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Energy Access for Socio-economic Development – Impact and Potential of Decentralized Electricity Generation in Rural Uganda

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Affidavit

I, **ELISABETH GAGER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ENERGY ACCESS FOR SOCIO-ECONOMIC DEVELOPMENT – IMPACT AND POTENTIAL OF DECENTRALIZED ELECTRICITY GENERATION IN RURAL UGANDA", 106 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Signature

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Abstract

Uganda, a landlocked country in East Africa, offers different opportunities to generate electricity in a sustainable way. Solar PV systems, micro-hydro schemes and biomass facilities are feasible to provide the country with renewable energy. Nevertheless, the country's rural electrification rate accounts for 3 %. Scattered population, low generating capacities and limited household budgets hamper the access to electricity.

The government and donors such as GIZ make use of solar photovoltaic systems to provide schools, health centres and administrative buildings in rural areas with energy. This thesis is based on primary field research to assess the impact of the technology on social institutions in Arua district. The investigation shows that with electricity academic and work performance strongly increased, working and studying time is used more efficiently and staff members enjoy an enhanced welfare. The use of photovoltaic systems entails challenges such as the system's sustainability: Limited budgets keep institutions from replacing broken components and lead to lengthy system outages. Moreover, system overuse and problems in terms of maintenance cause breakdowns.

Despite of their positive social impact, stand-alone systems can contribute to the overall goal of economic growth only in a limited manner. Agro-processing and mechanization applications for manufacturing require more and reliable electricity throughout business operation hours. Decentralized grids can offer a sustainable energy supply to consumers in rural villages. The thesis provides an overview of relevant literature on micro-grid technologies feasible for Sub-Sahara African developing countries and offers strategies and ideas to establish them in Uganda. Because of the geographic and meteorological conditions in the country, it is favourable to integrate different renewable energy sources, battery storage systems and fuel generators as system backup in a decentralized grid. The reliable energy produced can be used to serve important loads including vaccine refrigerators in health centres. Additionally, a closed-loop life-cycle strategy should be considered since system components can have severe negative impacts on the environment if not disposed appropriately. An integrated electrification approach based on micro-grids can lead to the facilitation of economic growth and to an increased energy access rate in Uganda.

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List of acronyms

A	Ampere
AC	Alternating current
ACP	African, Caribbean and Pacific Group of States
ADB	African Development Bank
CDM	Clean development mechanism
CHP	Combined Heat and Power
COMESA	Common Market for East and Southern Africa
CREEC	Center for Research in Energy and Energy Conservation
DER	Distributed energy resource
DC	Direct current
DG	Distributed generation
DRC	Democratic Republic of the Congo
EAC	East African Community
ERA	Electricity Regulatory Authority
ERT	Energy for Rural Transformation
EUR	Euro
est.	Estimation
Fig.	figure
GDP	Gross Domestic Product
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (now: GIZ)
GNI	Gross national income
GoU	Government of Uganda
GWh	Giga watt hours
HC	Health Centres
Hz	Hertz
i.e.	Id est
IEA	International Energy Agency
IMF	International Monetary Fund
ISO	International Organization for Standardization
km	kilometre
kV	Kilo volt
kW	Kilo watt
kWh	Kilo watt hours
kWp	Kilowatt peak
LC	Local Council
Li	Lithium
Li-Ion	Lithium-Ions
m^2	Square meter
MoU	Memorandum of Understanding
MEMD	Ministry of Energy and Mineral Development
MSME	Micro, small and medium enterprises
MW	Mega watt
NGO	Non-governmental organisation
Ni	Nickel
NiMH	Nickel metal hydride
ODA	Official development aid
OECD	Organisation for Economic Co-operation and Development

PC	Personal computer
PREEEP	Promotion of Renewable Energy and Energy Efficiency Programme
PV	Photovoltaics
RE	Renewable energy
RES	Renewable energy sources
SC-HQ	Sub-county headquarters
SHS	Solar home systems
SS	Secondary schools
UBL	Uganda Batteries Ltd.
UETCL	Uganda Electricity Transmission Company Ltd.
UGX	Uganda Shilling
UN	United Nations
UNDP	United Nations Development Programme
UNHCR	United Nations High Commissioner for Refugees
UNIDO	United Nations Industrial Development Organisation
USD	United States Dollar
UNCTAD	United Nations Conference on Trade and Development
V	Volt
W	Watt
Wp	Watt peak
WTO	World Trade Organisation

1. Introduction

1.1. Problem

Energy is one of the most crucial limiting factors for economic growth in developing and least developed countries. The absence of electricity to fulfil tasks such as lighting, vaccine refrigeration, agro-processing, information technology and mobile phone charging in enterprises, homes and social institutions hampers the rural prosperity. It increases the use of biomass and petroleum products that cause indoor air pollution, serious health effects, deforestation and environmental degradation. The time spent on collecting biomass entails high opportunity costs particularly for the female rural population, who could otherwise dedicate their time to income-generation, entrepreneurship or education.

