RURAL ELECTRIFICATION IN UGANDA

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Abstract—Access to reliable electricity is at least a co-requisite to sufficient human development. In many developing countries, the percentages of the rural population that have electricity access are often below 5%. Specifically in Uganda, only about 2% of the rural population is currently served by the electric grid. To create effective policy and implementation programs, this paper examines the current challenges and implications of the current energy sector of Uganda. Ostrom's Social-Ecological Systems framework is employed to organize the driving forces, interactions, and key players of the current system, including recent rural electrification programs that have resulted in some success. However, the implications of the current system include multiple barriers to widespread rural electrification, including high costs and little revenue. The push for solar photovoltaic systems in Uganda also has many shortcomings to improving development within the country. I end by discussing an alternative approach to rural electrification called the *Empower Ugandans to Power Uganda Project* that offers a locally driven effort to electrification and development.

Keywords— rural electrification, human development, energy technologies

I. INTRODUCTION

The energy problems of the developing world are both severe and widespread. Lack of access to sufficient and sustainable supplies of energy affects as much as 90% of the population of many developing countries (Barnes and Floor, 1996). Without efficient, clean energy, people are undermined in their efforts to engage effectively in productive activities or to improve their quality of life. The lack of electricity is also a hindrance to the provision of health services, community development, education, and industrial activity (Hankins, 1993). Alazraque-Cherni (2008) eloquently states that, “Energy is seen as an irreplaceable ingredient for societies’ economic and industrial progress. Energy powers economic growth and access to it is vital if poverty is to be alleviated. But it is very unequally accessed and consumed.” In other words, increasing energy access is at least a co-requisite to improving the living standards of billions of people, particularly in developing countries, who lack access to energy services or whose consumption levels are considerably less than those of individuals in industrialized countries (Anderson, 2000). Figure 1 provides an empirical comparison of human development, in terms of the Human Development Index (HDI), and per capita electricity consumption by country. It confirms that nations which obtain high levels of human development also consume relatively high levels of electricity. In the figure, the countries within the red region will likely not see improved HDI values from additional electricity consumption, since increased consumption in those countries will likely only add convenience and luxury, rather than improve development (i.e., the figure shows the saturation effect of consumption discussed by Martinez & Ebenhack, 2007). In the green region, many research and implementation programs are being completed since these nations are most likely to meet the United Nation’s (UN) Millennium Development Goals (MDGs) related to electricity access. However, countries within the yellow region are associated with extreme unavailable and unreliable electricity (Mechtenberg, 2011), many of which are located in sub-Saharan Africa. These countries could potentially see significant improvements in human development from small increases in energy consumption.

The energy needs within sub-Saharan Africa are dire, especially in the rural areas, where about 68% of residents reside (World Bank, 2000). According to Karekezi and Kithyoma (2002), sub-Saharan Africa is the least electrified region of the world, with rural electrification levels that are often below 5%. The main energy demand in rural areas of low income countries is for cooking and the main source of fuel for satisfying this demand comes from fuel-wood, dung, and other forms of biomass, which are inefficient and polluting (World Bank, 2000). This type of fuel is also expensive and requires intensive labor for collection (World Health Organization, 2000). The use of clean renewable energy technologies could play a critical role in national development in terms of job creation, income generation, and protecting the local environment (Karekezi and Kithyoma, 2002), while concurrently allowing the 'leap-frogging' of fossil fuel-based energy sources, along the energy-development path (Alazraque-Cherni, 2008).

Here I specifically focus on the energy sector of Uganda, a developing country in Africa with a large rural population. My interest in the country stems from a recent visit there, where I experienced first-hand the unreliability, and in some cases the inaccessibility, of the country's electric grid. The overarching motivation of the study is grounded in increasing human development in countries like Uganda by first understanding the current challenges and processes that are occurring there. To this end, in Section II, Elinor Ostrom's (2009) Social-Ecological System (SES) Framework is employed to analyze the key players, interactions and outcomes of the system. I include details of Uganda's recently implemented Energy for Rural Transformation (ERT) Program, which seeks to expand the current grid, as well as details of the PV Pilot Project for Rural Electrification (PPPRE). In Section III I discuss the challenges as well as the implications of the current system and energy programs. Next, I describe an alternative approach to energy access in Section IV, known as the *Empower Ugandans to Power Ugandans*

Project, which is based on technological capability transfer of locally built electricity generating devices through education and empowerment. I end by examining the impacts of the rural electrification programs on human development in Uganda.

