AgroLife Scientific Journal - Volume 2, Number 1, 2013
ISSN 2285-5718; ISSN CD-ROM 2285-5726; ISSN ONLINE 2286-0126; ISSN-L 2285-5718

LIFE CYCLE ASSESSMENT: BY-PRODUCTS IN BIOFUELS PRODUCTION BATTLE; RAPESEED VS. *Camelina sativa* L.

Stelian Matei PETRE[1], Ștefana JURCOANE[1], Paul DOBRE[1], Romulus PETCU[2], Delia DIMITRIU[3]

[1]University of Agronomic Sciences and Veterinary Medicine Bucharest, 59 Marasti Blvd., District 1, Bucharest 011464, Bucharest, Romania
[2]Romanian Research and development Institute for Gas Turbines "COMOTI", 220D Iuliu Maniu Blvd., District 6, Bucharest 061126, Bucharest, Romania
[3]Manchester Metropolitan University, CATE, John Dalton Building, Chester Street, M1 5GD, Manchester, UK

Corresponding author email: petrestelianmatei@gmail.com

Abstract

One of the main objectives of the Kyoto Protocol and also the global directives is the reduction of GreenHouse Gas emissions (GHG) from consumption of fossil fuels and biofuels used mostly for transportation. Nowadays, a very important aspect is the technology process for production of biofuels together with the by-products from different renewable sources of raw materials. In this study two sources of oil for biofuels production in Romania, are studied: the well-known Rapeseed (Brassica napus) and Camelina (Camelina sativa), a new source of oil for several type of biofuels.
Depending on the kind raw materials used, the by-products obtained during crushing of seeds and after transesterification or hydrogenation and hydrotreatment of the oil can be used either as feed stocks, or as secondary fuels.
In this study the Camelina cultivation requirements is assess by the authors, as well as the pilot scale oil recovery to calculate life cycle analyses of greenhouse gas (GHG) emissions and energy demand; a comparison with the rapeseed cultivation in Romania is also conducted. The team has determined the response to model assumptions including the allocation methodology, as part of N fertilizer application rate.
The use of Nitrogen as a fertilizer, the use of Rapeseed and Camelina by-products can also be related for further GHG emissions and energy consumption assessment and investigation. The best result obtained for camelina value chain, regarding the greenhouse gas emissions reduction was over 60% compared to petroleum jet fuel reported.

Key words: *life cycle assessment, renewable jet fuel, camelina cultivation, rapeseed cultivation, by-products.*

INTRODUCTION

The transport industry is an indispensable link for everyone, from public and private to small or big companies. Considering the safety of our planet, as well as energy security, we need to develop new renewable energy sources with less Green House Gas emissions, with gentle environmental impact. This is a global objective that makes the transport industry to seek new sources of alternative fuels.
The goal for reduction of (GHG) emissions is covered by the Kyoto Protocol and the EU Directive 2009/28/EC (RED). The Directive endorsed a mandatory target of a 20% share of energy from renewable sources in overall Community energy consumption by 2020 and a mandatory 10% minimum target to be achieved by all Member States for the share of biofuels in the transport sector by 2020 (UN Doc, 1997).
Moreover, the RED introduces environmental sustainability criteria for biofuels that are to be taken into account for the achievement of the imposed targets (UN Doc, 1997).
Camelina is a new oilseed crop that has been gathering a worldwide interest in bio-fuels. Other possible bio-based products from camelina include bio-lubricants and animal adjuvant feed. Most recently, the jet fuel market has emerged as a potential business opportunity for camelina oil and, therefore, camelina producers (Vakulabharanam, 2010). Camelina plant (*Camelina sativa*) is an annual crop, it grows to a height of approximately 60-

100 cm and the camelina seeds contain around 35-45% oil (Imbrea, 2011).

Camelina is primarily an energy crop, with high oil content for industrial use, as a feedstock to produce renewable fuels.

The *by-product* obtained from the oil extraction (camelina meal/camelina cake) is used as high protein animal adjuvant feed.

Camelina is suitable to be used as an oilseed *rotational crop* with traditional crops and more important, it has a good potential for cultivation on marginal, uncultivated and contaminated land.

Camelina, though cultivated for over 2,000 years in the area for its seeds containing 30-45% oil, it was used as adjuvant food, in the dye industry, in the soap industry, and, more recently, for bio fuel. However, it is little known at present in Romania, though soil and climate conditions are favourable for this crop (Bugnăruc, 2007).

