains values in GJ or kg per ha
  - farmti.csv contains fuel and energy consumption, and emissions from farm transport. The values are expressed in GJ per ha for energy consumption or kg per ha for emissions.

- fico.csv contains fuel, energy consumption and emissions due to in-field consumption of fuel for machinery operations in the field. The values are either expressed in GJ for energy consumption or kg per ha for emissions.
- machinery.csv contains data for machinery from the LCA.Input.table.csv file
- machinery.fuel.production.csv contains data regarding and emissions associated with the production of the fuel used during machinery operations. The values are either expressed in GJ for energy consumption or kg per ha for emissions.
- Machinery.use.inventory.csv contains data regarding energy consumption and emissions per ha associated with the use of machinery.
- md.csv contains data regarding power in hp and effective field capacity in ha h^{-1} for different field operations.
- nutrient.inputs.csv contains data regarding the input of various nutrients to the system via mineral fertiliser application, per ha. This file considers NH_3-N, NO_3-N and PO_4-P.
- seed.production.transport.csv contains energy consumptions and emissions for seed production and transport up to the farm centre. The values are expressed in GJ ha^{-1} for energy consumption and kg ha^{-1} for emissions.
- total.fertiliser.production.transport.csv contains energy consumption and emissions for fertiliser production and transport up to the farm centre or field depending on fertiliser. The values are expressed in GJ per for energy consumption or kg per ha for emissions.
- Total.machinery.production.transport.repairs.csv contains energy consumption and emissions for machinery production, transport, maintenance and repairs. The values are either expressed in GJ per ha for energy consumption or kg per ha for emissions.
- total.pesticide.production.transport.csv includes data for energy consumption and emissions due to pesticide production and transport up to the farm centre. The values are either expressed in GJ per ha for energy consumption or kg per ha for emissions.

6.1 GWP contribution.ha.csv file

The GWP contribution.ha.csv is shown in Fig. 17:



Year	Plot	Crop	machinery use (%)	machinery production maintenance and repairs (%)	fertilisers (%)	pesticides (%)	seed (%)	soil CO2 emissions (%)	soil CH4 emissions (%)	soil N2O emissions (%)	indirect N2O emissions (%)
2006	2	Maize	14.2	5	25.7	11.8	5.1	0	0	36.2	2
2006	3	Alfalfa	26	3.9	0	0.5	6	0	0	58.6	4.9
2007	2	Wheat	12.8	5.8	12.7	0.7	24.2	0	0	41.8	2
2007	3	Alfalfa	50.6	13.5	0	0	0	0	0	22.5	13.4
2008	2	Rapeseed	12	6.5	10.6	2	3	0	0	62.2	3.8
2008	3	Alfalfa	48.9	15	0	0	0	0	0	26.9	9.3

Figure 17 Lay-out of the GWP contribution.ha.csv file

- Column A: Year. The year value should be the same as the LCA.Input.Table.csv file
- Column B: Plot. The plots assessed should be the same as evaluated in the LCA.Input.Table.csv file.
- Column C: Crop. The crops assessed should be the same evaluated in column C of the LCA.Input.Table.csv file.

- Column D-L: Contribution percentage for different processes including soil greenhouse gas emissions and indirect N_2O emissions due to nitrate leaching, estimated using the procedure proposed by Lasco et al. (2006).

6.2 LCA.results.ha.csv file

The LCA.results.ha.csv file has the structure shown in Fig. 18:

Year	Plot	Crop	CED (GJeq ha-1 y-1)	GWP (kg of CO2eq ha-1 y-1)	EP (kg of PO4 eq ha-1 y-1)	AP (kg of SO2eq ha-1 y-1)
2006	2	Maize	18	3887.4	13.22	5.13
2006	3	Alfalfa	6	1495	11.52	2.29
2007	2	Wheat	19.6	4017.6	13.76	4.04
2007	3	Alfalfa	4.3	562.7	11.82	1.67
2008	2	Rapeseed	20.2	2628.1	17.2	2.78
2008	3	Alfalfa	6	812.8	11.83	2.33