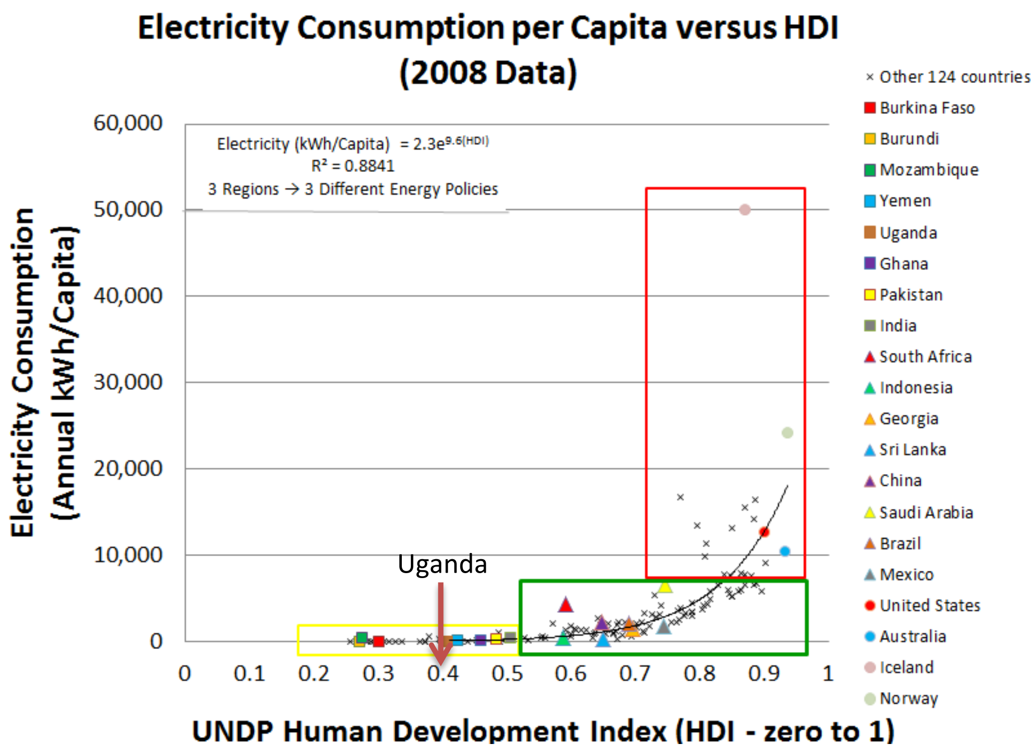

Figure 1. Empirical comparison of human development and per capita electricity consumption per capita by country
Source: Mechtenberg, 2011

II. UGANDA'S ENERGY SECTOR

Overview

Influences at the larger-scale help drive domestic policies and programs in Uganda. In Figure 2, I outline Uganda's energy sector according to the SES framework (Ostrom, 2009), showing the large scale social, political, and economic settings as well as the major players, interactions, and outcomes of the domestic system, which is discussed next. This figure serves as a platform for organizing the complex factors that drive policy outcomes within the current system.

The UN MDGs play a prominent role in Uganda's policy-making and influence the objectives of their domestic energy policy. Although, electrification is not a primary goal of the UN, researchers say that reliable energy access is critical for poverty alleviation (Anderson, 2000; Alazraque-Cherni, 2008; Hankins, 1993) which *is* a major objective of the MDGs. According to UN Development Program (UNDP, 2011), Uganda is likely to achieve several MDGs which include extreme poverty alleviation, and environmental sustainability in part due to small successes within their electrification programs. Also, as a member of the UN Framework Convention on Climate Change, Uganda is committed to implementing and reporting climate change adaptation measures (Kaijuka, 2007). These commitments place pressure on Uganda to incorporate climate change mitigation and adaptation measures into its energy sector development (e.g., control development of dams and hydroelectric plants along the Nile and manage forest areas to reduce deforestation and biodiversity loss). Although Uganda, like many other developing countries in Africa, contributes very little to the world's greenhouse gas (GHG) emissions, for them issues such as poverty alleviation, food security, and other development objectives rely on successful climate change adaption (Apuuli et al., 2000). Additionally, the promotion of renewable energy technology is a focus of the country's rural electrification strategy, giving Uganda the opportunity to benefit from internationally sponsored projects via organizations like the Global Environmental Facility (GEF) (Kaijuka, 2007).

