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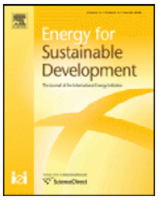

An analysis model for small-scale rural energy service pathways — Applied to *Jatropha*-based energy services in Sumbawa, Indonesia

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ABSTRACT

The potential role of bioenergy in the future energy mix and the performance of bioenergy conversion and use is a controversial issue. Life cycle assessment (LCA) is the key tool to assess the performance and impacts of bioenergy systems and services. As a fairly complex and costly tool, LCAs are rarely applied on small-scale rural settings, which at the same time make up for the largest share of global bioenergy demand. This study proposes an analytical model for rural energy service pathways (RESPs), which supports a simplified and manageable small-scale bioenergy planning by comparing energy and cost efficiencies as well as by pre-assessing possible livelihood impacts of rural energy service pathways for lighting, cooking and mechanical power. The model has been applied on a case study on the Indonesian island Sumbawa that uses the oil bearing scrub *Jatropha curcas* L. to provide rural energy services. Results of the quantitative and qualitative analyses are combined to evaluate different energy service pathways. Results show strong differences for the investigated service pathways. Cooking with plant oil or biogas cannot compete with firewood from the energy and cost analysis while the negative health impact of particulate matter support liquid and gaseous fuels as long as no low-emission wood stoves are available. Lighting with plant oil or biogas is not supported by both the quantitative and qualitative analyses. The provision of mechanical power shows the greatest potential if the technical service pathways can be further optimised and the institutional challenges can be solved.

Introduction

Access to both electrical and efficient non-electrical energy services is often considered an enabling factor for the development of rural areas (ESMAP, 2003; Modi et al., 2006; Practical Action, 2012). Even though, the number of people without access to electricity decreased from 1.6 billion in 2002 to 1.4 billion today, there remain an expected 1.2 billion in 2030 while the number of people relying on the traditional use of biomass for cooking, heating and lighting 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 in 2030 (IEA, 2002, 2010). This contradicts the objective set by the United Nations secretary-general to reach universal energy access by 2030 (AEGCC, 2010). Global bioenergy consumption makes up for 10% of total energy demand, of which the share of 'modern bioenergy and biofuels' is only 22%, while the remaining 78% comprises traditional use in rural areas (IPCC, 2011; WBGU, 2009). These rural areas are typically characterised by a weak infrastructure setup in terms of healthcare, education, sanitation, transportation, etc. Firewood, crop residue, dung, and sometimes kerosene are generally used for cooking, and kerosene and candles for lighting, while liquefied petroleum gas (LPG) and electricity are often 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, 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 (Legros et al., 2009). Renewable energy technologies (RET), increasingly employed in the rural context, include small and micro hydropower turbines, solar home systems (SHS), biogas digester and improved stoves (REN21, 2011). Biomass remains the primary energy source for cooking and heating in rural as well as many urban areas. The ongoing debate on how to improve traditional biomass use and strategically develop bioenergy potential in developing countries (Karekezi et al., 2004; Meyer and Börner, 2002) 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 (Sagar and Kartha, 2007).

Access to efficient energy services can enhance basic infrastructure, education and health, as well as increase productivity and local value creation. However, in reverse it can be stated that energy has no value in itself but that the value rather depends on its integration into rural livelihood frameworks and activities (FAO/FAO, 1999). In

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this context bioenergy has been highlighted as possible win-win solution providing rural energy services by offering at the same time rural employment and value adding. As it has been stressed large-scale industrial agriculture tends to reduce agricultural employment, the focus has been on small-scale bioenergy system, e.g. very prominently the '*Jatropha* System'. The expression *Jatropha* System has been introduced, among others by Henning (2004) based on experiences in the early 90s in Mali and describes the small-scale cropping, processing and use of the tropical oil bearing scrub *Jatropha curcas* L. for local energy demand and income generation. Even though *Jatropha* has already been planted for oil production 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 articles on *Jatropha curcas*, of which only 17% were published before 2007 (WorldCat, 2012). Beside numerous articles, important monographs on *Jatropha* include Münch and Kiefer (1986), Heller (1996), Gübitz et al., (1997), Jongschaap (2007) and NL Agency (2010). The *Jatropha* hype attracted substantial private investments that followed a large-scale approach to produce biofuels for the international market and quickly superseded the small-scale approaches. But the growing evidence of problems with the commercial cultivation of a non-domesticated plant and the failure of most of the large-scale *Jatropha* plantations is shifting the focus back to the smallholder- oriented *Jatropha* System (NL Agency, 2010). As the *Jatropha* system already failed during the 90s to reach economic viability it is important to build on the experiences made and research conducted so far.