Figure 18 Lay-out of the LCA.results.ha.csv file

- Column A: Year. The year value should be the same as the LCA.Input.Table.csv file
- Column B: Plot. The plots assessed should be the same as evaluated in the LCA.Input.Table.csv file.
- Column C: Crop. The crops assessed should be the same as evaluated in column C of the LCA.Input.Table.csv file.
- Column D: CED in GJeq per ha per year.
- Column E: Global Warming Potential per ha estimated using the IPCC (Intergovernmental Panel on Climate Change) 5th Assessment Report 100-year time-horizon (Myhre et al., 2013).
- Column F: Eutrophication potential in kg of PO_4^{-3}eq ha^{-1} y^{-1} estimated using the Styles et al. (2014, 2015), and CML (2015) procedure.
- Column G: Acidification potential in kg of SO_2eq ha^{-1} y^{-1} estimated using the Styles et al. (2014, 2015), and CML (2015) procedure.

6.3 P.loss.csv file

The P.loss.csv contains the amount of P loss and has the structure shown in Fig. 19:

Year	Plot	Crop	Phosphorus emissions through water erosion to surface water (kg P ha-1 y-1)	Phosphate run off to surface water (kg P ha-1 y-1)	Phosphate leaching to ground water (kg P ha-1 y-1)	Phosphate P loss to water (kg P ha-1 y-1)
2006	2	Maize	0.232	0.184	0.175	0.59
2006	3	Alfalfa	0.012	0.175	0.175	0.362
2007	2	Wheat	0.475	0.179	0.175	0.829
2007	3	Alfalfa	0.024	0.175	0.175	0.374
2008	2	Rapeseed	0.647	0.175	0.175	0.997
2008	3	Alfalfa	0.026	0.175	0.175	0.376

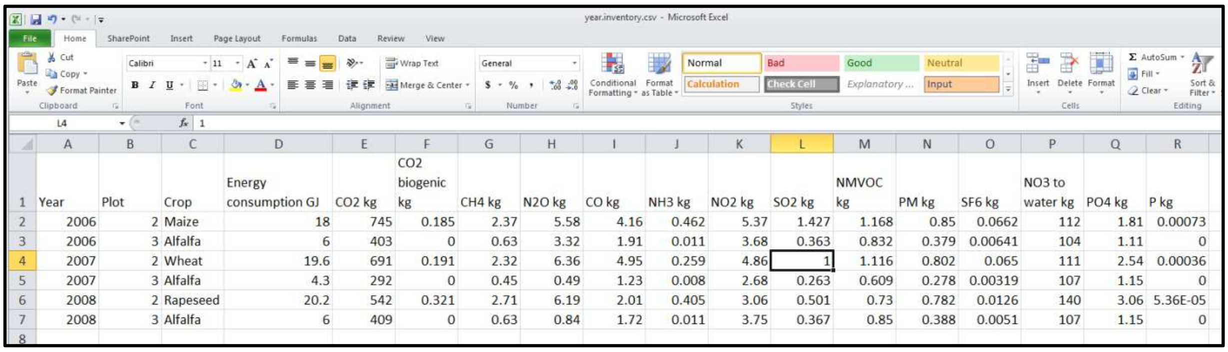
Figure 19 Structure of the P.loss.csv file

- Column A: Year. The year value should be the same as the LCA.Input.Table.csv file.

- Column B: Plot. The plots assessed should be the same as evaluated in the LCA.Input.Table.csv file.
- Column C: Crop. The crops assessed should be the same as evaluated in column C of the LCA.Input.Table.csv file.
- Column D: Phosphorus emissions through water erosion to surface water (kg P ha^{-1} y^{-1}), accounted using the SALCA-P model (Nemecek et al., 2014).
- Column E: Phosphate run off to surface water (kg P ha^{-1} y^{-1}), accounted using the SALCA-P model (Nemecek et al., 2014)
- Column F: Phosphate leaching to ground water (kg P ha^{-1} y^{-1}), accounted using the SALCA-P model (Nemecek et al., 2014)
- Column G: Phosphate P loss to water. Total P loss to water (kg P ha^{-1} y^{-1}), accounted using the SALCA-P model (Nemecek et al., 2014)

6.4 Year.inventory.csv file

The year.inventory.csv contains the data of the life cycle inventory for the 15 substances considered by the Crop.LCA tool (Fig. 20).