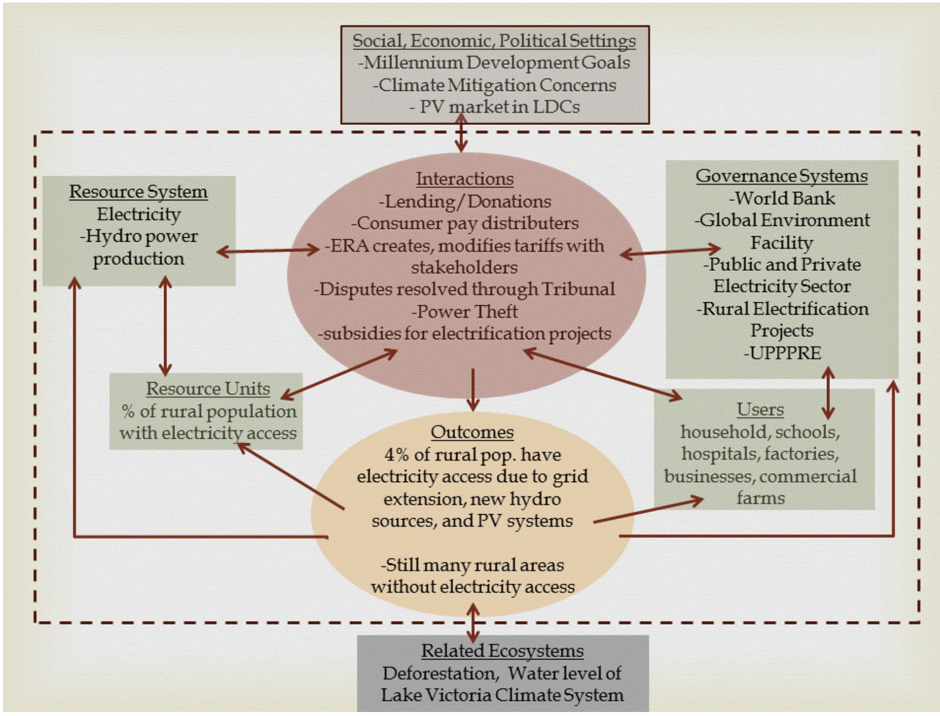

Figure 2. Social Ecological System Framework view of Uganda's Energy Sector. The larger scale social, economic, and political settings as well as related ecosystems play a role in influencing policies and programs in Uganda.

The primary source of energy in Uganda is hydroelectric power from major plants located on the shores of Lake Victoria, which borders Uganda to the South (Figure 3). There is a current market failure in which electricity is not supplied at a level that meets demand. According to the World Bank, the generation capacity of the current system in Uganda is 340MW, while peak grid demand is 380 MW. Additionally, as of 2007 the electric grid only serves about 2% of the rural population, and 5% at the national level (Figure 3) (Kaijuka, 2007). The major hydroelectric plants generate 99.3% of the electricity produced in Uganda. The remaining power is generated by smaller scale diesel plants, heavy oil plants, thermal generation facilities, solar PV stations, and other small hydroelectric projects (Ezor, 2009). Petroleum-based products provide only a small percentage of Uganda's energy needs. Petroleum is imported, and availability is affected by foreign currency constraints. High prices have caused many industries to switch from petroleum to other products such as wood and electricity (Ezor, 2009). Uganda's dependence on hydroelectric sources makes the country susceptible to natural and anthropogenic hydrological fluctuations. Recent periods of drought and upstream diversions of water (mostly for agricultural purposes) have caused a drop in the water level of Lake Victoria. As a result, power plants have been operating at less than half capacity since 2005. To deal with the low level of power generation, utility companies resort to load shedding, a process used to account for energy shortages by selectively cutting off power to certain customers (Ezor, 2009; Kaijuka, 2009). Although there are possibilities for extending the grid (Figure 3), the high cost of establishing electricity connections is a major constraint in a country with a widely dispersed population (Ezor, 2009). The government of Uganda has realized that demand is greatly outpacing supply, and has commissioned a variety of new power station, grid extensions and renewable energy projects in the near future (Ezor,2009; Kaijuka, 2007).