Thirty-three African states are classified as least developed since their three-year average GNI per capita lies below 905 USD (708 EUR), their human resource base is weak and economic vulnerability is high (United Nations 2011). In these countries a total of 585 million inhabitants live without access to grid-electricity, fuel generation, photovoltaic systems or any other electricity generation technology. The total electrification rate of the region amounts to 30.5 %, the rural ratio to 14.3 % and the urban rate to 59.9 % (International Energy Agency 2009), leading to a low average energy consumption per capita of 1-2 kWh per day (Venkataramanan and Marney 2008). Available power from the utility grid is often characterised by high tariffs, load shedding, inadequate distribution infrastructure and supply-demand-gaps (Muhoro 2010).

Figure 1: Illumination differences between Africa and Europe seen from space (source: NASA 2000)

Access to reliable energy is critical to fulfil socio-economic needs since it contributes to income-generation and growth. The procurement of secondary energy carriers and end use devices enhances the demand for educational and health services and further leads to poverty reduction (USAID 2005).

The international community, foremost the United Nations, have set the ambitious goal of achieving universal energy access by 2030. Effective mobilization of domestic and international funding as well as efficient government regulations and policies will play a central role in the fulfilment of this target. As a result, foreign and international donors as well as governments have created energy access programmes and established bodies concerned with rural electrification and strategy planning in a number of African countries (International Energy Agency 2009).

The Republic of Uganda, a landlocked country in East Africa, features total electricity access of 10 % and 3 % of rural energy access. In order to tackle economic development, the government facing one of the highest population growth rates in the world intends to reach a 10 % rural electrification rate by 2012 (GIZ 2012a). Rural energy expansion is achieved through the use of petrol or diesel generators, but most preferably through renewable sources including solar PV, wind generators and small hydro schemes connected to inverters, charge controllers and batteries (Muhoro 2010).

1.2. Hypothesis, Research Questions and Scope

With an average solar radiation amounting to 5.1 kWh/m² and day and numerous possibilities for hydro- and biomass generation, Uganda is an adequate playground for PV-technologies and their combination with other renewable energy sources to enhance the rural energy access and facilitate socio-economic development (MEMD 2007). Solar PV improves the welfare in rural communities without harming the environment and enables economic growth. Furthermore, the combination of PV with other RES, backup-systems and storage devices in a decentralized grid entails a more reliable access to electricity suitable to start-off small scale industries. However, these electrification concepts can only be successful and contribute to welfare if they are well planned, adjusted to the needs of the population and considered under technological, social and economic aspects so that any obstacles can be overcome.

In order to underline this hypothesis, two research questions have been defined:

- Which impact does the use of solar PV systems in social institutions in a developing, tropical country such as Uganda have? Which benefits and disadvantages can be observed related to the example of Uganda?
- How can micro-grid projects for rural electrification of Uganda be designed and organized in order to foster economic and social development?

The thesis is divided into three empirical parts: The second chapter will present background information on Uganda and on different generation technologies suitable for the country. Furthermore, the third chapter pictures a case study on the electrification of social institutions in Arua district, Northern Uganda. Finally, the fourth chapter suggests a strategy on how to develop decentralized grids to achieve a wider and reliable energy access in Ugandan communities.

1.3. Methodology

The thesis is based on an introductory literature review as a guiding concept to describe the current situation of rural electrification in Sub-Sahara Africa and Uganda, the state of economic development as well as technologies for rural electricity generation and for micro-grids in developing countries. This secondary research aims at collecting, analyzing and interpreting accessible knowledge in an analytical manner. It consults scientific articles, books, websites, reports as well as strategy and policy documents. Choosing the sources carefully and including different views shall contribute to an unbiased balance and quality of the work (Dawidowicz 2010).

The empirical part of this master thesis includes expert interviews paving the way for the subsequent qualitative field research on impacts of solar PV systems on social institutions. An expert of the GIZ (German International Cooperation) – Promotion of Renewable Energy and Energy Efficiency Programme in charge of the visited projects, an expert from the Ugandan Ministry of Education and Sports and an expert from the Ministry for Energy and Mineral Development were interviewed. The empirical part assesses the situation of social institutions provided with PV in Arua, Northern Uganda. The seventeen examined institutions include secondary schools, sub-county headquarters and health centres that are beneficiaries of the rural electrification project of the GIZ Promotion of Renewable Energy and Energy Efficiency Programme (PREEEP). The impact assessment was carried out in February 2012 and was organized in cooperation with the PREEEP head office in Kampala and the field office in Arua. The interviews were based on the method of qualitative social field research and obeyed the principle of openness. Its aim was to collect data in a systematic and analytical way to achieve descriptions, interpretations and relevant prognoses without deducing logical conclusions. The collection, coding and analysis were conducted simultaneously. The sampling was given by the number of social institutions in Arua that had taken part in the GIZ project (Glaser and Strauss 2008). Open guideline-questionnaires were set up and adjusted to each type of the institutions. Their target was to assess consequences and impacts evoked by the introduction of the PV systems. During interviewing the in-charges of the institutions, field notes that contained the essential content and information about the interview course, were taken and attention was paid to the mentioned key words. By constantly comparing the results of the interviews, similarities and differences could be identified and characteristics of samples generated (Glaser and Strauss 2008). After each interview, summaries were compiled so that context information and findings could be identified and re-examined in the following interviews. With the help of comprehension questions inconsistencies and ambiguities could be ruled out (Flick 2007).