Year	Plot	Crop	Energy consumption GJ	CO2 kg	CO2 biogenic kg	CH4 kg	N2O kg	CO kg	NH3 kg	NO2 kg	SO2 kg	NMVOC kg	PM kg	SF6 kg	NO3 to water kg	PO4 kg	P kg
2006	2	Maize	18	745	0.185	2.37	5.58	4.16	0.462	5.37	1.427	1.168	0.85	0.0662	112	1.81	0.00073
2006	3	Alfalfa	6	403	0	0.63	3.32	1.91	0.011	3.68	0.363	0.832	0.379	0.00641	104	1.11	0
2007	2	Wheat	19.6	691	0.191	2.32	6.36	4.95	0.259	4.86	1	1.116	0.802	0.065	111	2.54	0.00036
2007	3	Alfalfa	4.3	292	0	0.45	0.49	1.23	0.008	2.68	0.263	0.609	0.278	0.00319	107	1.15	0
2008	2	Rapeseed	20.2	542	0.321	2.71	6.19	2.01	0.405	3.06	0.501	0.73	0.782	0.0126	140	3.06	5.36E-05
2008	3	Alfalfa	6	409	0	0.63	0.84	1.72	0.011	3.75	0.367	0.85	0.388	0.0051	107	1.15	0

Figure 20 Structure of the year.inventory.csv (NMVOC: non methane volatile organic compounds; SF6: Sulphur hexafluoride; PM: Particulate matter)

- Column A: Year. The year value should be the same as the LCA.Input.Table.csv file.
- Column B: Plot. The plots assessed should be the same evaluated in the LCA.Input.Table.csv file.
- Column C: Crop. The crops assessed should be the same evaluated in column C of the LCA.Input.Table.csv file.
- Column D: Energy consumption in GJ per ha
- Columns E-R: Emissions in kg per ha.

7. R functions

In this section, the main R functions used by the Crop.LCA tool are listed and a brief description is given for each of them. All the functions are located inside the code folder as shown in Fig. 21.

- Ep.R calculates electricity production which is used in machinery production, maintenance and repairs.

- Farm.transport.R computes the fuel, energy consumption and emissions related to farm transport from the farm centre to the field, according to Goglio et al. (2014, 2012), considering the return journey of the machinery and the number of times the field operation can be done during the working day.

- Fc.R computes the fuel, energy consumption and emissions associated with fuel consumption for field operations, according to Goglio et al. (2014, 2012).

