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Potential of distributed wood-based biopower systems serving basic electricity needs in rural Uganda

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ABSTRACT

Current efforts to improve electricity services in Uganda evolve around satisfying growing urban demand as well as stabilizing and boosting a low electricity supply. Although virtually non-existent, rural electrification is receiving very little attention. This paper investigates the potential of wood-based biopower fueled from coppicing shrubs on its feasibility to provide affordable basic electricity services to rural Ugandan households. Gasification was the specific technology we assessed. In the calculations, a worst case scenario was chosen for wood-based biopower to compete with alternative sources of electricity: Cost and land use estimates assumed a rather high household consumption (30 kWh/month), a low household size (8 persons), a low area productivity (3 oven-dried tons per ha per year), a low electrical conversion efficiency (15%) and a high demand competing for fertile land with the biopower system. Cost estimates considered a high biomass price (18.5 US$/odt), a low capacity factor for the biopower system of 0.5 (therefore requiring installation of a larger unit) and high capital costs of 2300 US$ per kW installed. Additional pressure on fertile land would be negligible. Such biopower systems can outcompete other sources of electricity from a micro and macro-economic standpoint when looking at the local scale. Results indicate that biopower can deliver better and more energy services at 47 US$/yr and household or 0.11 US$/kWh which is below current average costs for e.g. off-grid lighting in rural Ugandan households. Additionally, only this biopower option offers the ability to households, sell wood to the biopower system and contribute at least four times as much to the local economy than the other electricity options used as terms of comparison. Further research has to focus on developing business plans and loan schemes for such biopower options including sustainable fuelwood supply chains based on coppicing shrubs which have the ability to contribute to agricultural site improvements. The approach outlined in this paper can further serve as a general framework to compare different options of electricity production across technologies and fuel sources especially for rural development purposes incorporating a multitude of aspects.

Electricity in Uganda — current supply and distribution

In the midst of renewed efforts to increase economic growth, Uganda has begun recently to focus its attention on bolstering its electricity sector. Reliable and high quality sources of energy are an obvious precondition for further industrial development, and constitute a significant increase in quality of life for individual citizens as well (Hall et al., 2001; Odum, 1971). Ugandan society will be shaped in part by the manner in which it chooses to pursue new domestic energy sources, especially in rural areas.

At the moment, Uganda's electricity needs are in the process of overwhelming its meager supply; the country is experiencing increasingly rationing of electricity to certain times of the day (load shedding), unmet demand, high electricity prices, uneven distribution, and inefficient production and transport of electricity. The progressive expansion of energy production within Uganda will have to face many logistic challenges. To date, Uganda's electricity supply is unevenly distributed. Only 5% of all Ugandan households have access to electricity. This is one of the lowest rates in Africa (Eberhardt et al., 2005). At the same time, about 84% of Ugandan households are located in rural areas. However, less than 3% of the rural population has access to electricity (Ministry of Water, Lands and Environment, Uganda, 2001). To put Ugandan energy consumption into perspective, it helps to quantify the importance of the non-monetary, traditional, non-electricity energy supply to Ugandans: 90% of the total energy needs of Ugandans are supplied by fuelwood, and only 1% comes from electricity (Bingh, 2004).

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This work will briefly discuss the current situation of the Ugandan electricity sector, and future supply scenarios. It will further assess electricity demand in rural Uganda and analyse how small-scale wood-based biopower systems such as gasification could contribute to developing the Ugandan electricity sector especially to people in rural areas who are currently unable to access modern types of energy. It also compares how such systems fare financially with other options for rural electrification. An economic analysis for electricity from biomass is difficult as the economic impacts of feedstock production have to be included in the comparison of, e.g., electricity from solar or wind. The analytical framework considers micro and macro-economic aspects of different electricity options and could serve as an example of how to meaningfully compare different electricity options for rural electrification while especially doing justice to the more complex economic calculations for biopower options and implications on competing use for productive land.