2. Uganda country situation

2.1. Demographics

The Republic of Uganda is a landlocked country in East Africa and home to more than 35.8 million people (July 2012 est.). 13 % of them live in cities. The state was colonized by Great Britain in 1894 and achieved full independence in 1962. The country has been experiencing a drastic population growth of 3.6 % annually – the fourth highest rate in the world. It results from a total fertility rate of 6.65 children per woman and is causing a median age of 15.1 years. Thus, 49.9 % of Uganda's population is between 0 and 14 years old. However, due to the high distribution of HIV/AIDS (1.2 million people, 6.5 % of adults between 15 and 49, are affected) and other life-threatening diseases life expectancy accounts only for 53.4 years.

The society of Uganda comprises different ethnic groups: The Baganda, the biggest group (16.9 %), counts 52 tribes and belongs to the East Bantu, who live mainly around Lake Victoria. The North of Uganda is mainly populated by Acholi (4.7 %) and Lugbara (4.2 %). About 41.9 % of Uganda's population is Roman Catholic, 42 % are Protestants, 12.1 % Muslims and 3 % are members of natural religions (Central Intelligence Agency 2012).

2.2. Politics and decentralized administrative structures

Uganda is a presidential republic governed by the Constitution of 1995. The head of the state and government, Yoweri Musevini, seized power in 1986. Presidential elections take place in a five-year-term. The first multiparty election was held in 2006.

The National Assembly consists of 375 representatives, of whom 238 are elected by popular vote, 25 members are nominated by legally established special interest groups and 112 are directly elected. Additional ex-officio members may be appointed by the president. During the last elections in 2011, the National Resistance Movement (NRM), headed by President Yoweri Musevini, was elected strongest party and won 263 seats.

Uganda is represented on the international scene as member of different international and regional organizations such as the ACP, the African Union, the East African Community, the

COMESA, the WTO, ISO and UN organizations including UNIDO, UNCTAD and UNHCR (GTZ 2009; Central Intelligence Agency 2012).

Uganda is divided into four regions: the Northern, Central, Eastern and Western region. These comprise a total of 111 districts almost all named after their chief towns. The state counts 126 counties, 11,116 sub-counties and 66,036 villages (Ministry of Local Government 2010). The smallest administration unit is the village consisting of 50 to 70 households and home to 250 to 1,000 inhabitants. On each of these administration levels and in the parishes that consist of a number of villages, the population is represented by local councils (LC) including local council committees headed by a chairman (Kavuma 2009).

These local governments play an important role in the implementation of the Energy for Rural Transformation Project (ERT) supported by the World Bank. The offices need and use electricity to run information technology equipment. As a result, they serve as a role model by raising awareness for the ERT programme amongst the population (Ministry of Local Government 2010).

2.3. Economy and development

Since Uganda has gained independence in1962, the country has experienced alternating periods of political and economic progress and decay. As landlocked country Uganda is dependent on its neighbours to access the Indian Ocean and thus the world markets.

2.3.1. Conditions for economy and growth

Uganda’s economic growth is characterized by several drawbacks: (1) The infrastructure is not developed adequately throughout the country. Energy, roads and telecommunication are insufficient in many places. (2) Human and institutional capacity is limited, thus a constraint for planning and budgeting processes and hindering the private sector development. (3) The high population growth rate entails obstacles for the development of the civil society. The provision of social services, for instance, becomes difficult. Additionally, total and youth unemployment rates are increasing. Unless family planning initiatives are of avail, the millennium development goals are difficult to be achieved in Uganda. The problem goes hand in hand with an increasing urbanization and poor housing construction. (4) Uganda earns only low revenues from taxes. The tax-GDP ratio accounted for 12.2 % of the gross domestic product. In comparison, the average in Sub-Saharan Africa lies at 20 %. The problem is mainly due to the fact that the country has only a small tax base, tax policy weaknesses and low compliance. As a result, the republic relies largely on donor aid. In 2008/09, it amounted to 42 % of Uganda's budget endangering foreign investment of 10 % of GDP to be edged out and economic development to slow down. (5) The export base and terms of trade are vulnerable to environmental degradation and climate change. Coffee is one of the most important export goods and its yield is seriously threatened by declining precipitation. Diversification is low. As a result, the country highly depends on commodity prices (African Development Bank 2010).

2.3.2. Current economic situation

After the end of an era of political instability and economic downturn during Idi Amin's term and two civil wars, the economy experienced an unprecedented growth at an average rate of 7 % per annum. In 2011 the GDP growth amounted to an estimated 6.4 % mainly driven by private consumption. The GDP added up to 45.9 billion USD (35.3 billion EUR) (est.), which accounts for a nominal GDP of 478 USD (366 EUR) per capita (African Development Bank 2010; Central Intelligence Agency 2012). However, compared to other states and regions, Uganda is one of the global economic rear lights:

