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A comparative study of small-scale rural energy service pathways for lighting, cooking and mechanical power

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HIGHLIGHTS

- ▸ Life cycle based analytical framework for rural energy service pathways (RESPs).
- ▸ Comparison of Jatropha-based RESPs for lighting, cooking and mechanical power.
- ▸ Weak performance of Jatropha oil in the categories lighting and cooking.
- ▸ The potential for power depends on capital, energy, labour, and transport intensity.
- ▸ Simultaneous use of plant oil and biogas at village scale shows best potential.

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ABSTRACT

The strong international growth of biofuels in the last decade brought the interest in bioenergy back on the agenda. While many life cycle assessments for biofuels mainly focus on environmental impacts and costs, over the last decade especially the energy balance of biofuel production chains has been a major point of criticism. This study applies a specially adapted and LCA-based analytical framework for rural energy service pathways (RESPs) to compare the use of Jatropha plant oil and biogas with other small-scale RESPs for lighting, cooking and mechanical power. The aim is to analyse their technological feasibility and economical viability by comparing the energy and cost efficiency. Results show strong differences for the investigated plant oil production and processing pathways, while the comparison with a baseline and a competitive renewable energy scenario reveals a weak performance of plant oil and even biogas in the categories of lighting and cooking. The potential for mechanical power depends largely on the careful optimisation of the energy service pathway by balancing the capital, energy, labour, and transport intensity. For the present case, the village scale production of Jatropha plant oil and biogas and their simultaneous use in a dual fuel engine to locally provide power and electricity would be the service pathway with the highest potential in terms of energy and cost efficiency.

1. Introduction

Service delivery in remote rural areas of developing countries remains a major challenge for both, electrical and non-electrical energy services. Latest data confirm the slow decrease of the number of people without access to electricity from 1.6 billion in 2002 to 1.4 billion today and an expected 1.2 billion by 2030 while the number of people relying on the traditional use of biomass for cooking and heating is still increasing together with the global population from 2.4 billion in 2002 to 2.7 billion today and an expected 2.8 billion by 2030 [1,2]. In any case, there remains a substantial gap between the objective to reach universal energy access by 2030 [3] and the business as usual scenario as described by the IEA. Due to the population increase, particularly in developing countries, the share of bioenergy in the continuously growing global energy demand remained stable at 10% in the past decade. Of this global bioenergy consumption, the share of so-called ‘modern bioenergy and biofuels’ is only 22%, while the remaining 78% comprise traditional use in rural areas where bioenergy often makes up over 90% of the total energy demand [4,5]. These rural areas are typically characterised by a weak infrastructural setup in terms of healthcare, education, sanitation and transportation. Alongside firewood and dung, kerosene and candles are traditional fuels for cooking and lighting, whereas liquefied petroleum gas (LPG) and electricity often are unavailable or cost-prohibitive for most of the rural population. The burden of firewood and dung collection for cooking rests mainly on women and female children, who at the same time are most affected by the indoor air pollution caused by inefficient stoves and open cooking fires. Worldwide,

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Nomenclature

Abbreviations

GHG	Green house gases
ICT	information and communication technologies
IDR	Indonesian rupiah, with 12,819 IDR/€in February 2010
IEA	International Energy Agency
LCA	life cycle assessment
LED	light emitting diode
LPG	liquefied petroleum gas
MHP	micro-hydropower
RESP	rural energy service pathway
RET	renewable energy technology
SHS	solar home system

Parameters

ALD	annual labour demand (wd/a)
$ANEC_{Base}$	annual net energy costs of the baseline (€/a)
$ANEC_{ExL}$	annual net energy costs without labour (€/a)
B_t	total benefits of the system in year *t*
C_t	total costs of the system in year *t*
C_{Cap}	annual capital costs (€/a)
C_{Fuel}	annual fuel costs (€/a)
C_{Inp}	annual input costs (€/a)
C_{Inv}	initial investment costs (€)
C_{Lab}	annual labour costs (€/a)
C_{Tra}	annual transport costs (€/a)
CED	cumulated energy demand (kW h/kW h or kW h/kLm h)
d	Real discount rate (corrected for inflation) (%)
E_{Aux}	total auxiliary energy input (kW h)
E_{Fin}	supplied final energy to the end-use process (kW h)
E_{Pri}	total primary energy input (kW h)
E_{Use}	levelised useful energy output (1 kW h or 1 kLm h)
E_{Use_a}	average annual useful energy output
E_{Use_t}	useful energy output in year *t*
GER	Gross Energy Ratio (kW h/kW h or kW h/kLm h)
n	lifetime of the project (a)
NEB	Net Energy Balance (kW h or kLm h)
NEC	Net Energy Cost (€/kW h)
NER	Net Energy Ratio (kW h/kW h or kW h/kLm h)
NEV	net energy value (kW h or kLm h)
NPV	net present value (€)
ROL	return on labour (€/wd)
η_{Use}	efficiency of the end-use appliance