Measures to address Uganda's current electricity crisis

Currently, Uganda's electricity supply is already dominated by domestic renewable sources, namely hydropower; however, these sources are no longer able to meet demand. Since 2005, low water levels in Lake Victoria have forced the hydropower stations to operate far below capacity. Load shedding occurs every other day even in the capital Kampala. Ugandan industries depending on electricity for production have always had to maintain backup diesel generators to protect themselves against power cuts, but are now increasingly dependent on this source of energy on a more regular basis. It is estimated that 34% of total private sector investment into the Power Sector is used for these diesel backup systems (Eberhardt et al., 2005). Additional hydropower facilities are scheduled to be constructed along the Nile but it is unclear to what extent they can satisfy the increasing urban demand as they take up to 5 years to be commissioned and the demand is growing steadily. The Electricity Regulation Authority (ERA) calculates that even when the two projected hydropower stations' (Bujagali and Karuma) combined capacity of 450 MW is fully available, this supply will barely meet a demand that is growing at 27 MW annually (The East African, 2006). It must also be noted that most of these measures target the nation's capital, in which most people already have access to electricity, and bypass rural areas.

Potential of domestic electricity supply in Uganda

On a large, agro-industrial scale, biomass residues (particularly bagasse and coffee husks, but also rice husks and sawdust) are massively underutilized for heat and electricity production in Uganda; in 2006, only an estimated 8 MW of electricity was produced from 425,000 t of bagasse (Bingh, 2004) and almost none from 280,000 t of coffee husks (Da Silva et al., 2003). Combined, there is a potential of 2600 MW of electricity from untapped agricultural residues (Bingh, 2004) with the biggest share accumulating at three specific processing sites. To utilize the resources from the three sites would double electricity generation in Uganda (Buchholz, 2006). Using all corn residues (2.4 million tons per year) could contribute another 90 MW (Da Silva et al., 2003).

Bingh (2004) estimates an additional potential electricity generation of 29 MW from municipal solid waste combustion in Kampala city alone, at a collection rate of 100%, or 11 MW for a more realistic collection rate, based on 2004 statistics. The total hydropower potential for large-scale applications is estimated at 2635 MW, and small-scale plants could additionally produce up to 123 MW (Wamaniala, 2002). Uganda's geothermal power potential, derived from the tectonically active Rift Valley in which it is situated, is estimated at 450 MW from three sites already surveyed. This resource continues to be explored and the figure is likely to increase (Kamese, 2004).

Rural electricity needs — neglected and ill-served with conventional electricity production?

Rural versus urban electricity supply and political framework

The current power crisis in Uganda is likely to remain for sometime given the steady growth of demand and all the problems related to financing power supply. Even when the power supply would be available, the cost of extending the grid to rural areas is a problem in itself due to the low and spatially scattered load consumption. It is against this background that the current electricity crisis that has attracted so much attention in Uganda does currently concern only 5% of the Ugandan population with access to electricity – mainly urban residents – and focuses on only 1% of Uganda's overall energy consumption. The prevailing focus is on keeping their consumption secured and less on expanding electricity services to people not served yet. The means chosen to serve the current electricity consumers like boosting diesel generators or hydropower and expensive grid connections seem to be unsuited for rural electrification as the slow advancements show.

Uganda aims to boost rural electrification to 10% by 2012 as announced in 2003 (Uganda Investment Authority, 2003) and restated in the current Rural Electrification Agency (REA) Strategic Plan which aims to “ facilitate an average connection rate of at least 1 percentage per year until 2012” (Rural Electrification Agency, 2010) which equals 40,000–50,000 households year. Together with the announcement of this policy, a rural electrification fund was established in collaboration with the World Bank. A special lifeline tariff assures favorable rates to those households connected to the grid which consume 30 kWh per month or less. Seven years into the program, the Ugandan rural electrification rate still lingers even below 3%. At the same time, experiences in West Africa have proven the feasibility of much more ambitious goals than a 10% rural electrification rate (Karekezi et al., 2004). Nevertheless, in the case of Uganda, even this low target is unlikely to be met considering current efforts and progress. Therefore, there is an urgent need to look into innovative schemes for rural electrification.