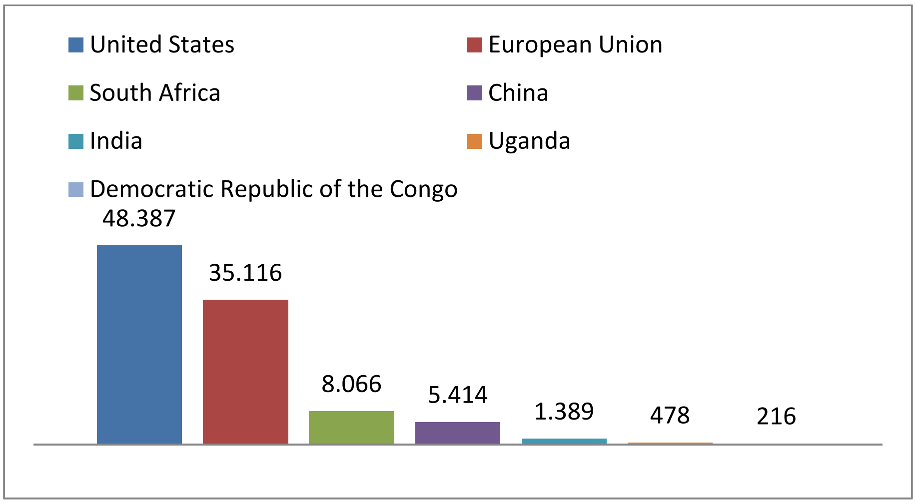

Figure 2: Nominal GDP per capita by country in USD (adapted from IMF 2012)

The last decade has brought some political change through the introduction of a multi-party system and the termination of the civil war in Northern Uganda in 2006. As a result, democratic governance is progressing, the country is becoming attractive for investment and thousands of displaced persons have returned to their homes re-engaging in agriculture and economic activity (African Development Bank 2010). Today, Uganda's business environment can be considered as open and liberalized. Due to memberships in several trade agreements, the government aims to create favourable trade conditions without restrictions on capital. For instance, there are no tax tariffs raised on renewable energy equipment (GTZ 2009).

The agricultural sector contributes 21.8 % to Uganda's GDP, the manufacturing industry 26.1 % and the service industry 52.1 % (2011 est.). The country's labour force consists of 16.02 million people. 82 % of these work in the agricultural sector (Central Intelligence Agency 2012). The total official unemployment rate accounted for 2 % in 2006/07. In rural areas it amounted to 7 %. Especially young people are prone to unemployment (22.3 %). 70 % of the workforce is self-employed in agriculture. As a result, the formal permanent employment lies only at 5 %. A total of 12 % of Ugandans were underemployed (OECD 2008; World Bank 2007.).

MSMEs constitute 90 % of Uganda's private sector. They employ 1.5 million people, 90 % of the non-agriculture employed. Albeit from this large economic potential, MSMEs contribute to only 20 % of the annual GDP. Due to their lack of competitiveness, the country experiences also one of the highest business failure rates globally (Muhoro 2010; UNDP 2012). Uganda's manufacturing sector grew by 7.2 % in 2010/11 in comparison to 6.1 % in 2009/10. Especially, the textile, beverages, tobacco, paper, chemical, cement and food processing industries have been attracting investment (KPMG 2011; ERA 2006). Access to reliable electricity would allow an enhanced industrialization of Uganda, the expansion of its agricultural markets towards a global marketplace, an improvement of productivity by introducing mechanization, increasing job creation and income generation as well as facilitation for the daily business of MSMEs (USAID 2005).

In 2011, the country exported goods representing the value of 2.6 billion USD (1.9 billion EUR), which led to a negative trade balance since the imports accounted for 4.8 billion USD (3.7 billion EUR). The exports mainly included coffee, fish, tea, cotton, flower, horticultural products and gold. The imports comprised capital equipment, vehicles, petroleum, medical supplies and cereals. Uganda's main trading partners are Sudan, Kenya, Rwanda, the DRC, UAE, Netherlands, Germany and Belgium in terms of exports and Kenya, UAE, China and India in terms of imports (Central Intelligence Agency 2012). The country has a number of precious natural resources that include copper, cobalt, hydropower, gold, limestone, salt and phosphate available (US Department of State 2012). Within the last decade oil sources have been discovered and causing political confrontations on drilling and exploration licenses. In February 2012, agreements with the British gas and oil exploration company Tullow Oil were signed without prior negotiations and law-passing in the Ugandan parliament (Kiggundu and Mutaizibwa 2012). In addition, the information technology and knowledge economy is growing fast. Tourism is emerging and serving as a source of foreign exchange. Annually, the industry achieves a turnover of 500 million USD (380 million EUR) (African Development Bank 2010).

2.3.3. Poverty

In 2009/10, 24.5 % of the population lived below the poverty line and had less than what is necessary to meet the daily calorific requirements available. Although the number has been sharply declining over the last two decades, the gap between rural and urban population is still large: 27.2 % of the rural and 9.1 % of the urban population live below the poverty line. Especially the country's North is poor (46.2 %) (UBOS 2012).

2.4. Health

The high annual number of births is a challenge to the Ugandan health sector. Deliveries and early life health care are some of the most important treatments in the country's health centres. The fertility rate lies at 6.65 births per woman. Maternal mortality and mortality of under-five-year-olds and infants are still issues even though their rates have been declining over the last decade. Moreover, the occurrence of malnutrition, viruses and illnesses was curbed. Nonetheless, malaria, malnutrition, respiratory tract infections, AIDS, tuberculosis as well as prenatal and neonatal conditions are major causes of morbidity and mortality.

