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Sayed Tamizuddin Gillani, Caroline Sablayrolles, Jean-Pierre Belaud, Mireille Montréjaud-Vignoles, Jean-Marc Le Lann. Assessment of *Jatropha Curcas* bioprocess for fuel production using LCA and CAPE. ESCAPE 21, 21th European Symposium on Computer-Aided Process Engineering (ESCAPE 21), May 2011, Chalcidique, Greece. pp.1341-1345. hal-04087428

HAL Id: hal-04087428

<https://hal.science/hal-04087428>

Submitted on 3 May 2023

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To cite this document : Gillani, Sayed Tamizuddin and Sablayrolles, Caroline and Belaud, Jean-Pierre and Montréjaud-Vignoles, Mireille and Le Lann, Jean Marc *Assessment of Jatropha Curcas bioprocess for fuel production using LCA and CAPE*. (2011) In: ESCAPE 21, 21th European Symposium on Computer-Aided Process Engineering (ESCAPE 21), 29 may - 01 June 2011, Chalkidiki, Grece .

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Assessment of *Jatropha Curcas* bioprocess for fuel production using LCA and CAPE

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Abstract

The importance of Life Cycle Assessment (LCA) as an environmental decision support tool continues to increase rapidly in the recent years. Research on the environmental impacts of chemical engineering has gain a lot of popularity but it still needs bundles of improvement and expansion for its implementation in the industrial process evaluation. In this study, Life Cycle Assessment of biofuel production from *Jatropha Curcas L.* was conducted using an attributional approach. The assessment encompasses the cultivation of the crop, the oil extraction stage and finally, the biofuel production stage. IMPACT 2002+ based on mid-point perspective was applied. This study demonstrates the potential of second generation biofuel production to reduce environmental impact. While LCA method is mainly focus on products and raw data collection, we want to define a new approach based on process system engineering. We suggest ways for an integrated LCA and CAPE approach especially for agro-chemical applications.

Keywords: Environmental Systems Engineering, Bioprocess, Life Cycle Assessment, Process System Engineering, Sustainability.

1. Introduction

The issues of fossil fuel like rapid increase of prices, the energy depletion and the awareness of the greenhouse gases effects has pushed many countries to face economic difficulties and environmental challenges. As a result, the developed countries have put their efforts on the improvement and development of renewable energy as an alternative future fuel. The potential environmental benefits that can be obtained from replacing petroleum fuels with biofuels and bioenergy derived from renewable biomass sources are the main driving forces for promoting the production and use of biofuels and bioenergy. However, questions arise about the validity of bioenergy as a means to reduce environmental impacts and dependence on fossil fuels.

There is a broad agreement in the scientific community that Life Cycle Assessment (LCA) is one of the best methodologies for the evaluation of the environmental burdens associated with biofuel production, by identifying energy and materials used as well as waste and emissions released to the environment (Consoli, Allen et al. 1993). Several LCA studies have demonstrated that the use of biomass to produce biofuel can help to minimize resource depletion (RD) and global warming (Ndong, Montrejaud-vignoles et al. 2009). Other studies have shown the opposite (Crutzen, Mosier et al. 2007; Searchinger, Ralph et al. 2008). These studies have concluded that most, but not all, biofuels substituting fossil fuels will lead to increased negative impacts (Larson 2006).

These environmental burdens are even more affected by site-specific assumptions than greenhouse gases and energy balances, showing that it is not easy to draw simplified conclusions.

In this study, we provide a generic and independent LCA, aiming to provide a general and profound insight in the environmental performance of the production and use of Jatropha biodiesel. The goal is to broaden the available information on the system's performance by assessing environmental impacts, to provide benchmark values of these impacts and identify options to improve the performance of current system.

2. Assessment of *Jatropha curcas* L. for Bio-diesel production

Jatropha curcas L. has taken a serious place in discussion that it is claimed to simultaneously produce bio-diesel, reclaim waste lands and enhance rural development (Francis *et al.* 2005). Its seeds contain toxic oil unsuitable for human or animal consumption, but easily extractable and convertible to biodiesel (Achten *et al.* 2008) meeting European and American standards. *Jatropha* was claimed to be able to grow in dry and degraded areas and thus would not affect food production. The LCA approach was carried out in accordance to the International Standard Organization guidelines (ISO 14040-44), and executed with MS EXCEL and SimaPro® LCA software.

2.1. Goal, Scope definition and System Boundaries

The *Jatropha* system is analyzed from cradle to grave, from *Jatropha* cultivation to biodiesel consumption (Figure-1). Operations include nursery and transplantation, cultivation, harvesting, oil extraction, refining and transesterification and end use. The functional unit (FU) is define as 1 MJ release to an engine fueled by *Jatropha* bio-diesel. The reference flow is the quantity (in kg) of *Jatropha* seed required to fulfill the functional unit.