What other electricity options does Uganda have for targeting rural populations? Unlike industries, large-scale consumers and urban populations whose energy needs are met by large systems as described above, rural consumers with low electricity consumption and dispersed demand require more flexible energy solutions. Unfortunately for rural development, political support for distributed, micro or small-scale technology and most renewable energy sources is lacking in Uganda. For instance, despite experience with distributed electricity – there are two isolated grid networks, and many diesel generators operate on a private basis – large-scale power plants and grid extension are still favored as can be seen in the scale of current hydropower expansion plans and the strategy of the REA Strategic plan (Rural Electrification Agency, 2010) where isolated grids and stand-alone systems are planned to contribute to less than half of additional future rural electricity connections. Moreover, the stand-alone systems are planned to be photovoltaics only, other sources of electricity such as biomass are not considered in the plan. Favorable feed-in tariffs exist only for bagasse-fueled electricity generation (Electricity Regulatory Authority Uganda, 2010), and easy access to financial support (e.g. low-interest loan schemes) for initial investment in small-scale electricity production equipment is absent. For instance, a tax waiver program for distributed electricity production announced in 2006 and responding to the growing inadequacy of grid supply across the nation focused on engines that were a) fueled by diesel and b) above 100 kW only (New Vision, 2006).[1] Such emergency measures focusing on fossil-fuel powered electricity further

[1] This program was terminated in the fiscal year 2008/2009 (The Monitor, 2008).

fail to address long-term considerations such as rising fossil fuel prices or negative trade balances through the purchase of foreign fossil fuels, not to mention greenhouse gas (GHG) emissions and the corresponding adverse climate changes.

Our understanding of the lacking political support for decentralized and multiple source electricity supply is that it is much easier from a political perspective to do grid extension and set up a subsidy system to connect people than getting a stand-alone or isolated project running sustainably.

Options for rural electrification and rural electricity needs

A consistent electricity supply is a prerequisite for real poverty reduction in rural areas. The United Nations, in its Millennium Development Goals, have set its target to halve extreme poverty by 2015. There are many studies stating that this goal is virtually impossible to meet without basic electricity supply (Modi et al., 2006; Department for International Development, 2002). But how much electricity is needed to fulfill these goals in rural areas? Ranges for basic rural household consumptions are from 15 kWh per year (Modi et al., 2006) to 30 kWh per month (White, 2002) covering needs such as lighting, communication, and entertainment devices. Further calculations in this paper are conservative (i.e. postulating high resource consumption) by assuming 30 kWh per household and month. White (2002) further estimated 20,000 kWh electricity for other commercial and public needs of a rural community of 2000 in habitants or 250 households (15,000 kWh/yr for business such as entertainment, communication, metal workshops, or food conservation, and 5000 kWh/yr for a school and health center). Table 1 shows basic assumptions on the example community considered in this project. The public and commercial electricity consumption chosen is representative for a trading center serving 2000 surrounding dwellers in rural Uganda.

Small-scale, wood-based biopower supporting Uganda's rural electrification goals

The development of small-scale, distributed biopower not derived from agro-industrial residues is still in its infancy in Uganda. However, feasibility studies (Buchholz, 2006; Tennigkeit et al., 2006), and first initiatives from industry in the 200 kW range (Buchholz et al., 2007a,b; Buchholz and Volk, 2007a) do support further expansion. Latest Indian small-scale, wood-gasification technology (Ravindranath et al., 2004) adapted to rural East-African conditions can produce electricity at a conservative conversion rate of 13%, consuming 1.5 kg of oven-dried wood (odt; oven-dried ton, containing 0% moisture) per kWh produced. This gasifier technology has proven to be robust and reliable under conditions of other tropical developing countries (Nouni et al., 2007; Banerjee, 2006; Ghosh et al., 2006, 2004) and the first systems are now installed in Uganda (Buchholz et al., 2007a,b). To make the schemes comparable and to keep transmission costs low, we assumed no standard grid construction from the power plant (or local transformer in the hydro option) to the households but assumed that households can initially be served with car batteries charged at the biopower plant or be connected by inexpensive Single Wire Earth Return grids (SWER, GSFA, 2004) depending on distance and distribution of housing clusters.