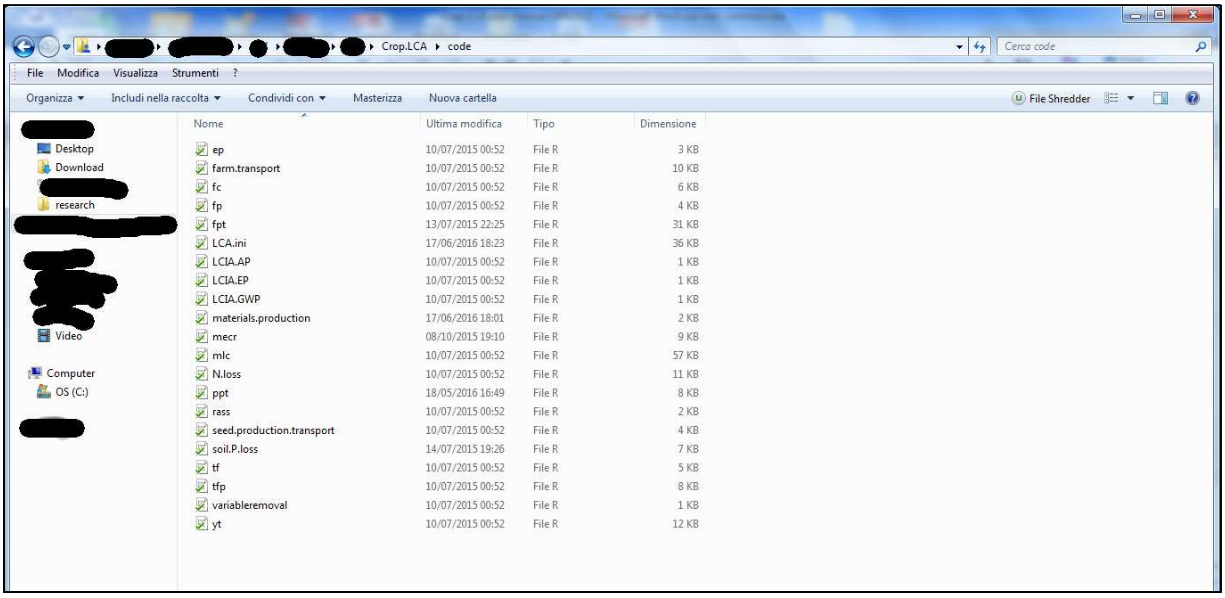


Figure 21 Code folder with R functions of the Crop.LCA tool

- Fp.R calculates the impact of fuel production according to GHGenius ((S&T)2. 2014).
- Fpt.R is used to account for fertiliser production and transport. The computation methodology is based on different sources (Brentrup, 2003; Sheehan et al., 1998; (S&T)2, 2014).
- LCA.ini.R is the main function of Crop.LCA which reads the files, calls all other functions and prepares the final results.
- LCIA.AP.R computes the acidification potential in agreement with Styles et al. (2014, 2015), and CML (2015).
- LCIA.EP.R calculates the eutrophication potential according to Styles et al. (2014, 2015), and CML (2015).
- LCIA.GWP.R accounts for the 100 year GWP (Global Warming Potential) according to the IPCC (Interngovernmental Panel on Climate Change) 5th Assessment Report (Myhre et al., 2013).
- Materials.production.R accounts for material production including seed, pesticide and fertiliser.
- Mecr.R prepares LCA.input.table.csv for the analysis, computes the power and effective field capacity in agreement with ASABE (2011b); Goglio et al. (2012).
- Mlc.R computes the impact of machinery production, maintenance and repairs from raw material extraction to the agricultural phase in agreement with Audsley et al. (1997).
- N.loss.R calculates nitrate leaching using the SQBC model (Nemecek et al., 2014).

- Ppt.R computes the impact of pesticide production and transport. Pesticide production is computed on the basis of the amount of active ingredient produced, while transport is computed on the basis of the total amount of fertiliser (Goglio et al., 2012, 2014).
- Rass.R reads the assumptions.csv and initializes all the variables related to the LCA assumptions necessary to carry out the assessment.
- Seed.production.transport.R computes the impact related to seed production and transport on the basis of the amount of seed read in column Q of the LCA.Input.Table.csv
- Soil.P.loss.R computes the soil erosion and soil P loss according to Faist Emmenegger et al. (2009) and Nemecek et al. (2014)
- Tf.R computes the inventory of transport according to GHGenius ((S&T)2. 2014), considering the return journey.
- Tfp.R calculates the impact of transport and fuel production for the fuel necessary for transport, according to GHGenius ((S&T)2. 2014), considering the return journey.
- Variable.removal.R is function to remove all variables present in the Global environment
    - ***WARNING:*** It should be used only by a user with a significant R expertise
- Yt.R is a function which computes the annual value of impacts.

A schematic representation of the relationships among output files, R functions and input files is shown in figure 22.