The oil from camelina seeds, a golden liquid, contains over 50% polyunsaturated essential fatty acids, and particularly linoleic and alpha-linoleic acids. Camelina oil is 10 times richer in these acids than many other vegetal oil and it is also suitable for human adjuvant consumption (Alice, 2007; Putnam, 1993; Tabara, 2007)

Camelina oil is also a rich source of essential omega-3 and omega (Tabara, 2007).

A cholesterol reducing effect of camelina oil was confirmed in some trials involving volunteers. The reduction of cholesterol in blood serum was ascribed to the synergistic effects of alpha linolenic acid and antioxidants (FAO, 2012).

Besides the major exploitation as dietary supplement in salads and in various cold dishes, camelina oil can be also used for cooking, baking and frying. An official test confirmed that camelina oil is suitable for frying beef, fish, eggs and vegetables (Reenberg, 1994).

During frying for up to 15 min at the temperature of 180^0C, no rancidity was detected. However, prolonged heating accelerated the release of volatiles and the formation of polymerization and oxidation products (Zubr, 2009).

Camelina meal is rich in protein, fat and essential n-3 and n-6 fatty acids, and could be incorporated into poultry rations as a source of energy, protein and essential n-3 and n-6 fatty acids (Zubr, 2009).

Camelina oil also helps cell regeneration and skin elasticity and slenderness recovery [8].

The specificity of camelina oil is due to its basic properties, i.e.:

- physical and chemical composition;
- long preservation period (up to 2 years);
- lower freezing point than rapeseed (-47/-48 C), which meets the requirements for aviation biofuel.

Life Cycle Assessment

Life Cycle Assessment (LCA) is a technique used to assess the environmental impacts of a product during its entire life cycle from the “cradle”, where raw materials are cultivated, through production and final application to the “grave” or in our study to the “engine” (ISO14040, 1997).

The evaluation of the life cycle of a product can also be used to compare two different production processes in terms of use of resources and emissions.

As defined by ISO standards and several studies, a correct LCA assessment consists of four major phases:

1) Goal and Scope Definition;
2) Inventory analysis;
3) Impact assessment;
4) Interpretation.

LCA stages

The Goal and Scope definition provides the basis of the study through 5 fundamental steps:

a) Drawing of initial flowchart for camelina cultivation chain;
b) Choice of functional unit and reference flow;
c) Choice of impact assessment method and related impact categories;
d) Definition of system boundaries;
e) Decision on allocation problems.

The initial flowchart is the starting point of the study and it shows which processes are involved in the system and their primary or secondary connections.

The functional unit is the unit of measurement to which all the data relate. It allows the comparison among different systems, which are functionally equivalent, determining energy and mass flows in relation to its value.

There are two different types of impact assessment methods: the methods which deal with the impacts caused by the production processes directly to the environment (mid points methods) and those dealing with the indirect effects to human health, ecosystem health and resources (end points methods). Both of them are characterized by impact categories (ISO14042, 2000).

System boundaries define the limits of the study stating for example the processes involved in the system (technical boundaries), the time horizon and the geographical boundaries.

Where physical relationship cannot be established as the basis for allocation, the environmental loads (resource consumption, energy consumption, emissions to air, soil and water etc.) should be allocated among the products in a way which reflects other relationships between them, for example the economic value.

The second phase of a LCA analysis is the *Inventory analysis* (LCI). This step includes: the construction of the assessment plan according to the system boundaries decided in the goal and scope definition phase; the data collection of the inputs and outputs flows in each technology or production process and the calculation of the environmental impacts of the system in relation to the functional unit.

The *Impact Assessment* (LCIA) is a phase which aims to describe the environmental consequences of the environmental loads quantified in the Inventory Analysis. The Impact Assessment is divided in four steps: Classification, Characterization, Normalization and Weighting [ISO14042,2000].

Life cycle *Interpretation* analyzes the findings of the preceding phases of the LCA, reaching conclusions and providing recommendations to improve the environmental performances of the system studied [ISO14043, 2000].

MATERIALS AND METHODS

This study assesses the cultivation requirements of Camelina in Agricultural stage and energy demand, as well as the pilot scale oil recovery to calculate life cycle analyses of greenhouse gas (GHG) emissions, as well as energy demand by comparison with the rapeseed cultivation in Romania.

LCA methodology

In this case-study for Romania, we used the data obtained during camelina cultivation in 2010-2011, in Romania, Giurgiu county, Prunaru village.

