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Life cycle assessment analysis of ethanol production from carob pod

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Progressive depletion of conventional fossil fuels with increasing energy consumption and greenhouse gas (GHG) emissions have led to a move towards renewable and sustainable energy sources. In this work, carob pod (*Ceratonia Siliqua*) is proposed as an economical source for ethanol production, especially, in arid regions. The carob tree is an evergreen shrub native to the Mediterranean region, cultivated for its edible seed pods and it is currently being reemphasised as an alternative in dryland areas, because no carbon-enriched lands are necessary. The global process of bioethanol production from carob pod by *Saccharomyces Cerevisiae* yeast cells were analyzed in a previous work. To take into account environmental impacts of the process, a Life Cycle Assessment (LCA) technique was applied, which allowed detailed analysis of material and energy fluxes. On the life-cycle basis, the net energy yield of carob pod (2.36 MJ/MJ) was found to be similar than to those values for traditional crops (i.e. Wheat,2.25 MJ/MJ).

1. Introduction

World faces the progressive depletion of its energetic resources mainly based on non renewable fuels. At the same time, energy consumption grows at rising rates.The solution to this problematic depends on the development and implementation of technologies based on the use of renewable energetic resources. In this context, conversion of biomass into biofuels is an important choice for the exploitation of alternative energy sources and reduction of polluting gases (Cherubini and Ulgialti, 2010). Worldwide ethanol production capacity in 2005 and 2006 were about 45 and 49 billion liters per year, respectively and total output in 2015 is forecast to reach over 115 billion liters (Licht, 2006). The aim of the present investigation was to identify savings in energy and emissions from bioethanol production and use, an evaluation from ‘‘cradle to grave” have been carried out. Life cycle assessment (LCA), a methodology explained in ISO 14040 international standards (Lund and Biswas, 2008), including inputs and related emissions from the production process, along with the future fate of a product (Robert and Ayres, 1995) have been employed to highlight possible improvements in the production chain. LCA have been recognized as one of the best

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methodologies for the evaluation of the enviromental impacts in biofuel production (Cherubini et al., 2009), but contradictory results are found due to differences in local conditions, production systems, calculation and allocation methods. Depending on these factors, bioethanol could be everything from good to bad from greenhouse gas emissions (GHG) point of view. (Börjesson and Tufvesson, 2010).

2. Life Cycle Assessment methodology

2.1 Goal and scope definition

Environmental life cycle assessment (LCA) is defined as a methodology for the comprehensive assessment of the impact that a product has on the environment throughout its life cycle (ISO 14040, 2006). The scope of the study includes the life cycle of ethanol use, including carob cultivation and ethanol conversion.

2.2 System definition and boundaries.

The system under study was divided in two main subsystems: carob pod cultivation and ethanol refinery, which are briefly described below. Figure 1 shows a detailed description of the unit processes and subsystems considered within the system boundaries.

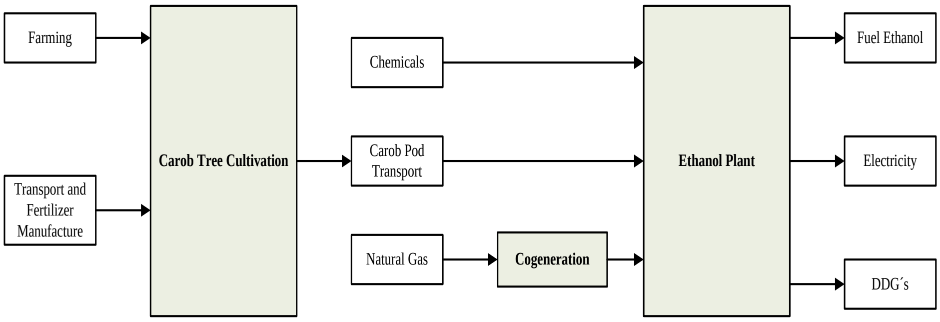

Figure 1: Life-cycle framework

2.2.1. Carob pod cultivation.

The carob pod cultivation subsystem boundaries included farm work, the production of process materials such as fertilizers as well as their transportation to the farm gate. Agricultural machinery production was not considered.

2.2.2. Ethanol Refinery.

The ethanol production subsystem includes: milling of carob pod, sugars extraction, fermentation, dry of DDG´s, ethanol distillation and dehydration, steam and electricity generation.

2.3 Data sources and software.

Data for the study was collected from different sources and procedures.

2.3.1. Carob pod cultivation data.

Data about farm work were obtained from IDAE (2005). The amount and efficiency of the fertilizers used were collected from Tous et al. (1996). Energy consumption and green house gas emissions for fertilizers production was extracted from IFA (2009) and Tore and Hydro (2003).

2.3.2. Ethanol refinery data.

For ethanol production process, the data source were the own authors and Lechón *et al.* (2005). Green house gas emissions for ethanol production processes were consulted in IPPCC (2006). Data for fuel consumption and transport were collected from BUWAL 20 database from SIMAPRO 7.1. The contributions to greenhouse gases (GHG) were analysed in detail. For that, the emissions of three global warming gases were considered: CO_2, N_2O and CH_4. The global warming factors considered in the analysis were the following: CO_2 (1), CH_4 (21) and N_2O (310).