Public health is influenced by education and housing conditions. About 75 % of Ugandan's live in houses constructed from temporary materials. The rural population is lacking in access to sanitation and clean water supply. Cultural beliefs and social behaviour such as husbands deciding over their wives' health care prevent parts of the population from accessing HCs. Also, income inequality is directly reflected in the prevalence of diseases, especially malaria, malnutrition and diarrhoea. Furthermore, health services are not available throughout the entire country. On average, 72 % of Ugandans live within 5 km of the next health facility. However, the utilization of health centres is often hampered by the lack of medicines and health supplies. Many facilities are in state of disrepair and employ too few staff, which leads to discouragement.

The health sector consists of equal parts of both privately and publicly held health centres. The ministries of health, local government, defence, internal affairs, gender, labour and social development play important roles for the publicly held HCs. The lead functions in terms of policy, budgeting and strategy are accomplished by the Ministry of Health. Some national autonomous institutions carry out specialized clinical support and regulatory functions. The district health systems consist of community health services, village health teams in Health Centres of different sizes and levels (I – IV), regional referral hospitals and national referral hospitals. At least one HC IV or general hospital exists in each sub-district.

The government spends 9 % of the annual GDP on health services. As a result, the public health sector is mainly financed through government revenue and development assistance (Ministry of Health 2010a). Part of the ministries strategy is to upgrade the water and electricity supply of health facilities. The stage of upgrading rural energy is still ongoing and basically funded by 200 million UGX (64,200 EUR) annually (Ministry of Health 2010b).

2.5. Education

Uganda’s total adult literacy rate accounts for 75 % and has experienced a steep growth from 56 % in 1991. A discrepancy between male (82 %) and female literacy (64 %) is observed. From 2005 to 2009, a net of 82 % of children were enrolled in a school – 15 % in a secondary school – and were attending classes regularly (UNICEF 2012; Index Mundi 2012).

Uganda’s school system is divided into seven years of primary education and 6 years of secondary education comprising four years of lower and 2 years of upper secondary school. Upper secondary school alternatives include 2-3 years at technical institutes, 2 years at Primary Teacher Colleges, Department Training Colleges or Upper Secondary Schools. Every year, 60,000 to 70,000 students complete upper secondary education enabling them to proceed with post-secondary education usually scheduled for 3-5 years. However, only 35 % of graduates obtain a study place at one of the universities (Southern and Eastern Consortium for Monitoring Educational Quality 2012).

3. The situation of electricity in Uganda

3.1. Main energy sources in use

The main energy source in Uganda is biomass. It accounts for 93 % of energy consumption. Charcoal and wood are used by 97 % of the population for cooking, water heating and commercial uses. The annual per capita consumption amounts to 240 kg of firewood and 120 kg of charcoal. The high population growth of 3.5 % per annum and the inefficient use apply pressure on forests. Only 9 % of households possess efficient cooking stoves that enable wood fuel savings up to two thirds. As a result, the deforestation rate amounts to 2.2 % and the price of wood fuel rises by 6 % each year. In 30 % of the country's rural regions forests are depleted or over-used. The forest area has shrunk to 7 % of the land area. Consequently, the distances to gather wood fuel become larger and are deemed to affect the country's productivity. Finally, biomass burning results in indoor air pollution and causes severe respiratory diseases of particularly women and children.

The utilisation of biomass energy has contributed to a high price of petroleum products, which account for 6 % of the country's energy consumption and are used for vehicles, illumination and thermal power plants. Uganda consumes 6 million tons of oil equivalents annually resulting in a per capita consumption of 0.2 tons – one of the lowest in the world. Nevertheless, petroleum accounts for 8 % of annual imports. About 95 % of rural households use kerosene and petroleum lamps, which are a poor and explosive lighting source and emit hazardous gases.

Electricity represents only a small share of energy consumption, namely 1 % (GIZ 2012a). Due to the fact that costs for grid connection and stand-alone energy sources are high and communities lack awareness of the benefits, electricity expansion is hampered (Szewczuk 2007).

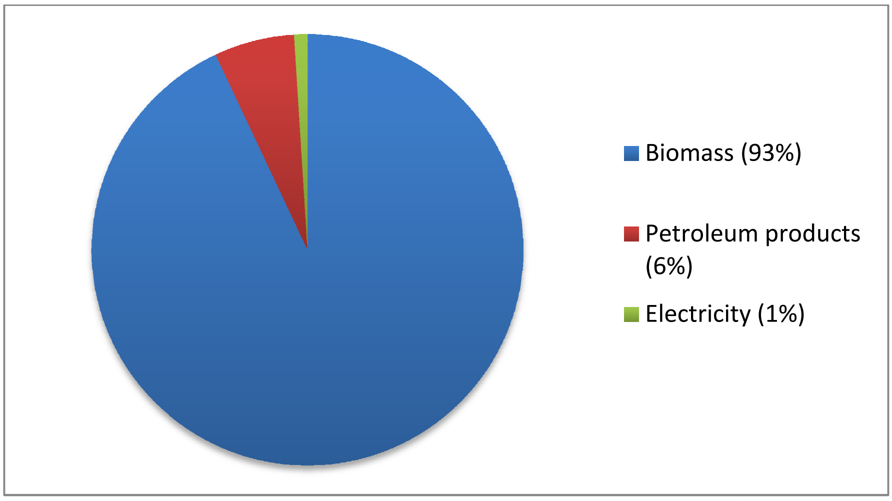

Figure 3: Energy sources used in Uganda (adapted from GTZ 2009)