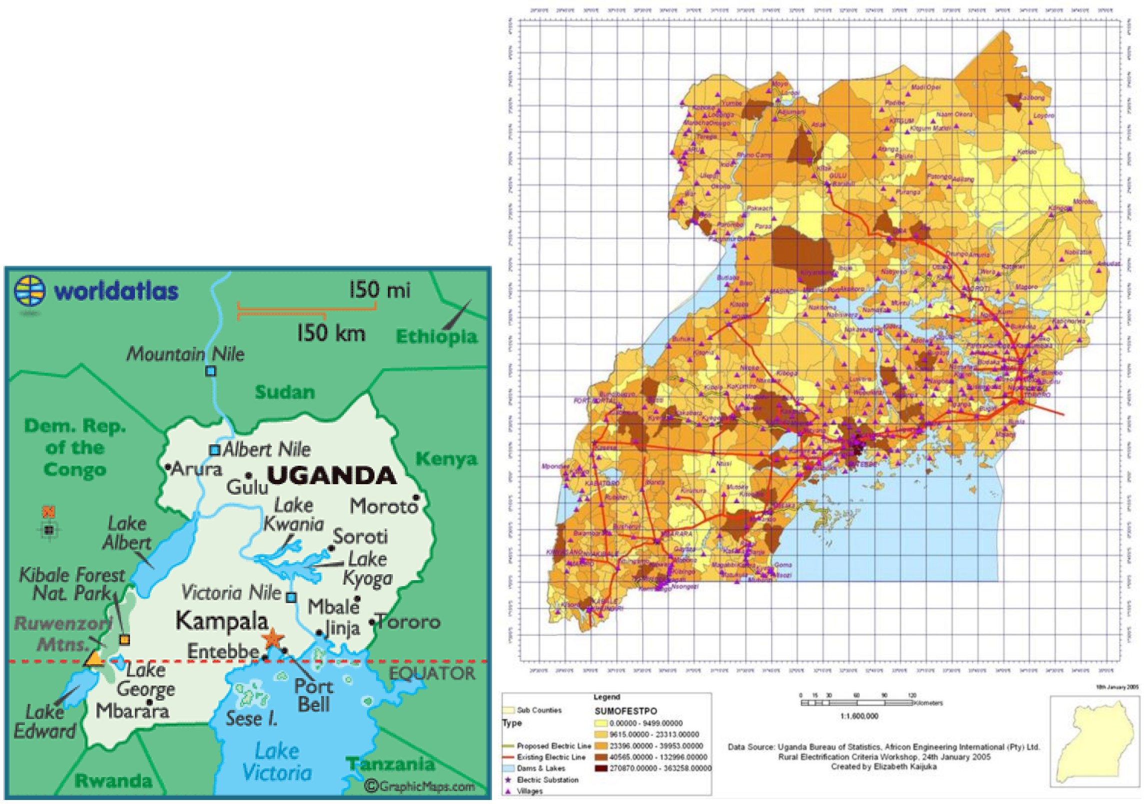

Figure 3. (Left) Uganda is located on the North shores of Lake Victoria and is home to it major tributary, the Nile River. These hydrological resources allow the country to produce most of its power through hydroelectric power plants.
(Right) Population distribution along the current and planned electric grid in Uganda. Source: Kaijuka (2007)

Institutional Players, Policies and Interactions

Before the 1999 Electricity Act was passed, Uganda's electricity was a state-owned, vertically integrated system that was subject to unaccountability and inefficacy. Since 1999 Uganda's power sector has evolved into a less-centralized system that involves both the government and private companies (Figure 4). This transformation was made in the hopes that the system would become more capable of meeting the needs of the people. Currently, three main private companies (Eskom Uganda, Kilembe, and Kasese Cobalt) handle 99.3% of power generation in the country. Transmission of power is controlled by Uganda Electricity Co. Ltd. (above 33 kV) and Uganda Electricity Distribution Co. Ltd. (below 33 kV). Distribution rights are held by Umeme, a company owned by Actis whose headquarters are in the United Kingdom. Actis provides funding for infrastructure and advisory services to Umeme in Uganda (Umeme, 2011). The average customer, however only interact directly with the distributers, when they pay their electric bills or issue complaints (Ezor, 2009; ESMAP, 1999).

