Life-cycle assessment of Bio-diesel from *Jatropha curcas* L.
energy balance, impact on global warming, land use impact

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Abstract
The pantropic oil-bearing woody plant *Jatropha curcas* L. (JCL) receives a lot of attention from Clean Development Mechanism project developers all over the tropical world. The crop as living fence is good for food production protection, erosion control and ecological restoration in degraded semi-arid regions. JCL is suitable for several agroforestry and intercropping cultivation systems as well. Nowadays JCL is widely planted as monoculture. Besides the cultivation, the production process of bio-diesel consists of extracting the oil from the seeds and conversion of the crude oil to bio-diesel. The production process results in a whole range of interesting by-products as well. At the moment no complete life cycle assessment of the bio-diesel production from JCL is available. The authors started research which will focus on such LCA, investigating the 3 different JCL cultivation systems using 2 reference systems and strengthened by a socio-economic impact study.

1. INTRODUCTION

*Jatropha curcas* L. (*Euphorbiaceae*) is a small deciduous tree (up to 5 m) which originates from Mexico and Central America, although nowadays is growing pantropic [1]. The multi purpose crop is traditionally used for medicinal purposes, but is also useful as living fence and for the prevention and control of soil erosion [2,3]. As a pioneer species, well adapted to semi-arid climates, JCL is promising to simultaneously combat desertification, produce bio-diesel and enhance socio-economic development in degraded rural areas in the South [4].

In normal conditions the plant will fruit once a year, yielding 2-5 tons of dry seed/ha/year, after 5 years, depending on the genetic variety, agro-climatical conditions and the management input [1,4,5]. The seeds contain 30-35 \% oil by weight, which can easily be converted into bio-diesel meeting the standards of US, Germany and European Standard Organisation [6]. The seeds and oil are not edible due to presence of toxins as phorbol esters, trypsin inhibitors, lectins, phytates [4].

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These properties persuade many Clean Development Mechanism project developers, investors and policy and opinion makers to choose JCL to tackle the energy dependency and greenhouse gas problems of fossil fuels, although the environmental impacts have not been investigated yet. There is a clear need for a LCA study of bio-diesel from Jatropha.

2. BIO-DIESEL PRODUCTION FROM JATROPHA

2.1. Jatropha cultivation

JCL’s high adaptability [1] allows it to grow in wide ranges of conditions. As a succulent that sheds its leaves during the dry season, JCL is best adapted to arid and semi-arid conditions. [7]. All soil types can support JCL except for Vertisols and soils with pH above 9 [5,8].

For establishment of long living plantations for oil production, seed propagation is preferred above vegetative propagation (cuttings) [1]. Seedlings are prepared in nursery condition and planted in planting pits which are best refilled with a mixture of soil, compost, sand, organic matter and/or artificial fertilizer [9]. Further management includes pruning and canopy management, fertilizing and irrigating according to the situation [9-11]. Due to uneven ripening, the fruits are harvested manually [1]. Separation of the seeds and husks can be done manually or mechanically [9]. These fruit husks can be gasified [12], fermented for biogas production [13] or combusted directly. The air or oven dried seeds go to the following production step.

2.2. Oil extraction

For extraction of the JCL oil two main methods have been identified: (i) mechanical extraction and (ii) chemical extraction [14,15]. Most common is the use of an engine driven screw press, achieving a yield of 70-80% of the available oil [5,16,17]. Manual presses achieve 60-65% [5,15,16].
Solvent extraction (using \( n \)-hexane, acetone, aqueous enzymatic oil extraction, ...) generally achieve higher yields (up to 98% of available oil) [2], but is only economical viable at a large scale production [18]. Furthermore, the conventional \( n \)-hexane solvent extraction is believed to have a high specific energy consumption and high greenhouse gas emission [18]. After extraction the oil is filtered through a filter press and is then ready for the conversion to bio-diesel.

The seed cake left over after extraction is valuable as bio-fertilizer, as it contains more nutrients than both chicken and cattle manure [4]. Before using the cake as fertilizer, the cake can serve as feed for biogas production as well [19,20].

