Energy for Sustainable Development 23 (2014) 258–265

Contents lists available at ScienceDirect

Energy for Sustainable Development

Effect of farming system and yield in the life cycle assessment of Jatropha-based bioenergy in Mali

Joana Almeida [a], Pieter Moonen [a], Iria Soto [a,b], Wouter M.J. Achten [a,1], Bart Muys [a,*]

[a] KU Leuven, Department of Earth and Environmental Sciences, Division of Forest, Nature and Landscape, Belgium
[b] Forest Science Centre of Catalonia, Direction of International Affairs, Spain

ARTICLE INFO

Article history:
Received 12 May 2014
Accepted 2 October 2014
Available online xxxx

Keywords:
Biodiesel
Bio-oil
Global warming potential
Cumulative energy demand
Fossil depletion
Smallholders

ABSTRACT

Jatropha has been promoted in sub-Saharan Africa as a smallholder energy crop promising additional revenue and energetic self-sufficiency. In this case-study located in Southern Mali we performed a comparative life cycle assessment shedding light on the influence of smallholder participation and yield fluctuations on the global warming potential, fossil resource depletion and energy demand of *Jatropha*-based rural electrification in comparison to a fossil fuel-based reference. We found that the global warming potential of *Jatropha*-based electrification can be 13% higher to 20% lower than fossil diesel, depending on the yield. In terms of energy use and fossil fuel depletion, *Jatropha* is more favourable than fossil-based electricity. In either perspective, the activities related to cultivating and processing grain from small farmers accentuate the environmental impacts, owing to low yields. We conclude that outgrower engagement in tending and harvesting *Jatropha* is a key factor for improving the environmental performance of the system.

Introduction

Despite its low energy demand of only 3% of the global energy production, Africa has a fast growth rate of per capita energy use of 4.1% annually (IEA, 2011), which is more than anywhere else in the world. This growth rate is driven by improved infrastructure and the pursuit of better living standards. In 2010, Mali's national rate of access to electricity was 27.1%; this figure is as low as 14% in rural areas (versus a global average of 93.7 and 68% respectively) (Coulibaly and Bonfiglioli, 2012; IEA, 2011). As the benefits of electrification range from improving health and education to reducing food insecurity and inequality, access to electricity has been considered an important strategy for development (Dasappa, 2011; Lahimer et al., 2013; Mohammed et al., 2013).

Biomass is by large the main energy carrier in Sub-Saharan Africa, where rural populations and low income earners rely on the combustion of traditional fuels such as wood and charcoal for cooking and heating (Dasappa, 2011; Mohammed et al., 2013). Given the high bioenergy potential of most sub-Saharan countries, it is claimed that harnessing and structuring the collection, conversion and use of biomass must be part of a greater developmental plan for energy security in the region (Mohammed et al., 2013). It is in the context of improving access to electricity that governments and NGO's throughout the region have been supporting projects for Jatropha-based off-grid energy solutions (Achten et al., 2007; Eckart and Henshaw, 2012; Favretto, 2013; Garg et al., 2011; Gilbert, 2011).

Jatropha curcas L. is a small tree that yields oil-bearing seeds. Once extracted the high quality oil can be used directly or converted into biodiesel, either being suitable for use in engines of automobiles or electrical power generation. It was thought initially that Jatropha would fulfil the promise of empowering communities with self-provision of energy and additional income with very little impact on the environment, owing to its low requirements of fertilizers, pesticides and water. Moreover, its proclivity for marginal soils would ensure little competition with food resources (Fairless, 2007). These early hype claims have been in the meantime rebated by experience (reviewed by Contran et al. (2013)). The lack of improved high yielding varieties (Achten et al., 2009; Contran et al., 2013) has often turned it into a drawback for investors and small farmers (Skutch et al., 2012). Jatropha's contribution to biodiesel production in developing countries is predicted to be 10% by 2020, a modest contribution hindered by a low-competitive yield capacity in face of crops such as soybean and oil palm (OECD/FAO, 2011).

Life cycle assessment is widely used as a sustainability evaluation tool for bioenergy studies. This standardized and well accepted tool accounts for all the inputs and outputs of a product's life cycle, from raw material acquisition, over processing, distribution and use, till final disposal, to comprehensively profile its environmental impact. Earlier LCAs indicate that Jatropha-based biofuels have a favourable environmental performance relatively to fossil fuels in terms of

* Corresponding author at: Department of Earth and Environmental Sciences, KU Leuven, Celestijnenlaan 200E-2411, BE-3001 Leuven, Belgium. Tel.: +32 16 329721.
E-mail address: bart.muys@ees.kuleuven.be (B. Muys).
[1] Present address: Université libre de Bruxelles, Institute for Environmental Management and Land Use Planning, Gestion de l'Environnement, Société et Territoire, Belgium.

http://dx.doi.org/10.1016/j.esd.2014.10.001
0973-0826/

greenhouse gas (GHG) emissions and energy use (e.g. Achten et al. (2010), Almeida et al. (2011), Gmünder et al. (2010), Ndong et al. (2009), Pandey et al. (2011)).