The Electricity Act also established the Electricity Regulatory Authority (ERA), an autonomous regulatory body that provides licenses and creates tariffs. The ERA is required to have public consultations and include stakeholders in any modification processes, but this does not always occur. The power sector also utilizes an Electricity Disputes Tribunal that hears disputes involving consumers, power companies and/or regulatory agencies (Ezor, 2009).

Lastly, the Electricity Act created the Rural Electrification Board (REB) and the Rural Electrification Agency (REA) as part of the Rural Electrification Project (REP). These regulatory bodies oversee rural electrification programs through both the public and private sector. The REB is comprised of a supervisory board with members representing the public and various departments within the government. The REA reports to the REB and is responsible for analyzing rural electrification policy issues. Both the REB and REA operate beneath the Ministry of Energy and Mineral Development, solicit funding from parliament, donors, and other agencies (e.g. World Bank and Global Environmental Facility) through a Rural Electrification Fund (REF), and recommend appropriate types of electrification projects in the country (Kaijuka, 2007; Lule, 2006). Section 63 of the Electricity Act requires that the Minister shall submit a report on progress and achievement of the rural electrification plan to Parliament once each year (Lule, 2006).

Uganda's Rural Electrification Project (REP) has the goal of achieving a 10% rural electrification rate, a net increase of 400,000 households, by 2012. The primary objective is to reduce inequalities in access to electricity and associated opportunities for increased social welfare, education, health, and income generation (Kaijuka, 2007). Moreover, the plan sought to promote development and use of Uganda's indigenous, renewable energy resources on a cost-effective basis with a tentative target of about 70 MW of power generation from small renewable energy resources (Lule, 2006). As of 2010, about 4% of the rural population had access to electricity, compared to about 1% in 2001. In addition, about 1,000 isolated solar PV systems have been installed in over 50 districts of Uganda (Lule, 2006).