Despite the growing body of publications on *Jatropha* as well as on bioenergy in general, results are contradicting and difficult to compare. Life cycle assessments for biofuels in general, mainly focus on the sole production of liquid fuels, possible by-products and the related land-use impact and GHG emissions (Cherubini and Stromman, 2011; Leung et al., 2010; UNEP, 2009). For *Jatropha*, beside ongoing research on botanical properties (Divakara et al., 2010) and a lively debate on the water demand of *Jatropha* (Gerbens-Leenes et al., 2009; Hoekstra et al., 2009; Jongschaap et al., 2009; Maes et al., 2009), most analyses focus on industrial scale of biomass processing and the provision of final energy carriers (biofuels) (Ofori-Boateng et al., 2012; Ou et al., 2009; Prueksakorn et al., 2010; Reinhardt, 2007). The end use of the plant oil, biogas or biodiesel, which is typically the sub-system with the highest losses, is addressed so far only by few articles. Examples are Achten et al. (2010) focussing or transport services and Gmünder et al. (2010) focussing on village-scale electricity supply as well as Grimsby et al. (2012) who specifically investigates the issue of manual processing.

To support decision making on the optimised use of local resources in a rural setting, an analysis needs to compare and describe both the end-use of energy for different types of energy services (e.g. lighting, cooking and mechanical power) and the different service pathways, already established as baseline, newly proposed as e.g. the *Jatropha* system and possible alternatives (e.g. solar or hydro power). The aim of the present research therefore is to propose an analysis model for rural energy service pathways that evaluates the energy and cost efficiency without losing track of other important livelihood impacts. The proposed model has been applied on a *Jatropha* case study in Sumbawa, Indonesia and both results and methodology are discussed.

Methods

First, a two-step analysis model for rural energy service pathways was developed consisting of a quantitative energy and cost analysis and a qualitative livelihood impact pre-assessment. The model was tested on a case study based on extensive *Jatropha* cultivation and use on the Indonesian island of Sumbawa. For this case study, interviews were conducted during a project visit in February 2010, both with experts from government and the private sector, as well as with farmer groups in 10 villages that grow and process *Jatropha* seeds. The aim was to analyse and compare the *Jatropha*-based energy service pathways with existing or realistic alternatives. To that end, first a baseline scenario and a competitive RET scenario were defined as benchmarks. Then, three different *Jatropha* sub-scenarios were developed, focusing on the household, village or region as scale and production unit. All three scenarios and the *Jatropha* sub-scenarios are evaluated and compared regarding their energy and cost efficiencies. As the case study and the energy and costs analysis has been published separately (Gaul, 2012), it is only summarised before the livelihood impact pre-assessment is discussed.

Definition of system boundaries and functional units

For the conceptual definition of rural energy service pathways (RESPs), the built infrastructure system model of Vanek (2008) is combined with a general energy system and energy supply sector model (Nakicenovic, 1996) as shown in Fig. 1. The model distinguishes between an institutional (the energy service delivery) and a technical (the energy service pathway) dimension and separates the latter into four core sub-systems: (1) the extraction/production of a primary energy carrier, (2) the conversion to a secondary energy carrier, (3) the distribution of the final energy and (4) the end-use of the

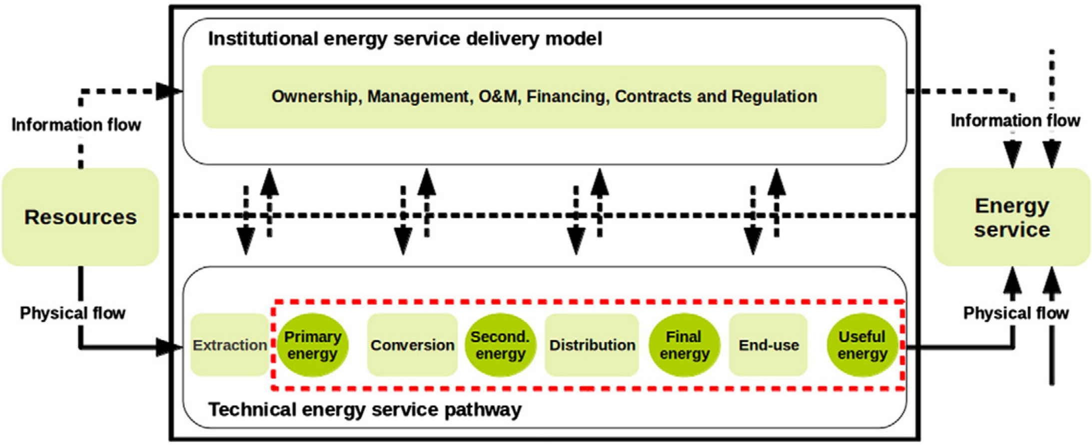

Fig. 1. Definition of a RESP and the applied balance area.