The LCA methodology was applied for agricultural step.

Plant description

From 2010, in cooperation with several farmers from different regions of Romania, we started to cultivate *Camelina sativa* as a new source of oil in order to obtain different biofuel sources for public transportation, including jet fuel and meal for live feed stocks (Figure 1).

Our first assessment focused mostly on the agricultural stage, involving later the seed crushing technology, including oil and meal obtained after crushing; the economic and also environmental benefits were also relieved.

From GHG point of view, the agricultural stage is the process that causes major GHG emissions because the technical level of the technology for production of oilseeds (>60%) includes the emissions due to the utilization of direct energy by using mechanical equipment and also indirect energy, such as N fertilizer.

Other important aspects of vegetable oil production are the by-products obtained at the crushing stage and their subsequent use. Camelina has sustainable by-products that can be used as feed stocks with no other further conditioning.

Figure 1. Camelina plant at flowering

Cultivation technology

Agricultural stage of *Camelina sativa*:

- The cultivation technology of camelina sativa was the following one: sowing was done 1-2 cm in the soil, with 6 kg/ha of seed. The biological material used was a local population of the NARDI-Institute of Fundulea (Romanian Camelia variety).

- Winter wheat was the pre-emergent crop.
- Soil works consisted in summer till 20-23 cm in the soil, with a plough aggregated with a star harrow, done right after wheat harvesting and straw removal from the field.
- Phosphorus fertilizers applied as superphosphate and potassium fertilizers applied as potassium salts were incorporated under the summer till, while nitrogen fertilizers applied as ammonia nitrate was incorporated in spring, upon preparation of the germination bed, with a combinator.
- Sowing was done in all three experimental years in the third decade of March.
- Maintenance works consisted of harrowing after sprouting and weeding when the plants were 7-10 cm tall.
- During vegetation there was no need to treat the crop to control diseases or pests.
- Harvesting was done upon maturity, with a Hege experimental combine.
- The crop from each variant was cleaned from silicules, weighed and reported per ha. Crop assessment was done when moisture reached 11%.

RESULTS AND DISCUSSIONS

In order to check the LCA inputs we calculated the costs for camelina crop (Table 1).

The technology costs with minimal tillage was calculated for camelina crop (1 ha, 2011):

Table 1. Camelina technology costs with minimal tillage

Operation	**€/ha**
Ploughing	44.00
Power harrowing	15.00
Fertilizing	5.00
Fertilizers	112.00
Disk harrowing	14.00
Seeds	10.00
Seeding	14.00
Harvest	52.00
Seed sifting and drying	27.00
Lease	40.00
Unexpected expenses – weed and pest control	56.00
TOTAL*	**387.00**

± 10%, depending of each farmer level of agricultural machines and equipment

In the Table 2, we can see the production yield for Camelina sativa (2011 in Romania, Giurgiu county) and rapeseed, too.

Table 2. Production yield between camelina and rapeseed

Area counted - 1 ha	**Camelina sativa***	**Rapeseed**
Seed production (kg)	1500	3400
Oil content %	40	43
Oil quantity after crushing (kg)	484	1190
Oil density at 20^0C (g/cm^3)	0.9219	0.9186
Oil quantity after crushing (l)	525	1295
Cake quantity after crushing (kg)	1016	2210

Minimal tillage

Chemical characterization of camelina products

Chemical characterization of camelina oil, obtained in 2011, in Romania is described in Table 3.

Table 3. Chemical characterisation of camelina oil

FATTY ACID	U/M	VALUE
FATS (F)	**g%g sample**	**Camelina Oil**
MYRISTIC ACID C14:0	g%g (F)	0.10
PALMITIC ACID C16:0	g%g (F)	6.51
PALMITOLEIC ACID C16:1	g%g (F)	0.18
STEARIC ACID C18:0	g%g (F)	2.15
OLEIC ACID C18:1n9	g%g (F)	16.27
LINOLEIC ACID C18:2n6	g%g (F)	20.99
LINOLENIC ACID C18:3n6	g%g (F)	35.58
CONJUGATED LINOLEIC ACID C18:2	g%g (F)	1.06
LINOLENIC ACID C18:3n3	g%g (F)	11.59
ERUCIC ACID C22:1n9	g%g (F)	1.60
ARACHIDONIC ACID C20:4n6	g%g (F)	1.11
DOCOSADIENOIC ACID C22:2n3	g%g (F)	2.24
OTHER FATTY ACIDS	g%g (F)	0.61

The value of Erucic Acid, Linolenic Acid and Docosadienoic Acid makes the camelina oil suitable for animal diets.