Uganda has one of the highest bioenergy potentials in the world (Hoogwijk et al., 2005). Uganda's many hectares of marginal agricultural land, unsuitable for food production, could easily be adapted to grow woody crops for bioenergy feedstock. Species like Eucalyptus spp. or the native *Acacia mearnsii*, *Sesbania sesban*, and *Markhamia lutea*, which regrow after being cut at ground level (called “coppicing”), are among those woody shrubs that would be most suitable for biomass production (Buchholz and Volk, 2007b). Combined with modern biopower conversion technology, woodlots, hedgerows and energy forests managed for fuelwood production embedded in current land use patterns, can provide distributed power sources well-suited to meet rural electrification goals. With appropriate species choice and management regimes, these systems can even contribute to site improvement of degraded soils through enhanced nutrient cycling and erosion control (Volk et al., 2004; Reijnders, 2006). The development of wood-based biopower can provide local income generation opportunities, reduce energy imports, improve the national trade balance, and decrease negative environmental impacts associated with fossil fuel based systems.

Biophysical background for generating small-scale rural biopower

Table 2 shows the data related to land and biomass use. To feed a person, 0.5 ha would be required (Lal, 1989). Pimentel et al. (2002 in Reijnders 2006) estimates an overall sustainable biomass production as low as 3 odt per ha and year for temperate and tropical regions. This is a conservative number as many sources suggest fuelwood productivity in the tropics in a range from 3 to over 25 odt/ha/yr.

Fig. 1 shows the land use pattern when assuming this very conservative biomass production potential of 3 odt/ha/year only for both wood and a vegetarian food production as introduced in Table 2. Considering a purely vegetarian diet of 0.3 odt/person/year, only 0.1 ha would be under food production each year leaving another 0.4 ha or 53% under fallow for site regeneration, surplus production, cattle grazing, etc. According to these calculations, sufficient biopower production to cover basic electricity services would require only 0.03 ha/person or 4%

Table 1
Community input data.

Category	Unit	Number
Average community size (Modi et al., 2006)	Persons	2000
Average household size[a]	Persons/household	8
Average number of households	Households/community	250
Electricity need per household (Uganda Investment Authority, 2003)	kWh/month	30
Public electricity needs (school, health center)[b]	kWh/year	5000
Commercial electricity needs (grain mill, cell phone charging, barber shops, metal workshop, food conservation, etc.) [b]	kWh/year	15,000
Total community electricity need	kWh/year	110,000

[a]) Conservative estimate. Modi et al. (2006) assumes 10–20 persons per household for rural electricity relevant consensus data on sub-Saharan Africa.
[b]) See White (2002) and Modi et al. (2006) for public and commercial electricity needs.

Table 2
Biophysical input data for biomass production serving various human needs in rural Uganda.

Category	Unit	Number	Source and comments
Agricultural land to feed a person adequately	ha/person	0.5	Lal, 1989
Sustainable biomass production	odt[a]/ha/yr	3	Pimentel et al., 2002 in Reijnders, 2006
Food consumption	odt/person/yr	0.3	Haberl, 2002
Fuelwood consumption for cooking and heating	odt/person/yr	0.5	Modi et al., 2006
Wood consumption for construction (timber and poles)	odt/person/yr	0.5	Estimates range up to 0.2 odt (Haberl, 2002; Boudreau et al., 2005)
Fuelwood consumption for household electricity	odt/person/yr	0.068	Considering assumptions on community electricity needs as outlined in Table 1 and a wood consumption of 1.5 kg/kWh
Fuelwood consumption for school, health center, and businesses in trading center	odt/person/yr	0.015	

[a]) odt: oven-dried tons containing 0% moisture.

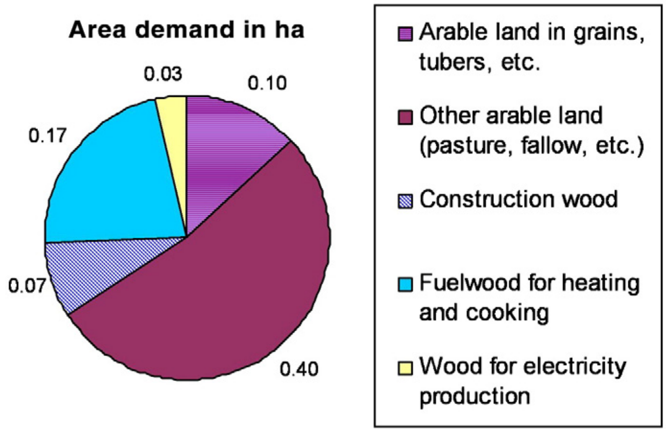

Fig. 1. Land use requirements when assuming biomass consumptions as indicated in Table 2 (0.76 ha per person).