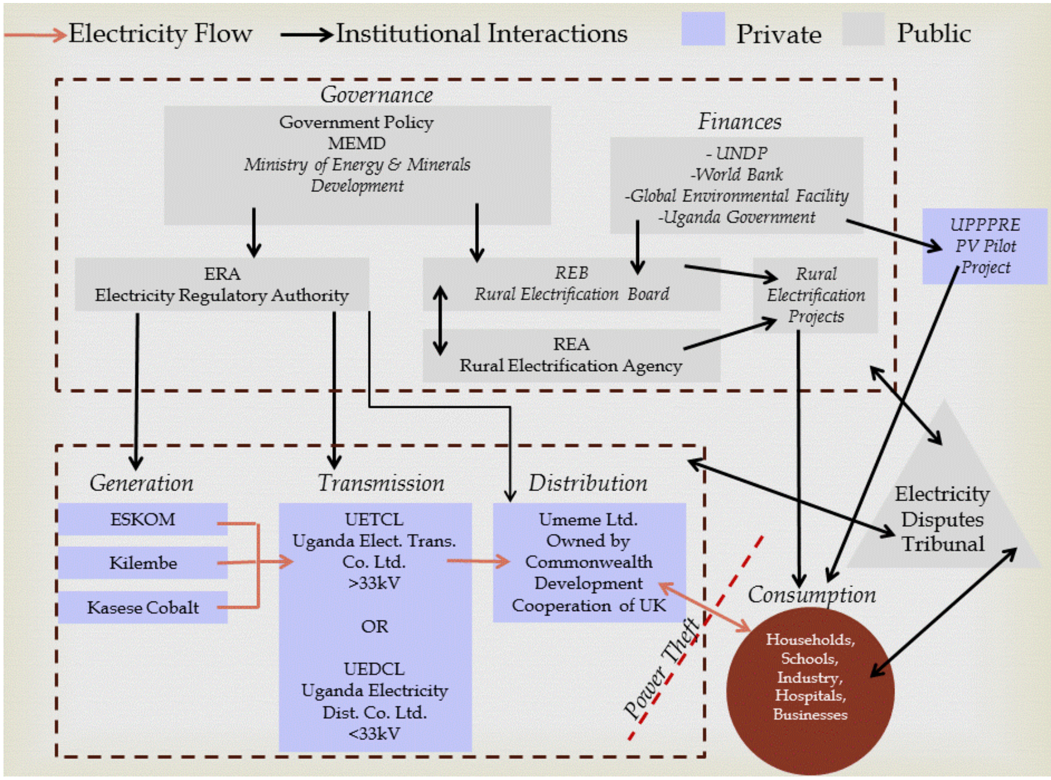

Figure 4. Concept map of Uganda's Energy Sector. The system has a public and private sector, a result of the 1999 Electricity Act that liberalized the once state-owned, vertically integrated system.

Another project aimed at addressing the rural electrification issue in Uganda is the Photovoltaic Pilot Project for rural Electrification (UPPPRE)**,** which was coordinated by the department of Energy and aimed at popularizing the use of photovoltaics (PV) in the rural areas where the hydropower grid has not reached. It was designed as a three-year pilot project, funded by the UNDP and GEF, and began in 1998. The program aimed to establish viable financial and institutional mechanisms for offering solar PV systems on a commercial basis to households, businesses, and communities. In the first two years of implementation, the project has led to the installation, by solar companies, about 1,000 solar household systems and 42 institutional systems (Turyahikayo and Sengendo, 2001). Some of the institutional systems have been installed in collaboration with the Ministry of Health and local government agencies to provide lighting for clinics and vaccine refrigeration facilities (Sengendo, 2001). The UPPPRE is targeted to improve the socioeconomic and technical conditions of the rural communities in several aspects, such as domestic homes, education, health care and employment. The project included awareness raising campaigns that informed residents of the benefits of solar power, and environmental issues. Moreover, the UPPPRE engaged stakeholders, in particular women who were offered training in technical skills and system installation, with the idea that this it would produce benefits that would extend to all household members and the community at large (Sengendo, 2001).

III. CHALLENGES AND IMPLICATIONS

Extending the Electric Grid

The difficulties of grid expansion in Uganda are many, stemming from the large, dispersed, and poor rural population of the country. The cost of implementing and maintaining power generation, transmissions, and distribution facilities in rural areas is very high, while the collection of revenue from consumers is low. It is found that in low income households that consume only small amounts of energy, the costs of meter reading, billing, revenue, collection and administration outweigh revenue collected (Ezor, 2009). Consequently, without government assistance or subsidy, rural electrification is commercially undesirable to private utility companies, making it also an unsustainable endeavor. In addition, Uganda losses about 40% of power due to system thermodynamic inefficiencies and power theft from unauthorized connections. This constitutes a monetary loss of about $50 million a year (Ezor, 2009). To make it worse, power theft is a self-perpetuating activity, as lower collection revenue drives higher tariffs. Power equipment is also susceptible to being stolen; highly valued copper wires can be sold in scrap yards for about US $10 per kilo (Ezor, 2009). Uneven access to the grid has been known to cause competitors of local grain mills that run on gasoline to cut the wires of competitors that are using electric sources. Furthermore, Umeme and UEDCL workers, who are paid on commission and have an incentive to create additional repairs, have been known to cut lines to create more work for themselves. Low generation capacity also causes load shedding, which is often at the expense of smaller, less-reliable customers in rural areas (Ezor, 2009). Given these barriers to extending the current electric grid, Uganda may benefit from more dispersed energy generating systems, such as renewable technologies, the most predominate of which is solar PV devices. However, these devices do not come without their own set of shortcomings.