Because energy use and efficiency and climate change mitigation are intended by biofuel models, these are also the environmental issues that Jatropha-based bioenergy LCAs mostly tend to. In this study we assess the global warming potential (GWP), cumulative energy demand (CED) and fossil depletion (FD) of generating electricity from Jatropha biodiesel in the region of Koulikoro, in Southern Mali. The centralized conversion facility is sourcing grain from own fields as well as from a network of outgrowers present in the region. The involvement of outgrowers is an integrated approach to energy provision that results in more resilient systems from the socio-economic perspective (Muys et al., 2014). In this study, we aim to investigate the effect of this mixed supply on the environmental impact. A comparative LCA approach further includes evaluating the systems' performance for two measured yield levels conditioned by climatic conditions in two consecutive years.

Materials and methods

Goal and scope definition and data collection

The aim of this LCA exercise is to calculate the cumulative GHG emissions, fossil fuel use and energy use and efficiency of the production of Jatropha biodiesel-based electricity production in the region of Koulikoro (13°N, 7°W), in Southern Mali.

The system comprises all phases of the production chain, from nursery to combustion in the electrical generator, and assumes a plantation rotation time of 20 years (Fig. 1). Grain processing and fuel production occur centrally at the facilities of Mali Biocarburant (MBSA) in the town of Koulikoro. The grains are coming from an outgrower scheme and from fields managed by MBSA.

MBSA produces biodiesel to fuel both automotive and stationary engines, according to their needs. We chose to model the end use phase with technology available in the factory: combustion of the biodiesel in the factory-owned electrical generator. We acknowledge, however, that plant oil would be the most reasonable choice to feed a stationary engine (Muys et al., 2014). For this reason, we highlight also the environmental impact of bio-oil-based electrification. We assumed similar in-engine efficiency and tailpipe emissions for biodiesel and bio-oil (Soltic et al., 2009).

The inputs to the system are fertilizers, pesticides, transesterification reagents, transport of grain between fields and the press and the transport of equipment for extraction, transesterification and electricity generation before installing in the MBSA facilities. Land use is excluded from the system and, as such, potential GHG emissions resulting of land use and land use change were not taken into account. Likewise, carbon sequestration in the Jatropha biomass, and carbon tailpipe emissions are excluded.

We collected data on all production stages through direct observation and questionnaires (described in Almeida et al. (2011)) presented to MBSA. Information on the cultivation practices of outgrowers were retrieved from household interviews (Achten et al., 2012). Inventory gaps left by the questionnaires and interviews were filled with information from literature. Background data to all processes was retrieved from the LCA database ecoinvent® v.2.2 (ETH and EMPA, Switzerland). Although most data in this database does not have an African context,

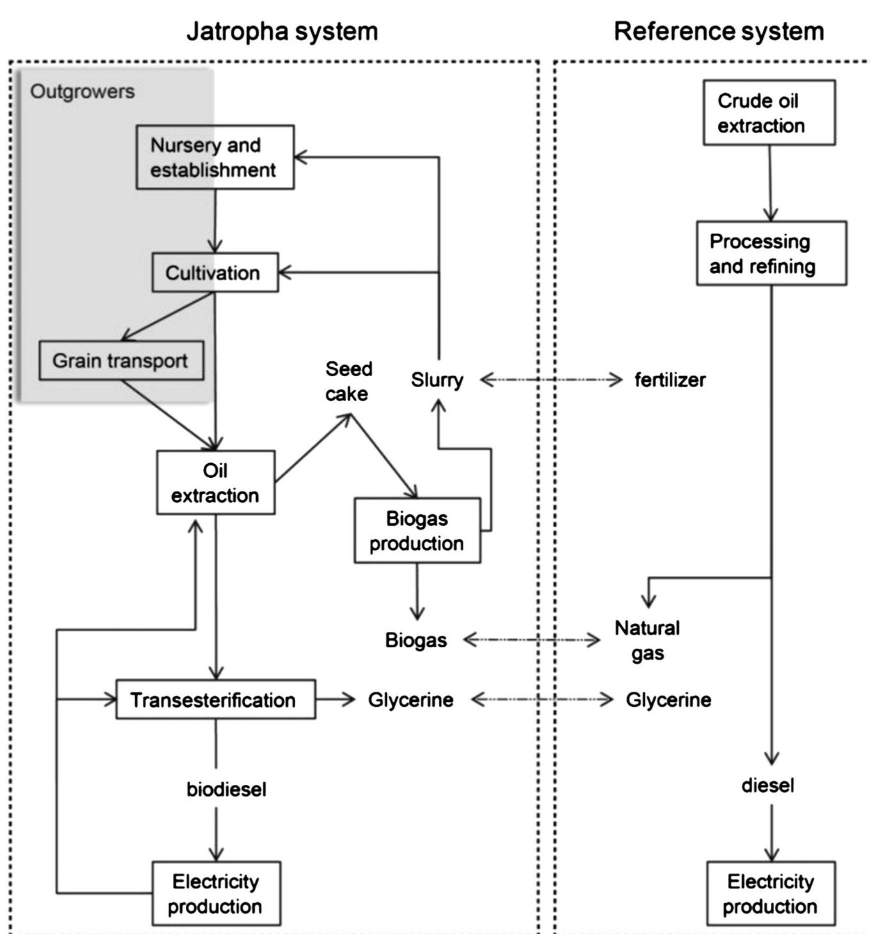

Fig. 1. The production systems in Koulikoro and its relation to the reference system. The dashed lines represent the system boundaries, the dotted arrows indicate substitution by system boundary expansion, and the grey boxes show the outgrowers' farming system.