of the available productive land. When planted in 1.5 m wide hedgerows of coppicing shrubs, this would equal around 180 m of hedgerows per person. In this scenario, 35% of available productive land (Fig. 1: including the items 'construction wood', 'fuelwood for heating and cooking', 'wood for electricity production') would be under extensive wood production for construction and energy provision.

The total land required for energy production (fuelwood and wood for biopower) is 0.1 ha/person or 26% of all productive land, which is close to historical estimates of 25% of farmland serving energy needs (draft animals) in pre-industrial Germany (Saan-Klein et al., 2004). Our estimations equal an area requirement of 0.24 ha per household for fuelwood production to generate biopower. This estimate is on the conservative side, i.e. assuming a high land demand for the gasifier system; for instance, Abe et al. (2007) estimate only 0.02 ha per household for a similar wood-based gasifier setup in rural Cambodia, however, these authors assumed only a third of the electricity consumption (10 kWh/household/month) we used. Abe et al. also calculated with a more than threefold biomass site productivity (10 odt/ha/yr) as done in this paper, therefore reducing land requirements significantly.

Cost estimates for different supply options satisfying basic rural electricity needs

Table 3 gives the input and output data of the cost calculations for four electrification alternatives conceivable for rural Uganda. The electricity alternatives chosen to which the biopower option would be compared included distributed fossil-fuel powered generators, large-scale hydropower with its associated grid extension, and solar home systems (SHS). These alternatives were chosen based on the specific situation in central Uganda. For instance, biodigesters, relying on large herds of cattle and zero-grazing methods (Walekhwa et al., 2009), were unsuitable here, while wind speed is generally below 3 m/s in Uganda, which is too low to produce electricity (African Wind Energy Association, 2009). Capacity factors play an important role, for instance, we assume that more kW of solar panels have to be installed to produce the same output as a fossil-fuel generator that can run more hours per day. Systems also differ in life expectancy, replacement costs were considered. The least expensive options in terms of money spent per kWh consumer are distributed wood-based gasifiers (0.11 US$/kWh) and hydropower (0.05 US$/kWh), followed by solar (0.19 US$/kWh). The most expensive option is fossil-fuel generated electricity (0.39 US$/kWh). In terms of money spent per household, biopower is the second least expensive option after hydro, costing 47 US$ per year and household. To put these expenses into perspective, Buchholz and Volk (2007c) and Da Silva (2008) estimate that average rural households or businesses spend 40 to 60 US$ per year on candles, kerosene and dry-cells for lighting. Therefore, the cost for biopower is deemed competitive, given that an average household

Table 3
Cost calculation and allocation of revenues for four electricity alternatives aiming at an output of 110,000 kWh/yr (see Table 1).

Category	Unit	Distributed, small-scale wood-based gasifier	Distributed, small-scale fossil fuel generator	Large-scale, grid-connected hydropower	Individual solar panels
Capacity factor		0.5	0.8	0.3[a]	0.3[b]
Installed capacity	kW	25.1	15.7	41.9	42
Capital costs	US$/kW installed	2300[c]	500	3200[d]	9000[e]
Project lifetime	Years	10	5	30	20
Grid connection costs	US$	–	–	26,000[f]	–
House connection	US$/house	60[g]	60[g]	60[g]	60[g]
Maintenance, labor	US$/year	3000[h]	1000[h]	–[i]	1000[h]
Maintenance, material	US$/year	500	300	–[h]	100
Fuel	US$/year	3053[j]	35,200[k]	–	–
Electricity production costs	US$/kWh	0.11	0.39	0.05	0.19
Costs per household	US$/year	47	169	23	86
Potential average earnings per household	US$	12.2[l]	–	–	–
Project turnover	US$/yr	8776	39,570	5831	21,436
Average annual turnover circulating within community[m]	US$/yr	4053	1000	–	1000