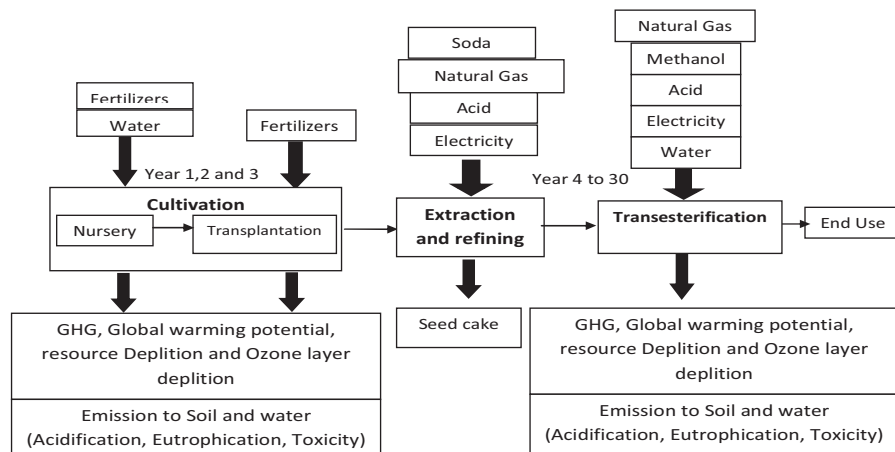


Figure-1: Diagrammatic presentation of Jatropha LCA system

2.2. Life cycle inventory analysis

Data were gathered from different sources: field observations, literature and databases. Background data were acquired from ECOINVENT database. The production of a *Jatropha* plant system is recorded to be for the period of 30 years on average base line. *Jatropha* did not produce any grains for the first two years and the grain production start after second year of establishment. Seedlings are grown in the nursery before transplantation. Then after these plant requires fertilizer of N, P and K as an inputs for

their growth. The amount of fertilizer inputs varies at different stages of Jatropha life cycle. Many field emissions to air, soil and water were included accordingly due to land application. Seeds were refined and oil extraction was carried out by cold pressing with electric screw presser. Transesterification converts 97% of the extracted oil to biodiesel. Reagents and catalyst inputs like Soda, Methanol and Acid were used in the refining and transesterification stage.

2.3. Impact assessment

Impact assessment was carried out with the Impact 2002+ methodology (Jolliet et al., 2003). A mid-point evaluation of Jatropha bio-diesel system environmental performance was evaluated by quantifying its non-renewable energy requirement (MJ), global warming potential (GWP) (kg CO₂-eq), ozone layer depletion (OD) (kg CFC11-eq) and acidification (kg SO₂-eq). For each impact categories, the share of the different contributing production phase like nursery establishment, transplantation, refining, oil extraction transesterification and end use are indicated.

2.4. Results and discussion

The actual cultivation phase has a share of low energy consumption in comparison to all other stages like refining and transesterification. Indeed, the transesterification stage consumes more than half (60%) of the energy consumption. Total of 30.8 and 22.4 kWh electricity in refining and transesterification stages respectively was used for per ton production of Jatropha Methyl Ester.

Figure-2 presents the potential impacts in different unit processes in Jatropha bio-diesel production system.

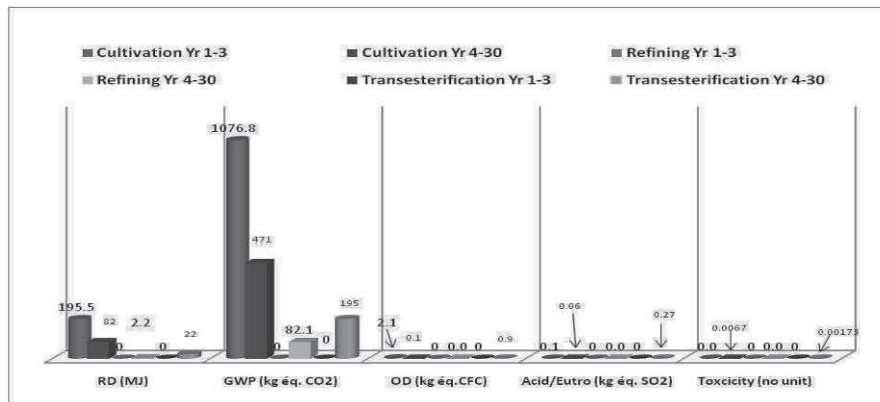


Figure-2: Difference between Impacts in the cultivation/grain production, Refining and transesterification phase in the Life cycle of Jatropha

Large proportion (>90%) of greenhouse gases emission occurs during the agricultural cultivation phase due to the use of fertilizers and pesticides. The phase that has more energy consumption has the low GHG emissions as compared to the cultivation phase. This is not a common finding as according to (Prueksakorn and Gheewala 2008) have more than 70% energy consumption in the cultivation phase rather than transesterification phase but this is because of the methodology issue. Our results show the total impact of non-renewable energy resources of 195 MJ for the first three years and 104 MJ for the year 4th onwards. This means that the Jatropha system consumes 8 times less energy consumption than the fossil fuel (Prueksakorn and Gheewala 2008). The impacts for energy resource during the cultivation phase were 184 MJ and only 11 MJ for the transesterification phase in the first 3 years. For the 4th year onward we have

the value of 22 MJ resources depletion for transesterification and refining phase and 82 MJ from the production phase through use of fertilizers NPK.