3.2. Current electricity situation

Uganda’s consumption of constant electricity amounted to 63.98 kWh per capita in 2009. This value is low in comparison to other countries and regions:

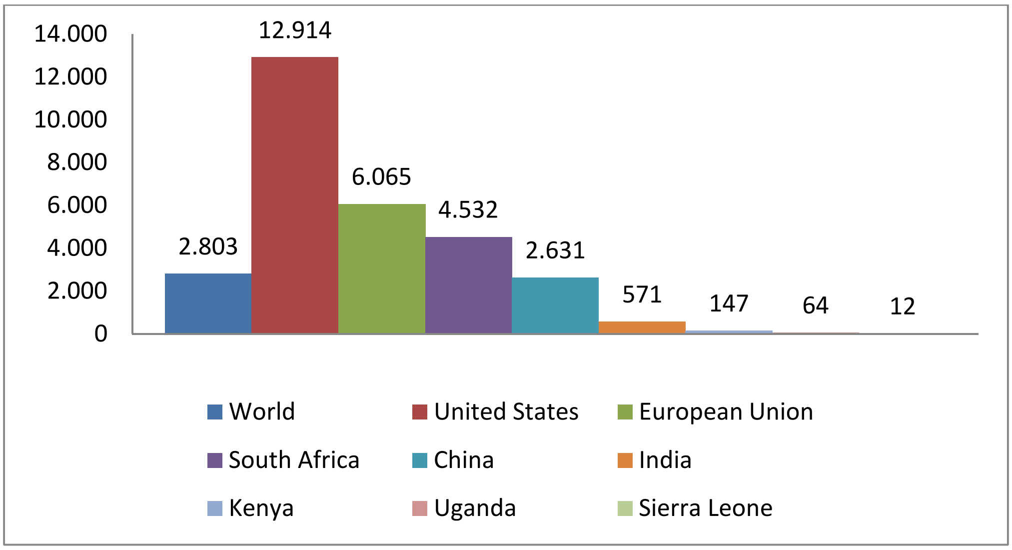

Figure 4: Average Electricity Consumption by Country in kWh per capita (adapted from United Nations Data 2009)

The energy access rate of households amounts to 10 % on a total and to 3 % on a rural scale. In February 2012, 350,000 households, 2,000 large and medium size companies as well as 90,000 small scale enterprises, of which the main part is located in the central region, were connected to the utility grid (GIZ 2012a; Byekwaso 2012) The Kampala-Jinja region, home to 12 % of Uganda’s population, consumes 72 % of the electricity produced. About 400,000 households are planned to be connected in near future. To achieve this target, emphasis is put on attracting domestic and foreign investors. Hence, the Rural Electrification Board has elaborated an investment guide to promote rural electrification and renewable energy in Uganda (Rural Electrification Agency 2011). About 1 % of the electricity is produced by off-grid technologies including fuel generators, car batteries and small solar PV systems (GIZ-PREEEP 2012).

In comparison to other developing nations, Uganda has a low electricity access rate as illustrated in the figure below:

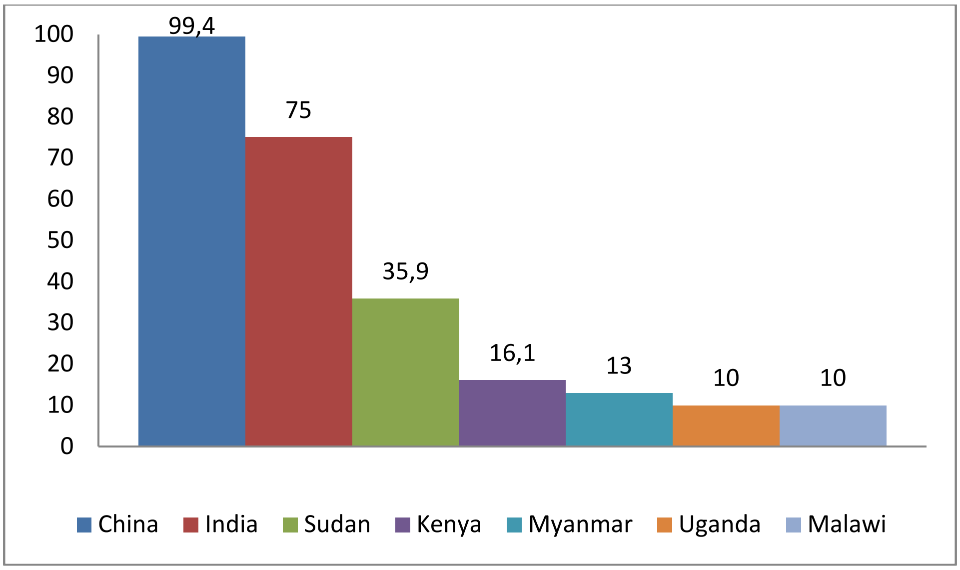

Figure 5: Nationwide electricity access rates 2009 data by country in % (adapted from IEA 2012)