Physical and chemical properties of camelina meal are presented in Table 4 and 5.

Table 4. Physical and characteristics of camelina meal

Description	U/M	Value
Dry substance	g%	91.37
Crude Protein	g%	33.35
Crude Fat	g%	9.34
Crude cellulose	g%	12.64
Crude ash	g%	5.96

Table 5. Chemical characteristics of camelina meal

FATTY ACID	U/M	Value
MYRISTIC ACID C14:0	g%g (F)	0.17
PALMITIC ACID C16:0	g%g (F)	9.12
PALMITOLEIC ACID C16:1	g%g (F)	0.52
STEARIC ACID C18:0	g%g (F)	2.70
OLEIC ACID C18:1n9	g%g (F)	17.71
LINOLEIC ACID C18:2n6	g%g (F)	24.58
LINOLENIC ACID γ C18:3n6	g%g (F)	0.13
LINOLENIC ACID α C18:3n3	g%g (F)	26.92
ARACHIDIC ACID C20:0	g%g (F)	1.17
EICOSENOIC ACID C:20(1n9)	g%g (F)	10.10
OCTADECATETRAENOIC ACID C18:4n3	g%g (F)	0.80
ACID EICOSADIENOIC C20:n6	g%g (F)	1.61
ERUCIC ACID C22:1n9	g%g (F)	0.86
ARACHIDONIC ACID C20:4n6	g%g (F)	0.26
EICOSAPENTAENOIC ACID C20:5n3	g%g (F)	2.18
DOCOSATETRAENOIC ACID C22:4n6	g%g (F)	0.30
DOCOSAPENTAENOIC ACID C22:5n6	g%g (F)	0.16
DOCOSAHEXAENOIC ACID C22:6n3	g%g (F)	0.43
Other fatty acids	g%g (F)	0.28

It can be observed that Camelina meal contains important amount of Linolenic acid (18:3 n-3) (an omega-3 fatty acid), and crude protein. Due to the high oil content, omega-3 fatty acid and crude protein, finding alternative use of camelina meal (a co-product obtained from camelina seed after oil extraction) in animal diets will increase the market value of the crop. The GHG emissions for using the by-products as feed stocks are reduced to minimum value and also the economically impact for the entire chain will be a significant one.

We calculated the energy input annual-equivalent CO_2 emission per ha and per GJ; the results are shown in Table 6.

Activity	Combiner		Surface ha	Diesel		Energy MJ	Agro chemicals
	Track	Agriculture equipment		Specific consume L/ha	Consume L		Specific consume kg/ha
0	1	2	3	4	5=3*4	6=5*ρ*LHV	7
Preparing for sowing. Disc harrowing 1	JD 7530 Premium	Super disc 6.4	3	11.5	34.5	1,237.1	-
Fertilization: complex 20.20.0 – 250 kg/ha	U 650	MA 6	3	1.7	5.1	182.9	**50** a.s. N **50** a.s. P_2O_5
Disc harrowing 2	JD 7530 Premium	Super disc 6.4	3	11.5	34.5	1,237.1	-
Seeding	U 650	Seeder SC31DN	3	4.2	12.6	451.8	**6.0** (seed)
Fertilization: ammonium nitrate – 250 kg/ha	U 650	MA 6	3	1.7	5.1	182.9	**82.5** a.s. N
Herbicides (Ridomil 68 VG)	-	Self-propelled	3	2.0	6.0	215.2	**1**
Harvesting	-	Harvesting combine NH	3	11.0	33.0	1,183.4	-
Total	**-**	**-**	**-**	**-**	**-**	**4,690.4**	**-**

LHV_{diesel} = 43.1 MJ/kg, ρ_{diesel} = 832 kg/m^3,
a.s. – active substance

In this experimental assessment we calculated indirect inputs and emissions: intrinsic energy, i.e. that spent to obtain agricultural production factors (fertilizers, pesticides, machinery, infrastructure, etc.) and emissions generated in the crop technique processes (Fazio, 2011).