2.3. Transesterification

Transesterification is the displacement of alcohol from an ester by another alcohol [21]. In case of JCL oil, (m)ethanol displaces glycerol from triglycerides, leaving (m)ethylesters (i.e. bio-diesel).

In order to shift the reaction to the right an alcohol excess (molar ratio alcohol:oil = 6:1) and a catalyst (NaOH, KOH at 20% by weight on oil basis) are necessary [22]. An optimal ester yield of 98% is achieved after 90 min. of reaction at 60°C [22]. Crude glycerol is separated and can be used as a raw material for soap production or other cosmetica.

3. RESEARCH OBJECTIVES

An independent, generic, comparative LCA will be made, comparing 3 different JCL production systems, using 2 reference systems: (i) an other tropical bio-diesel system and (ii) the conventional fossil diesel system (figure 4). The functional unit where all inputs and outputs will be related to is ‘100km driven with a 4×4 pick up’. Energy balance, global warming potential and land use impact are seen as the most relevant impact categories.

4. PRELIMINARY RESULTS AND EXPECTATIONS

4.1. Energy balance

The energy balance is reported to be positive [23,24]. In both reports transesterification is shown to be an energy intensive production step. The big difference between the two studies lies in the share of the jatropha cultivation in the overall energy input (50% in [23] and 17% in [24]) (figure 5). This shows the importance of the applied cultivation intensity. Fertilizer and irrigation are energy intensive agricultural practices.
Based on these reports it is believed that the energy balance of bio-diesel from *Jatropha* is positive but is thought to become less positive:
- After transesterification
- Without energetic use of the by-products
- With increasing intensification and mechanization of the production cycle
- If the product is shipped to remote markets (such as Europe)

### 4.2. Global Warming Potential

Tobin & Fulford [24] and Prueksakorn & Gheewala [23] also showed positive results on the life cycle greenhouse gas emission of the production of *Jatropha* bio-diesel in comparison to fossil diesel (figure 6). Again there is a clear difference in the obtained results of a high cultivation input (described in [23]) and low cultivation input system (figure 6).

Figure 6 and 7 indicate that the impact on the global warming potential is positive. But the impact becomes less positive with the intensification of the *Jatropha* cultivation.
(mainly fertilizer and irrigation application are greenhouse gas intensive inputs). Furthermore it is clear that also the transesterification is a big greenhouse gas contributor (figure 7).

4.3. Land use impact

The land use impact assessment will be made, based on the method described by Peters et al. [25]. A theoretical background based on ecosystem thermodynamics uses the hypothesis that in absence of human land use impact, all ecosystems tend to maximize the internal exergy level and control over incoming and outgoing exergy fluxes. In order to measure land use impact, the deviation from the site specific maximum ecosystem performance in exergy terms is estimated using 17 quantitative indicators and aggregated into four thematic scores: soil, water, vegetation structure and biodiversity. Thematic scores are multiplied by the area x time needed for the production of the functional unit [25].

Expected results for Jatropha bio-diesel:
- Impact on soil: (i) Mostly positive impact through erosion control and carbon sequestration, but (ii) negative impact if intensively grown with high input of fertilizers and machinery
- Impact on water: based on Heuvelmans et al. [26]: positive on-site effects, but negative off-site (more research necessary)
- Impact on vegetation structure: (i) Positive if wasteland is reclaimed, (ii) negative in case of re-allocating (semi-)natural vegetation to Jatropha.
- Impact on biodiversity: (i) negative in monoculture. Improvement possible by intercropping, agroforestry and set aside part of the land. (ii) Positive in case of low use of biocides. (iii) Further there are some unchecked reports on invasiveness.

4.4. Other impact categories

Since JCL seeds and oil contain several toxins, such as phorbol esters, curcin, trypsin inhibitors, lectins, phytates, to such levels that the seeds and the oil are toxic to human health. Attention should be paid to human health and work environment. These impact categories are also at stake in case of solvent extraction.

5. CONCLUSIONS

Jatropha curcas L. is a promising energy crop for the semi-arid regions. Preliminary results show a positive energy balance and impact on global warming potential. More research is necessary to get a good insight in the environmental sustainability of this production system. The land use impact is an absolute must to address those sustainability issues.

6. ACKNOWLEDGMENTS

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