Implications of PV Technology

There are also many challenges to the implementation of PV technology in Uganda. The main issue is the high upfront costs of PV systems; a 50Wp system costs about US$800 (Turyahikayo and Sengendo, 2001). Household PV systems provide energy for limited energy service at relatively high costs per unit, estimated to be US$1.7–2.88/kWh for select developing countries, whereas the conventional grid systems provide relatively less limited energy services at tariff rates at US$0.03/kWh–0.10/kWh (ibid). The UPPPRE did include a 6 to 24 month payment plan to allow customers to pay over time for their system. The project established collaborative credit agreements with domestic credit institutions, which (in theory) would provide credit to users and vendors. However, since most rural Ugandan residents have seasonal income based on agricultural activities, they often have difficulty borrowing from financial institutions that require consistent monthly payments. If the banks did approve a loan, it would include high interest rates that were too costly for customers. Also, potential borrowers were subject to the bank's collateral requirements, since the solar devices have limited resale potential. In fact, nine months after the credit system was created, only three users (one household and two solar companies) had obtained credit for solar system loans (Sengendo, 2001). The provision of subsidies for solar projects has been a successful mechanism for rural electrification (Wamukonya, 2005), but subsidies in general are problematic because they create dependency on funds from outside sources that are usually only provided in the short-term (GSI, 2011).

If a project like UPPPRE is to be successful at enabling energy access to the rural poor, another financial model should be used. The exploration of community level, micro-finance organizations that operate closely with users may be more successful. Such organizations could allow payments on a timeline that better aligns with seasonal agricultural profits. Also, to be successful at contributing to development, PV systems need to not be considered more than a consumer good that provides lighting in households, but they need to provide the relevant services needed to generate income that will also improve human (Turyahikayo and Sengendo, 2001; Wamukonya, 2005).

Even if a user is able to purchase or receive a PV system, the long-term use of the system in problematic. Service personnel may be inadequately trained to handle repairs of the systems that are designed and produced elsewhere. That is, the lack of local knowledge about imported systems can inhibit repairs of the systems. Also, insufficient infrastructure systems (e.g., roads, mail delivery system) slow the transportation of spare parts for system maintenance (Ezor, 2009). Furthermore, the lack of environmentally safe disposal and/or recycling facilities in Uganda is a critical impediment to the sustainability of the PV technologies (Varho, 2002). There are potential hazards with leaching of toxic materials, such as cadmium, and can become increasingly problematic with the disposal of large numbers of modules. Lead acid batteries used in conjunction with the PV systems also represent a serious environmental hazard, if not handled appropriately (Varho, 2002). There are also more batteries than solar modules, since the batteries have to be replaced several times during the lifetime of the panels. Recycling systems for batteries do exist in some developing countries, but often only in urban areas. The sparsely populated areas and the rugged terrain in Uganda makes organized recycling difficult (Varho, 2002).

IV. AN ALTERNATIVE

A less conventional endeavor to enable energy access to the rural poor is the *Empower Ugandans to Power Africa Project* that seeks to encourage Ugandans to innovate their own electricity generating devices (EGDs). The program was started by Dr. Abigail Mechtenberg (an Associate Professor at Clark University) and Dr. Moses Musaazi (a professor at Makerere University in Uganda) and involves teaching technical students in Uganda the basics of generating electricity. Through week-long workshops, students create small versions of EGDs with Legos and plastic gears, and are empowered to design actual prototype EGDs through the use of readily available materials in the local market-place (Figure 5). Innovation and creativity are stressed, allowing the devices to be co-designed with the people who will actually use them. For example, a local women’s group in Fort Portal, Uganda are working on weaving light-weight but durable wind turbine blades at very low cost (Figure 5). Students that take the course are expected to pass on their knowledge to other students, so the program becomes sustainable within Uganda. The human powered devices created and tested so far include hand cranks, bicycle generators, and merry-go-round generators (MGR), in addition to other renewable energy harnessing devices such as small hydroelectric generators as well as vertical and horizontal wind turbines. Each human powered device is designed to target the needs of specific sectors that impact human development. The bicycle generator is intended to be used in domestic settings and in small businesses. The hand-cranked surgical lamp is designed for hospitals as back-up electricity and health centers in off-grid conditions. The MGR is designed to provide electricity in schools that cannot afford either grid electricity or off-grid rural electrification (Mechtenberg, 2011).

Figure 5. (Left) Weaved turbine blades are being completed by a women's group in Uganda using locally dried plants. (Right) A technical student at St. Joseph's Technical Institute in Fort Poratal, Uganda makes a hand cranked electricity generating device out of Legos in class.