The utility grid is mostly supplied through diesel generators and large hydropower sites (Kaijuka 2007). The sinking water level of Lake Victoria and droughts caused the production capacity to decrease. Consequently, in 2009 the hydro output accounted only for 140 MW generated out of total 300 MW installed hydropower capacity. In response, the government has installed three thermal power plants with a total capacity of 150 MW running on diesel. Moreover, 17 MW can be produced by cogeneration using residues from sugarcane in two inner-factory hydro-electric plants near the Ruwenzori Mountains. The thermal energy captured in these facilities is used for the sugar manufacturing process or to heat the factory buildings (Madhvani Group 2005; MEMD 2007). The resulting average peak supply of 317 MW still falls short of meeting the total demand of 368 MW, especially during the evening hours. As a result, the grid-operator is dependent on load shedding to keep the load low (GIZ 2012a; MEMD 2007). The Electricity Regulatory Agency (ERA) estimates that the power demand will increase by 8 % annually (ERA 2006).

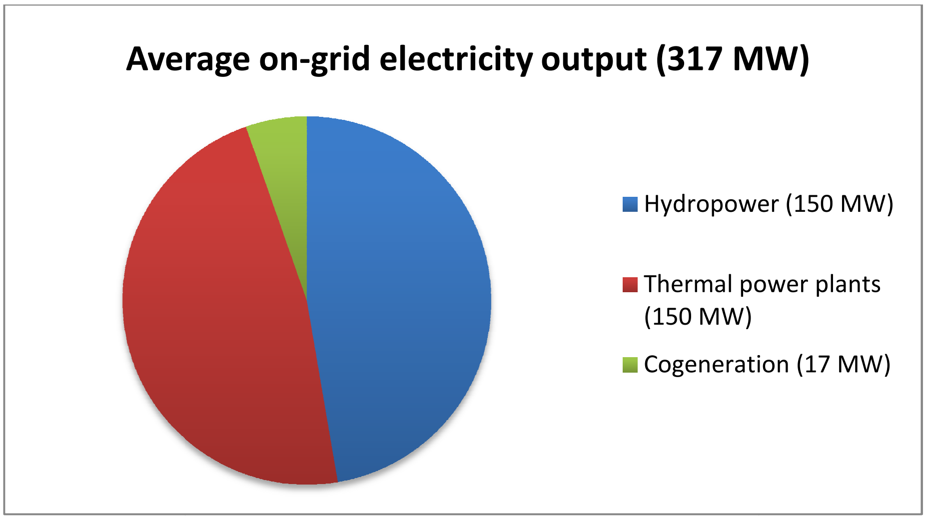

Figure 6: Average on-grid electricity output in 2009 (adapted from Saundry 2009)

The Bujagali Hydroelectric Power Station, designed to produce 250 MW, is planned to start full operation in July 2012. In addition, four hydropower plants with a total capacity of 1,250 MW are planned to be constructed on the long-run (Saundry 2009; GIZ 2012a). Large-scale energy projects are financed by international donors and lenders that give grants and loans to the government, which subsidizes utility companies (ERA 2006).

In grid-connected areas, parts of the population are unable to afford the connection fees. Additionally, due to the scattered character of the rural homesteads grid-extension is an expensive, uneconomic solution and unattractive for private sector investment. Hence, regions such as Northern and North-eastern Uganda will continue to have low electrification rates. A faster pace of electrification could be obtained with the application of renewable generation technologies. Therefore, a mix of grid-densification, micro-grids and stand-alone systems including conventional backups is crucial to meet the goals of the nationwide electrification strategy (GIZ-PREEEP 2012).

Even though the coverage of electricity has been low so far, power is an important factor to initiate social development and economic growth by facilitating applications in the following Ugandan industries and sectors:

- Agriculture: land preparation, fertilization, watering, agro-processing and conservation
- Communication: charging of mobile phones and telephones
- Education: lighting for reading hours and adult education, PCs, radios and TVs

- Health Care: facilitation of patient treatment by the use of medical equipment and illumination, storage of vaccines
- Households and communities: illumination, TV, radio
- Industry and commerce: production using up to at least 100 kW
- Water: collection, distribution and purification (Wan 2010).

3.3. Electricity use in different consumer units

3.3.1. Homes

Rural homes have low electricity requirements and are mainly in need of illumination. Thus, solar PV poses a cost-effective solution to meet their demand. A 14 Wp system, for instance, is usually sufficient for a family to provide appropriate lighting for at least 5 hours a day. The rising kerosene and petroleum price attracts the consumers' attention to pico PV and small PV systems. Their price amounts to 200,000 UGX (63.5 EUR) (Wafula 2012).

A study by GIZ-PREEEP (2011c) showed that the use of illumination provided by pico PV is gender-specific: Women living in households with solar PV systems do not use lighting to read, but they use it to do even more housework than before. Men, however, use electricity for listening to the radio or watching TV. As a result, development organizations are afraid that women are even longer exposed to hazardous wood smokes from cooking. Some households continue to use kerosene or candles for lighting, since they are afraid that solar PV systems may fail or they are simply habited to use them.