The impact of global warming was recorded to be 195 kg CO₂-eq versus 471 kg CO₂-eq of transesterification and plant production respectively. This provides a base that the cultivation phases contribute highest percentage of impacts then all other unitary processes of Jatropha biodiesel system. For Ozone layer depletion, Jatropha system has a clear advantage over other fossil fuel. The impact concerning ozone layer depletion was recorded to be 0.1 kg CFC11-eq and 0.9 kg CFC11-eq in the refining/transesterification and plant cultivation phases respectively.

Different then what we found in our previous impact categories, acidification and eutrophication potential has then higher impacts for transesterification than grain production which in total is 0.05 kg SO₂-eq for cultivation phase and 0.27 kg SO₂-eq for transesterification phase. This is mainly due to NH₃, NO_x and SO_x emission caused by the use of methanol, acid, soda and KOH which improve the acidification and eutrophication score.

The result indicates that Jatropha biodiesel is a promising bio-fuel plant which has low global warming potential than that of fossil fuel (Achten *et al.* 2008). It should be noted that the results do not include land-use impacts; hence it omits a potentially large impact through loss of carbon stock. Compared to other bio-fuels, Jatropha global warming potential reduction rate is the lowest among available literature (Cherubini, Bird *et al.* 2009).

3. Discussion

Biofuel has been expected to substitute fossil fuel because of its renewability; however this may also raise the issue of environmental impacts. As already mentioned the use of LCA as a tool for assessing the environmental impacts of product, processes and activities related to them is gaining some good acceptance. At the same time there are some limitations which affect the uniformity and quality of LCA results. These limitations include geographical dependency, databases required, consequences for the environmental risk (cause by the real impacts not potential impacts), and the variations in LCA results due to the quality of data. One example of geographic dependency is France and Canada as Canada mainly uses hydal electricity while France uses the resources like nuclear for electricity. This will surely not lead to the same impacts and results at the end. Limited number of studies has been reported in the literature (Azapagic and clift, 1999) for LCA to get potential benefits in collaboration with process simulation and optimization.

In order to tackle these difficulties, CAPE has the potential and primary importance by simulation of whole process, unit operation and physical property as well as reference processes. In chemical industry the simulations has been intensively valued both in the literature and practical application. Subjective comparison made in LCA could be evaluated through different simulations. This will help to compare different assumptions more efficiently and quickly. Through CAPE we will be able to perform LCA at the planning phase where available design information are limited and standardized procedure of process simulation as inventory is strongly demanded. Between various steps of LCA, the least standardized step is Impact assessment. This is because of many methods that are in use currently (Sugiyama *et al.*, 2006). These methods can put different levels of importance for various impact factors, which often not leads to identical conclusion as described in our results. Therefore it would be more beneficial to have an environment in which the parameter could be changed easily in order to reflect

the differences in various methodologies used for LCA. CAPE can help to create or modify simulation for the reconciliation between LCA impact methodologies.

Following the completion of our bioprocess study based on a common LCA, the next step is to progress on an approach that benefit from CAPE concepts, methods and tools, through a “process engineering driven LCA”. In order to suggest such approach, many questions related to the process have to be raised like the purpose (evaluation, comparison, and environmental optimization), the type of process (new or existing), and the step in the process life cycle (economic evaluation, preliminary design, design, operation), the data and model availability and relevance, the requested level of details. (Kikuchi *et al.* 2009) illustrate CAPE and LCA tools integration for biomass process design. Basically in general a LCA process assessment and a CAPE process design, as well as the associated software tools, are not located on the same analysis level. So to couple both, LCA and CAPE for an environmental conscious process, is clearly hard. In our *Jatropha* bioprocess, according to a “CAPE for LCA” scheme and multi scale modeling we plan to integrate a unit operation model in order to improve the whole environmental assessment. As shown in section 2, the transesterification phase has a key impact on the final result. We estimate that a simulation based on phenomenological CAPE models should improve the analysis of *Jatropha* bioprocess. In this way we have to develop interoperability between our different software tools.

Conclusion

Liquid biofuel has been promoted as an effective measure to lower the environmental burden in comparison to fossil fuel. *Jatropha* has gain primary attention these days as a promising biodiesel plant that can lower the impacts. Based on a common LCA through Excel, Simapro, ECOINVENT and impact2002+, we have now a solid ground for the integration of CAPE methods and tools in order to improve this study.

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