Units

a	year, unit of time, 8760 h
h	hour, unit of time
J	Joule, unit of energy
l	litre, unit of volume
Lm	Lumen, unit of the luminous flux
m	metre, unit of length
W	watt, unit of power
wd	workday, unit of the labour demand (assumed as 8 h per day)

SI-Prefixes

k	kilo, 10^3
M	mega, 10^6

almost two million deaths annually from pneumonia, chronic lung disease, and lung cancer are associated with exposure to indoor air pollution resulting from cooking with biomass and coal. Of these deaths, 99% occur in developing countries [6].

As it is widely accepted that even for the coming decades large parts of rural population will not be connected to central power grids or fossil fuel logistic chains [2,7], the development of decentralised rural energy systems using local renewable resources has come into greater focus. Renewable energy technologies (RETs), increasingly employed in the rural context, include small and micro-hydropower turbines, solar home systems (SHSs), biogas digesters, and improved stoves [8]. Biomass remains the primary energy source for cooking and heating in rural as well as many urban areas. Due to growing populations and the subsequent rise in land, water and energy demand, urban and rural settlements and their energy systems have in many areas increased the pressure on local resources. While natural firewood resources diminish with growing speed and the prices for fossil fuels climb rapidly, the regions concerned are now faced with varying degrees of environmental stress. Although wood clearance for new agricultural land (and not for firewood) is in many areas the driving factor for deforestation, soil erosion and desertification, the growing firewood demand can often not be fulfilled with the shrinking wood resources [9]. The ongoing debate on how to improve traditional biomass use and strategically develop bioenergy potential in developing countries [10,11] has been further sharpened in the last decade when the demand for bioenergy and biomass increased globally, as a consequence of public policies of industrialised countries in the context of climate change and energy security [12].

Biomass resources can theoretically be used in many different conversion pathways to cater to all kinds of (rural) energy services, but not all of these pathways are equally favourable in terms of resource, conversion or cost efficiency and green house gas (GHG) emissions. For the present research, a project using the oil of the tropical scrub *Jatropha curcas* L. has been chosen since Jatropha oil provides the above stated flexibility and the Jatropha System has been discussed as a particularly promising example of small scale bioenergy development. The expression Jatropha System has been introduced, among others by Henning [13] based on experiences in the early 1990s in Mali and describes the small-scale cropping, processing of Jatropha for local energy demand and income generation.[1] Globally, the bioenergy debate is focusing on the supply side, analysing cost, accessibility and competing use of agriculture residues, as well as agricultural performance and land use impacts of specific 'energy crops' [5,22,23]. In the case of Jatropha research concentrates predominantly on plant characteristics and cropping systems, or the possible use of Jatropha oil for biodiesel production [24–27]. Little is known about the potential of Jatropha-based rural energy services. This is due to the limited practical experience and research on Jatropha to date as well as due to the complexity and difficulties of comprehensive energy analyses in

[1] Even though Jatropha has already been planted as an oil producing scrub a century ago, systematic research has just started during the last two decades and gained momentum only in 2007. By the end of 2011, WorldCat lists a number of more than 2200 books and journal articles on *J. curcas*, of which only 17% were published before 2007 [14]. Heller [15], Gübitz [16] and Jongschaap [17] provide overviews on plant characteristics, cropping and processing, while GEXSI presented 2008 a very optimistic global outlook on Jatropha projects and activities [18]. The FACT Jatropha Handbook [19] and an IFAD/FAO publication [20] collect many practical information on small-scale Jatropha systems, however do not provide an overview on scientific research. To provide this overview is the aim of a study commissioned by the NL Agency of December 2010 that evaluated 200 studies on agronomic and socio-economic aspects of Jatropha [21].