



Comparative life cycle assessment of biodiesel from algae and jatropha: A case study of India



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HIGHLIGHTS

- Algae could be an alternative source for biodiesel due to Indian meteorological and geographical conditions.
- The environmental performance of algae and jatropha biodiesel could be superior to fossil diesel.
- Seed yields have a significant impact on the environmental performance of jatropha biodiesel production.
- Efficient utilization of co-products is essential for algae biodiesel production.

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ABSTRACT

Algae and jatropha, two types of promising and unconventional biomass, are investigated in this study for large-scale production of biodiesel. The aim is to evaluate the potential advantages and the magnitude of closeness of life cycle balances between these two biodiesel pathways compared to fossil diesel, by taking into account possible uncertainties. The geographical location of this study is India with a prospect of utilizing available wastelands in southern regions. The results indicate that the environmental performance of algal biodiesel is comparable to that of jatropha biodiesel. Both show significant GHG emission and fossil energy depletion reductions which are in the range of 36–40 and 10–25% respectively compared to fossil diesel in the studied geographic context.

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1. Introduction

As a developing country with high rate of economic expansion, India has been excessively relying on fossil fuels where petro-based fuels account for about 95% of India's transportation energy demand (National Policy on Biofuels, 2009). India's dependency on foreign crude oil has been increasing rapidly and domestic production can merely provide 24% of the total oil demand (US EIA, 2013). It has been estimated that with the current trend of development, the country will have a fleet of nearly 500 million vehicles by the next two decades, from the current 150 million (Sharma, 2011). This threefold increase would exacerbate India's dependence on imported energy and it is likely to intensify the environmental adverse effects attributed to fossil fuels consumption such as greenhouse gas (GHG) emissions.

Among few available alternatives to substitute some parts of fossil fuels' share in transportation sector, biofuels are considered to be a promising source of renewable energy because they can

be easily blended with fossil fuel and used in conventional engines. As a legislative attempt to augment the share of biofuels in India, the ministry of new and renewable energy set up a national policy which defined an indicative target of 20% blending of biofuels – whether biodiesel or bioethanol – by 2017. Bioethanol mandate has been effective since October 2008 however blending levels for biodiesel are intended to be recommendatory for now, despite arrangements for research and development of new generations of biomass such as lignocellulosic, jatropha and algae (National Policy on Biofuels, 2009). Both jatropha and algae can be utilized for production of biodiesel and despite fundamental differences in cultivation and harvesting, there are many similarities in downstream stages. This similarity along with other mentioned reasons are justifying a comparative LCA study.

Few previous scientific attempts are available to evaluate production of transportation fuels from jatropha and algae. These studies have shown substantial uncertainties in analysis of energy and environmental performances. For instance and for the case of jatropha biodiesel (JBD), the reported net energy ratio (NER) values are in the range of 1.2–8.6 and the GHG emissions reduction compared to fossil diesel is ranging from 40% to 107%. Variations in values are mainly due to the influence of system boundaries considered in each LCA study, such as energy, mass and market

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value allocation, without allocation, irrigated and rain fed, displacement of energy and fertilizer, variation in seed yield selected for the LCA (Achten et al., 2010; Kumar et al., 2012). Similarly for algal biodiesel (ABD), reported net energy ratios (NER) range from 0.1 to 4.2, while the GHG emissions for a functional unit of 1 MJ of produced biodiesel range from 35 to 140 gCO₂eq. Some studies claimed that energy and environmental performance of ABD could be sustainable and superior when compared to fossil diesel (Campbell et al., 2011; Sills et al., 2013). Some others indicated low differences between ABD and fossil diesel (Lardon et al., 2009; Stephenson et al., 2010; Frank et al., 2011); while a few claimed poor performances with negligible advantages (Khoo et al., 2011; Liang et al., 2013). It is essential to consider certain conditions for a case study of these types of biofuels, and then to perform uncertainty analyses in order to assess influences of each factor on the entire process. Gnansounou et al. (2009) previously have shown how important the wide range of system definitions, boundaries, functional units and reference systems could be for the final results. Furthermore, Sills et al. (2013) studied the effects of inconsistent system boundaries and uncertainties on the LCA studies of algal biofuels and illustrated the wide discrepancy between the results. The focus of this study is to compare the life cycle assessment of jatropha and algae production in India concerning some of these uncertainties.