Table 6. Experimental camelina cultivation total inputs and emissions for agricultural step (1 ha)

Crop technique camelina					Energy input (MJ)	Emission (kg CO2)	Input	energy input (MJ/kg)	CO2 emission (kg/kg)	machine wearing (kg/h)
Establishment year:	2011									
ploughing	2	h/ha	120 kW tractor		133.6	4.3				
disk harrowing	1	h/ha	120 kW tractor		66.1	3.0	N	50	9.1	
power harrowing	1	h/ha	120 kW tractor		112.3	5.2	P2O5	50	1.2	
Fertilizing	1	h/ha	60 kW tractor		3157.5	482.4	Rydomil 68 VG	405	13.2	
triple superphosphate	50	kg/ha	20%	P2O5			Seeds	150.6	0.5	
N	256	kg/ha	20%	N			Diesel Fuel	53	3.1	
Weed control	1	h/ha	60 kW tractor		495.7	17.2	tractor 120 kW	126	5.6	0.38
Rydomil 68 VG	1	kg/ha					tractor 60 kW	126	5.6	0.72
Seeding	1	h/ha	60 kW tractor		994.3	7.0	plough	70	3.3	0.27
camelina seed	6	kg/ha					Disk harrow	70	3.3	0.26
combine harvesting	1	h/ha			1260.0	56.0	power harrow	70	3.3	0.92
total fuel consumption	43.6	kg/ha	diesel		2310.8	135.2	fertilizer spreader	62	3.8	0.11
				Total	8530.3	710.2	combine harvester	126	5.6	10

The assessment of indirect inputs and related emissions per Ha was performed by the following principle:
Goods totally consumed (e.g. fertilizer, pesticides):
Energy input = unit energy* input x total amount used
Emissions = pollutants per unit x total amount used
Goods and infrastructure partially consumed (e.g. machinery):
Energy input = unit energy* input x amount used x % wearing**
Emissions = pollutants per unit x amount used x % wearing**
*of the energy spent to produce the good, not of the energy contained in it.
**example: tractor weight (100 kW) 6500 kg; expected lifetime 10000 h; utilization 20 h/ha; fraction consumed = 6500 x 20/10000 = 13 kg/ha;

unit energy input 126 MJ/kg or 5.6 kg/kg CO_2 equivalents;
Energy input: 13x126 = 1638 MJ; CO2 eq. emission: 13x5.6 = 72.8 kg
Also for direct inputs, the energy spent to produce them must be added to the intrinsic content (e.g. diesel intrinsic energy = 44 MJ/kg; as direct input, 53 MJ/kg).
During our study the response to model assumptions has been determined, including the allocation methodology, as part of N fertilizer application rate.
LCA calculation for agricultural stage, with minimum tillage, shows 31404.4 MJ/ha energy input and 1218.9 kg/ha of CO_2 emissions.
The results obtained for camelina value chain, regarding the greenhouse gas emissions reduction was over 60% against petroleum jet fuel reported.
The use of Nitrogen as a fertilizer, the use of Rapeseed and Camelina by-products can also be related for further GHG emissions and energy consumption assessment and investigation.

CONCLUSIONS

This paper deals with the assessment of Life Cycle Analysis of camelina value chain in Romania, considering the GHG emissions reduction according to Kyoto protocol and the RED. It identifies the LCA phases, its stages, and methodology.

Cultivation technology is explained in depth and results are illustrated in several tables. A comparison is made between camelina yield and the rapeseeds. Also, the chemical characteristics of camelina meal are presented, as well as its cultivation inputs. The assessment of indirect inputs and related emissions per ha was performed.

LCA calculation for agricultural stage, with minimum tillage, shows 31404.4 MJ/Ha energy input and 1218.9 kg/Ha of CO_2 emissions. The assessment energy inputs and CO_2 emissions were related to the experimental field from Prunaru, Giurgiu county, Romania, for autumn camelina (2010-2011).

The step with the highest energy input and also CO_2 emissions is the fertilizing with N.

The by-products are very important for the entire value chain, they are suitable to be used as poultry, fish or animal diets with a perspective of a small amount for further GHG emissions.

The results obtained for camelina value chain regarding the greenhouse gas emissions reduction was over 60% against petroleum jet fuel reported.

However, more research is needed to have a better picture of the LCA across the entire camelina value chain.

ACKNOWLEDGEMENTS

This work was funded by a European Consortium representing 4 EU states with Airbus as Project manager:
- AIRBUS - France;
- TAROM - Romania;
- Camelina Company Espana (CCE)- Spain;
- UOP, a Honeywell Company - USA/UK.

Sustainability of the camelina value chain was assessed by:
- Manchester Metropolitan University - UK;
- COMOTI - RO;
- BIOTEHGEN - RO;
- USAMVB - RO.

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