Because these devices can be locally manufactured using materials that already exist in the developing economy they are less expensive and more sustainable. For example, a bicycle generator can be produced anywhere that vehicles exist with low toxicity. This can be done by purchasing a vehicle alternator and connecting it to the bicycle wheel to charge existing batteries (Mechtenberg, 2011). However, imported devices like solar panels cannot be locally manufactured in villages and without a recycling program, there are policy implications for semiconductor materials within solar panels getting into the local environment (see discussion above). The main drawback of the bicycle generator is that it requires someone to bike and requires more operation and maintenance than solar panels. However, the burden of cycling can be shared between members of a community, and maintenance is less technical, less expensive, and able to be completed by local community members that actually designed the device in the first place. Unlike solar panels, during a crisis (or cloudy day) the bicycle generator can provide light on-demand, enabling basic capabilities for hospitals and households in particular. Furthermore, compared to solar PV systems, the bicycle generator is more cost effective at generating electricity, especially if the bicycle generator is shared by multiple households for battery charging (Mechtenberg, 2011).

V. IMPACTS ON HUMAN DEVELOPMENT

There exists no single technology or policy that will improve development in isolation. Access to electricity is just one of many important factors in addressing poverty. According to Ezor (2009), "Electricity serves as a catalyst, making other pillars of development—education, modern healthcare, income generating activities, etc.—possible." The barriers to grid expansion and PV systems are important to consider, but the actual technology or infrastructure that delivers the energy is not as meaningful as the capabilities that those energy generation systems provides the people.

Conventional electrical grid systems meet most end-user energy demands, while typical household solar systems provide limited energy for lighting, and for operating TV or radio for limited time periods (Wamukonya, and Davis, 2001). Individuals that were able to buy solar PV systems have reported improved living conditions including energy that provides opportunities for income generation (e.g., refrigeration and battery charging), better conditions while performing daily talks, improved health conditions, and greater conservation of natural resources (Sengendo, 2001). The indicator of welfare gains has mainly been the extended hours for the household. These can be used by the children for studying, while women put additional hours of labor into household tasks (Wamukonya and Davis, 2001). Increased socializing under solar lights in villages of Senegal has been noted as a welfare benefit (Youm et al., 2000). Obviously these benefits are useful, but the extent to which they contribute to actual human development is unclear. The justification that PV systems free up time spent on gathering wood fails to acknowledge the fact that the wood is still needed for thermal energy (e.g. cooking, heating) (Youm et al., 2000). In addition, it is not a determined that the time diverted from wood gathering could be used for productive development purposes. Interviews with Namibian rural women revealed that they would use the freed time on housework and not necessarily on leisure or income-generating activities. The reasons for not dedicating the extra time to income generating activities were attributed to the lack of opportunities and capital, not necessarily energy access (Wamukonya, 2005). It is clear that other services, besides access to electricity in isolation, is needed for significant gains in human development.

One direct way of improving livelihoods is job creation. Grid extension projects, solar PV system programs, and projects like the *Empower Ugandans to Power Uganda* all will stimulate employment at some level. However, the latter creates employment and uses materials that help to stimulate the local economy. Individuals in Uganda educate others in Uganda about how they designed the system, and tacit knowledge is built locally about the devices, rather than relying on the knowledge of outsiders. The cost effectiveness of the locally made devices may allow energy access to the rural population much faster than other methods that rely on state-owned, donor funding, and/or financial incentives. In addition, devices that are designed to target the electricity needs of schools (MGR), hospitals (hand crank surgical lamp), and households (bicycle generator) will transfer directly into human development objectives like improved health care and education (Mechtenberg, 2001).

VI. CONCLUSION

The motivation behind rural electrification is not driven by the need to get energy to the people, but to give the people the capability to live improved lives through the services that energy enables. As discussed above, the current power sector of Uganda is very complex, driven by a plethora of interests and outside forces, and is limited by many barriers to meeting the needs of the rural population. Recent changes and programs implemented to address rural electrification issues have had some success but the percentage of people in the country with electricity access remains very poor. Perhaps the fastest way to get energy to the people is to empower the people of Uganda to take action, rather than waiting until modern energy sources come to them. Through projects like the *Empower Ugandans to Power Uganda*, less conventional and local efforts may potentially be an improved approach, or least a complimentary strategy, to alleviating poverty and thus improving livelihoods in Uganda.

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