2.4 Key assumptions.

2.4.1. Carob pod cultivation.

Two main products were obtained from the cultivation of carob pods, the seeds and the pods, in the ratio 10:90 w/w. This ratio were taken into account in the calculation of environmental and energy charges. The average production was estimated to be 2750 kg pod/ha. The average distance for fertilizers transport was set on 150 km and an emission factor of 1% w/w of the nitrogen supplied in fertilization was assumed to be released as N_2O (Lechón et al.,2005).

2.4.2. Ethanol refinery.

For the bioethanol production subsystem the following guides were taken into account: (i) the process is "carbon neutral", (ii) the co-products consider were solid waste of sugars extraction (DDGs) and electricity generation for power plant, (iii) the origin of the pod was set on four different locations with an average distance of 509, 253 and 49 km for road transport and 504 km for sea transport.

2.4.3. Reference scenarios.

Reference scenarios for avoid products were considered: (i) the alternative to carob pod cultivation was two labours of cultivator, (ii) for DDG´s production, the equivalent amount of wheat was considered, (iii) for electricity generation, the same amount was considered from the International Spanish Electricity System (REE, 2008).

3. Results and Discussion

Results obtained from energy and green house gas emissions balance in carob pod cultivation could be see in Table 1.

Table 1: Energy and greenhouse gas emissions balance.

	MJ/ha carob pod	**Carob Pod Emissions kg-eq CO_2/ha**
Labour	3575.30	262.58
Fertilizers Production	1215.45	102.42
Fertilizers Transport	64.51	4.87
Referente Scenario	-585.65	75.94
TOTAL	**4328.15**	-48.63
Carob pod transport to etanol plant	2358.27	167.36
TOTAL	**6686.42**	**564.54**

The comparative results of the LCA for total energy inputs and green house emissions from carob pod tree cultivation and others crops are shown in Table 2.

Table 2:. Total energy inputs and green house emissions from carob pod tree cultivation and others crops [Börjesson and Tufvesson., 2010].

Crop	Total Energy input [a]	Kg- eq CO_2 ha^{-1} yr^{-1}
Wheat	15200	3840
Carob Pod [b]	5395	466
Sugar Beet	9300	3800
Maize (whole crop harvest)	10700	3910
Willow	24000	1260

[a]Units MJ ha^{-1} yr^{-1}; [b] Pod and seed.

As can be seen in this table, the energy input required for carob pod tree cultivation is significantly lower than that needed for cultivation of other crops. Furthermore, a huge decrease in green house emissions can be achieved when carob pod is used. Data for ethanol refinery inputs- outputs and energy and green house gas emissions balance for ethanol refinery are shown in Table 3 and 4.

Table 3: Inputs – Outputs in Ethanol refinery(Source the Authors)

Inputs		Outputs	
Carob Pod (Ton/year)	68000	Ethanol (Ton/year)	15053
Sulphuric Acid (Ton/year)	150.53	DDG´s (Ton/year)	30106
Urea (Ton/year)	150.53	Electricity (Gwh/year)	248.0
Yeast (Ton/year)	225.80		
Mono amonium phosphate (Ton/year)	150.53		
Natural Gas (10^6 Nm^3/year)	47.41		

Table 4: Energy and greenhouse gas emissions balance for ethanol refinery.

	MJ/kg Ethanol	**Kg - eq CO_2/ kg Ethanol**
Natural Gas	109.53	6.15
Carob Pod	10.94	0.92
Sulphuric Acid	0.004	0
Urea	0.0243	0.00088
Yeast	1.55	0.061
Mono amonium phosphate	0.0022	0.00019
Reference Scenarios		
DDG´s	-8.92	-0.87
Electricity	-98.76	-5.545
TOTAL	**14.36**	**0.72**

On the life-cycle basis, the energy required for ethanol conversion is 14.36 MJ/kg ethanol and the green house gas emissions of the process are estimated in 0.72 kg eq CO2/kg ethanol. It is worthy of note that a recent work supported by the European Union (BEST, 2009) have reported the greenhouse gas emissions balance for two wheat ethanol plants in Spain. The net balances for these plants are 81.0 kg - eq CO2/ GJ ethanol, and 72.6 kg - eq CO2/ GJ ethanol. Since this value for carob pod is 24.3 kg - eq CO2/ GJ ethanol, it means that greenhouse gas emissions reductions of 70.0% and 66.5%, respectively, could be achieved using carob pod as feedstock in these plants.
Table 6 shows the net energy ratio (NER), which is the ratio of output to input energy needed to produce a fuel from a feedstock) of ethanol production from carob pod and other ethanol crops. As can be seen in this table, net energy ratio of ethanol production from carob pod is similar to those values for traditional crops.

Table 6: NER of ethanol production from carob pod and other ethanol crops. Data adapted from [Yuan et al., 2008].

Feedstock	**NER**
Carob Pod	2.36
Wheat	2.25
Sugarcane	3.5
Sugar beet	3.0
Sweet sorghum	7.5
Miscanthus	42.5
Switchgrass	30.0
Poplar	15.0

4. Conclusions

From the Life Cycle Assessment results it can be concluded that, the net energy yield for carob pod to ethanol system is similar to those for traditional crops. Furthermore, a huge decrease in greenhouse gas emissions balance (up to 70%) is achieved in comparison with other bioethanol production processes in Spain. Others enviromental benefits could be achieve with the encouragement of carob pod cultivation like brake the desertification process in Spanish Southeast Region.

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