[a]) Assuming a capacity factor of 0.55 (0.3–0.8, Center for Energy Efficiency and Renewable Energy, 2010) and transmission losses of 25% for large-scale grids (Eberhardt et al., 2005).
[b]) This low capacity factor reflects the fact that PV can produce only around 4 to 5 h of equivalent full output power per day depending on sunshine conditions.
[c]) Source Buchholz et al., 2007a,b.
[d]) US$ 1500–4000 independent of location, took average US$ 3250 (IEA, 2005).
[e]) PV cell and installation costs reflect costs for small-scale rural household applications taken from for a Sri Lankan survey (Wijayatunga and Attalage, 2005); costs varied between 6700 and 11,900 US$/kW installed.
[f]) Modi et al. (2006) calculates an average distance of 2.1 km between villages in rural Kenya and 10,000 US$ per km land line construction costs and US$ 5000 US$ for a transformer.
[g]) Assuming a car battery for every household or inexpensive single wire earth return (SWER) connection. Replacement after 10 yrs.
[h]) One full-time working individual maintaining electricity systems.
[i]) Included in capital costs.
[j]) US$ 18.5 per odt fuelwood (Buchholz et al., 2007a,b).
[k]) Assuming a consumption of 0.3 l diesel per kWh at a constant cost of US$ 0.9 per liter diesel as recorded in Uganda in 2007.
[l]) Total annual fuelwood requirement divided by total households: 0.66 odt fuelwood delivered by every household at US$ 18.5 per odt.
[m]) Measures financial flows within the community associated with the electricity production. Turnovers considered are local labor costs as well as fuelwood costs for the gasifier option.

also receives considerably improved light services, health care and schooling.[2]

Results presented in Table 3 also show the difference in total financial turnovers associated with each electricity option. While maximizing total turnover might be interesting for companies manufacturing materials (e.g. solar panels) or governments interested in an increase of the gross domestic product, large turnovers as associated with e.g. the solar option and especially the fossil fuel option do not benefit the rural local economy. Taking into consideration the total amount of money circulating within the community, biopower is by far the most favorable of all options, leaving the highest share of turnover and total cash flow within the community of all options considered if the fuelwood is sourced within the community. Assuming that this fuelwood is grown by and purchased from within the community through individual household woodlots or more commercial schemes, additional income of up to 3035 US$[3] per year can be generated within the community by selling wood to the power plant. This fuelwood trade results in a local financial turnover that is four times as high as for the fossil-fuel generated electricity option and the solar power option (4530 US$/yr for the biopower option including revenues from the sale of fuelwood and wages through system maintenance vs. 1000 US$/yr for the fossil fuel and solar option including wages for system maintenance only) while a large-scale hydropower option would not offer any benefit to the local economy besides delivering electricity. Of all electricity options considered in Table 3, the biopower option provides the largest economic value added to the community through the local sourcing of fuelwood. When factoring in increasing interest rates and diesel costs – as it is very likely to happen in future – capital-intensive alternatives like hydropower and solar, as well as fossil-fuel dependent systems like diesel generators are expected to perform more poorly than calculated here. It also has to be noted that long-term options such as hydro and solar panels can unfold their economic advantages only when they operate during the whole lifespan without interruptions or premature determination. Moreover, it is unclear to what extent large-scale hydro power will be used for rural electrification considering that the top priority for future electricity supply lies in the high and unsatisfied urban demand in Uganda. Local solutions like biopower seem to be more suitable for rural areas.

Conclusions

To assess the financial viability of small-scale biopower in rural areas, we used conservative estimates — a low biomass productivity (3 odt/ha/yr) and rather high household consumption (30 kWh/month). The actual fuelwood demand created by biopower is marginal — 83 kg of dry wood per person and year; however, this rather minuscule biomass demand compared to other forms of current biomass consumption would make a great difference in living standard. Subsequently, biopower based on wood serving basic needs would not increase pressure on productive land significantly. However, Uganda has only an estimated 0.4 ha arable and pasture land per capita and Uganda is net food importer (FAO, 2004). Hence, when setting up a biopower system, fuelwood production therefore needs to be restricted to marginal sites or combined with agriculture (agroforestry) using appropriate shrub species to restore soil fertility and avoid competition for land with food production. From a strictly farming perspective, easing competition for productive land in Uganda also depends on the take up rates of improved agricultural practices and dynamics in subsistence farming in Uganda and agricultural zoning practices especially in the light of climate change which could lower especially traditional crop harvests drastically (Wasige, 2009).