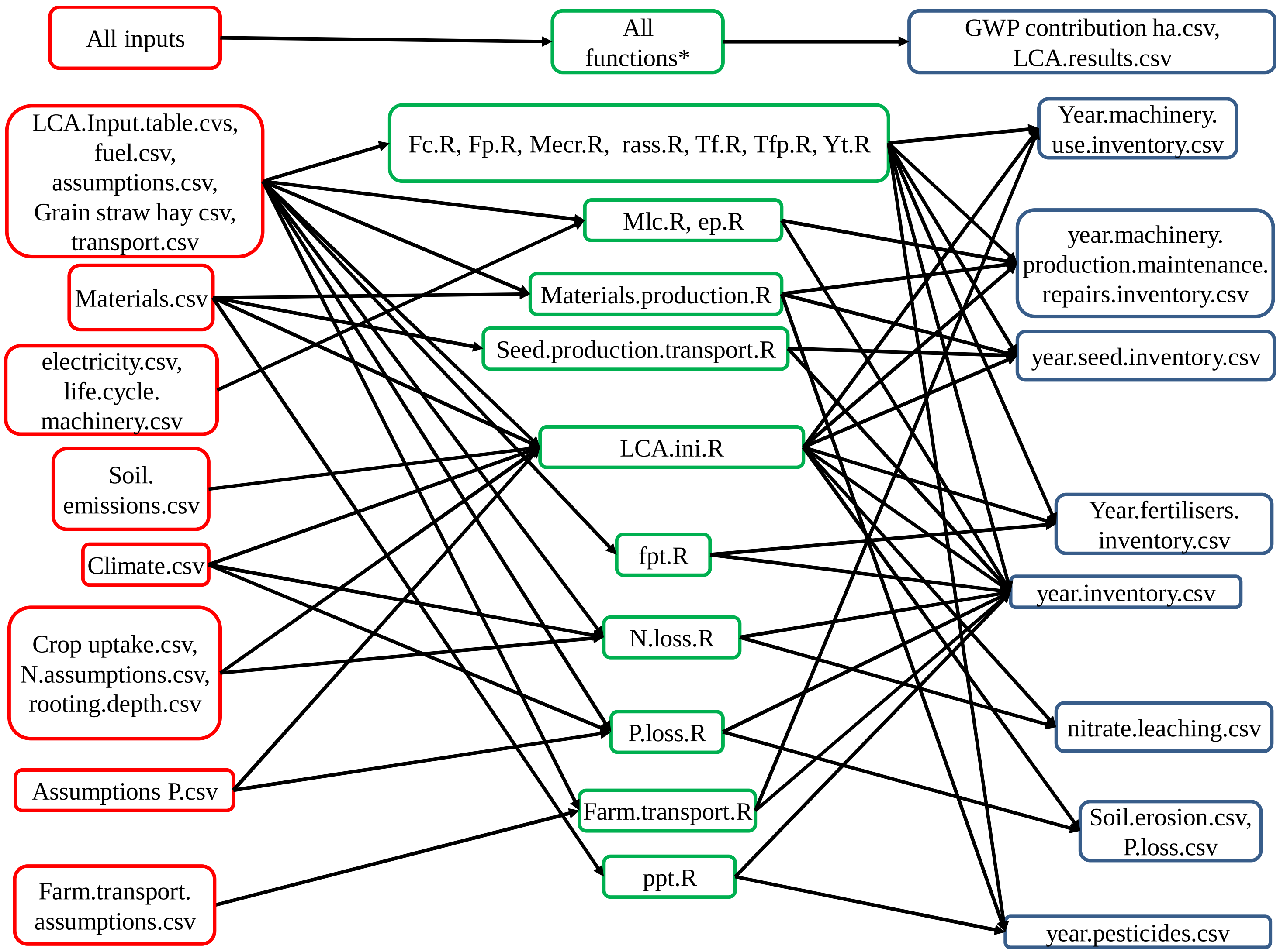


Figure 22 Relationships between input files, R functions, output files. Red: input files; Green: R functions; Blue: output files. *excluding variableremoval.R function which can be used to remove all the variables in the local environment.

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