2. Geographical context of India

Despite being relatively energy deprived, India has numerous potentials for development of renewable energies, particularly biofuels. Availability of vast areas of wastelands is one of these potentials. Ramakrishnaiah (2006) described Indian wastelands as any degraded land which “can be brought under vegetative cover with reasonable effort and which is currently underutilized” and estimated that there were up to 32 million hectares of waste land in India mainly in forms of covered with scrubs and saline, abandoned and degraded forests. The objective of this study is to evaluate environmental performance of large-scale production of biodiesel from algae and jatropha based feedstock in India, with a focus on the southern region (Tamil Nadu) and by considering utilization of local potentials. This is due to the fact that, potential to grow jatropha and algae is high in this region due to waste land, coastal line, industry availability and favorable meteorological conditions suitable for jatropha or algae and its co-product utilization and also the region is well known for jatropha and algae cultivation (Chanakya et al., 2012).

Indian electricity network is connected locally and the energy matrixes are different from one region to the other. Electricity authority in India is divided into five regions namely Northern, Southern, Eastern, Western and North-Eastern. Coal, hydropower, natural gas, nuclear, diesel, biomass and other renewables are the main sources of power generation in India. The energy mix of the southern region for electricity generation in 2011 is as follows: coal 44%, hydropower 21%, biomass and other renewables 22%, natural gas 9%, nuclear 2%, and diesel 2% (Energy statistics, 2012). An average transmission and distribution loss of 18% in the southern region was also taken in account.

3. Process description

3.1. Jatropha cultivation and harvesting

Jatropha curcas L. is a perennial drought tolerant oil-bearing bush that is native to tropical regions and can be cultivated on semi-arid and marginal lands where it does not compete with food crops. Jatropha cultivation process involves land preparation, sow-

ing, irrigation, fertilizer and pesticides application, pruning and seed harvesting. Initial investigations indicated promising results on jatropha, as a source of biomass for bioenergy; however more recent studies have proved that actual yields could be much lower than theoretical yields depending on region, cultivation, irrigation and crop maintenance characteristics (Singh et al., 2013). Cultivation data (fertilizer, water, pesticides and diesel) used for modeling in this study were collected from literature and normalized for 1 kg biodiesel produced (Table 1). Minimal mechanization was considered for agricultural activities and all works were considered to be done manually unless it is stated. Cultivation land was irrigated using diesel pump for which the energy consumption was taken into account. Leaves shed during plant growth were assumed to be left on the ground whereas, the twigs accumulated (410 kg/ha) after pruning were considered as a co-product with a lower heating value of 16 MJ/kg (Wani et al., 2012). Seeds were harvested manually. A yield of 2 t/ha and oil content of 35% (w/w) in dry seed were assumed for the base case scenario.

3.2. Microalgae cultivation and harvesting

Raceway ponds and closed bioreactors are the most studied methods of large-scale production of algal biomass. Higher productivity with water, CO₂ and nutrient saving and protection from contaminants which provides the option of high-value added co-products are the advantages of closed bioreactors. However, high maintenance cost and technical difficulties have so far made this method un-economical (Stephenson et al., 2010). Raceway ponds on the other hand are relatively cheap with easier maintenance and the operation is more energy efficient which would suit for India. As a result only raceway ponds were considered in this paper. Depending on the strain, microalgae can be both cultivated in freshwater or seawater. Considering the capacity of a large scale biodiesel production and the scarcity of fresh water in India, only seawater algae strains were considered. During cultivation, microalgae absorb CO₂ for photosynthesis. A feasible economic algae cultivation system requires a source of carbon with higher concentrations than the atmospheric CO₂ (FAO, 2009). Carbon capture from flu gas emissions, particularly from power plants that burn fossil fuels can be a promising option to provide high concentration of CO₂ (up to 20%) and postpone carbon emissions at the same time. For this study, it has been assumed that a readily available CO₂ stream can be utilized for the raceway ponds and has been previously cooled down and stripped from NO_x and SO_x emissions before entering the system boundary.

Few studies modeled cultivation of algae in raceway ponds. A well-established numerical method was used by Stephenson et al. (2010) where an energy input of 7.2 MJ was considered per kg of algal biodiesel. Lardon et al. (2009) also modeled a raceway pond system where the energy input was 20.8% lower compared to the latter. In this paper, the model described by Frank et al. (2011) was considered as a base to characterize the raceway ponds. Among algal species, *Chlorella* with an oil content of 25% of total dry biomass was assumed for the case study of India. Additionally recycle pumping and pumping from off-site were included by considering similar pumping designs described in Davis et al. (2012). The total energy inputs were then normalized and the data are described in Table 2.

For further processing, the cultivated biomass should be separated from its growing medium.

There are various technical and conceptual technologies proposed for harvesting algal biomass (FAO, 2009). The harvesting stage of this study has been modeled based on three consecutive stages: settling tanks coupled with the cultivation ponds, a dissolved air flotation (DAF) unit and centrifugation. Chitosan which

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