Other transformations than land use change caused by an increase in (bio)power is less likely to occur. As electricity is restricted to particular end uses, i.e. lighting, powering entertainment, refrigeration or communication, introduction of basic electricity supply for Ugandan rural households is unlikely to alter other forms of energy consumption for e.g. heat and cooking. Therefore, an indirect impact reducing or increasing consumption of other resources is considered unlikely (Madubansi and Shackleton, 2006).

Besides the differences in capital costs (US$/kW installed) and electricity production cost (US$/kWh) the methodology used in this study highlights the importance of the macro-economic factors when assessing rural electricity options. For instance, the example and methodology of analysis presented in this paper shows that biopower, while ranging amongst the cheapest options measured in electricity production costs, can contribute four times more in this example to a local economy over the project's total lifetime. At the same time, it has to be kept in mind that high capital costs are a major hurdle in capital constrained rural Uganda. Innovative loan and business models are urgently needed to serve this market and allow realization of long-term rural economic development. The next step to support such business models is to develop and improve financial analysis models including above mentioned macro-economic benefits as well as interest and depreciation rates to communicate benefits of rural electricity options transparently to both politicians and investors alike.

Bioenergy based on small-scale, distributed technology might be able to serve the basic electricity needs of rural Uganda in a cost-effective, affordable, ecologically sustainable, and socially beneficial way.[4] Besides the fact that its costs compare favorably with those of other energy sources, it does not compete with food production, and it has the potential to have beneficial impacts on site conditions when fuelwood supply is managed responsibly and reduce carbon emissions from two ends by a) reversing carbon emissions from land use changes while b) also offsetting carbon emissions from fossil fuel use occurring in the present (such as lighting with kerosene) and in future (such as providing an alternative to fossil-fueled generators producing electricity), both factors that contribute to an equal share to Africa's total carbon emissions (Canadell et al., 2009). Compared to the other energy options examined in this paper, distributed, small-scale bioenergy creates the most economic opportunities within the community.

This study investigated the environmental and economic potential of wood-based biopower systems serving rural electricity needs in Uganda. Though promising, results are of a theoretical nature resulting in a – however cautious and conservative – technical potential of such systems which still needs to be tested. To realize wood-based biopower serving rural electricity needs in Uganda, there is a need to develop business plans on how to run, maintain, and finance such schemes. Also, the implications of small vs. large-scale options of power generation need to be better communicated to decision makers such as politicians and investors. Analytical frameworks to compare large and small-scale options need to be developed that especially address where macro-economic benefits occur — on the local or national or global scale.[5] Such assessments rely on a clear setting of assessment boundaries such as including transmission losses when calculating overall efficiency of centralized systems when comparing them to onsite power generation. Results indicate economic viability and sufficient purchase power for electricity. To assure sustainable wood supply benefiting agricultural production rather than competing with it, schemes have to be developed on how to ensure steady, secure, and environmentally sustainable fuelwood supply with coppicing

[2] For an in depth discussion on the impact of improved lighting see also Mahapatra et al. (2009) on the example of India.

[3] At a price of 18.5 $/odt for fuelwood (Buchholz et al., 2007a,b).

[4] While social aspects such as electricity allocation between different social groups is beyond the scope of this paper, we acknowledge the importance of this aspect, especially the tendency that the better off benefit the most from increase electricity services (see e.g. Kooijman-van Dijk, 2010; Buchholz et al., 2007a,b).

[5] See e.g. Buchholz and Volk (in press) for a discussion on including scale in energy assessments with Ugandan case studies.

shrub species. These biopower systems – independent of the technology used – are also a promising option to tap into global carbon finance markets to benefit small communities. To realize this promise of small-scale, distributed biopower for rural electrification in Uganda and comparable regions, further studies need to identify a pathway for the private sector to engage in this venture as a profitable business.

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