Refrigeration is not a common necessity in Ugandan households since it requires too much electricity and is thus unaffordable to maintain for large parts of the population. Since a common refrigerator demands 1 kWh per day, it necessitates an installation of 400 Wp. Moreover, it has to be coupled to battery banks in order to operate during days with less sunshine. As a result, common refrigeration is in many cases uneconomic for solar home systems (Oksolar 2012). Nevertheless, energy saving and solar fridges have been developed and are available for the Ugandan market.

Especially high-income households and tourist facilities are purchasers of thermal systems ranging from 100 to 3,000 litres per day. Most of these systems are based on flat collectors. The market price for a common 200 litre system amounts to 2 million (720 EUR) up to 3 million UGX (1,080 EUR) (GTZ 2009).

3.3.2. Social institutions

The main part of rural social institutions in Uganda does not have access to electricity. Energy poverty concerns schools, HCs and administrative buildings such as sub-county headquarters. The lack of electricity leads to a lower quality of education and health services and the utilization of information and communication technologies is limited. As a result, remote areas have become even more isolated (GIZ 2012a).

HCs rely on energy to (1) efficiently pump or purify water from clean sources, (2) introduce cost-effective lighting for night-time emergencies, (3) provide vaccine refrigeration, (4) run communication equipment such as PCs and cell phones, (4) provide cooking and instrument sterilisation and (5) offer staff accommodated on the premises to fulfil their basic energy requirements (USAID 2005).

About 50 % of secondary schools have access to electricity. Their energy applications include (1) illumination of study rooms and the provision of outdoor security lighting during evening hours, (2) power for educational equipment such as TV-sets and VCRs, (3) the facilitation of communication through phone charging and using PCs and (4) the preparation of meals (USAID 2005). The Ministry of Education and Sports plans to improve the energy use for water pumping, heating and cooking (Ssenozi 2012).

Administration buildings need electricity for indoor lighting, outdoor security lighting, to charge mobile phones and run communication equipment such as printers and PCs. The necessary amount of electricity depends on the size of an office and the number of employees.

3.3.3. MSMEs

The main part of micro and small enterprises in rural Uganda uses generators or electrical storage systems such as automotive lead batteries that are charged at least weekly at a charging station. Power applications include lighting, mechanization of processing, food preservation, extension of opening hours and production time, cell phone charging and running TV-sets or radios. Reliable access to electricity allows MSMEs to switch from labour-intensive and low-level production to value-added operation (Muhoro 2010; USAID 2005). Due to electricity, the productivity per worker rises and results in lower product prices, enhanced sales and revenue growth by up to 125 %. Furthermore, the quality and range of goods produced enhances. Electricity lowers local communication costs and improves banking services available in the towns (Kirubi et al. 2008). The key to economic success is not only simple access, but also good quality of electricity since costs of outages and backup systems are high for manufacturing businesses and hamper their growth (USAID 2005).

3.4. Potential and applications of renewable energy in Uganda

The potential of renewable energy is generally high throughout Uganda. This chapter will present aspects on RE sources that would be feasible for decentralized grids: solar PV, micro-hydro power and wind. The estimated potential of RES in Uganda is summarized in the table below:

Table 1: Potential of single RE technologies in Uganda (GIZ 2012a; MEMD 2007)

RE source	Potential
Biomass (agro-residues, wood fuel)	1,650 MW (50 million tons p.a.)
Geothermal	450 MW
Large hydropower	2,000 MW
Mini-Hydropower	210 MW
Peat	800 MW (250 Mtoe)
Solar	200 MW (5.1 kWh/m²)
Wind	Not assessed yet
TOTAL	**5,310 MW**

3.4.1. Solar photovoltaics

Solar PV is a simple and relatively inexpensive source of energy. Uganda has high potential for solar electricity generation.

3.4.1.1. Technical implications

Solar cells produce energy by converting sun energy directly into electricity by the means of the photovoltaic effect and without the interference of a heat machine. PV power generating systems consist of cells, mechanical and electrical connections as well as mountings that regulate and transfer the electrical output. The capacity of PV systems is expressed through watt peak (Wp) or kilowatt peak (kWp) that indicate the amount of electricity that can be produced as the sun stands directly overhead on a clear day (Bhubaneswari et al. 2011).

Solar panels consist of semi-conductor crystals such as silicon that create an electric current when being hit by light photons. At low temperatures they act as insulators. As heat is applied, electrons are knocked free and replaced by electrons of neighbouring bonds pretending a positive charge. The balance can be shifted by adding one more valence electron leading to the n-type material, e.g. phosphorus. The opposite, the doped p-type material, e.g. boron, has one valence electron less (Wenham et al. 2007). Due to the frontier concentration differences, electrons flow to the p-regions and the holes to the n-regions. This process builds up an electrical field at the junction. As light falls in, the concentration of minority charge carriers, the free electrons in the p-regions, rises. Electrons flow to the space charge zone and are divided by the electrical field. At the location where n- and p-regions adjoin, a tension (V) is produced and if a load resistor (R) is applied, current (I) is generated and electricity is dissipated. Thus, the maximum power generated can be calculated by the means of maximal current and voltage:

$$MPP = I_{mp}V_{mp}$$

The ratio between this Maximum Power Point and the optimal power produced (product of short-circuit I and open-circuit V) is the fill factor (Krauter 2006).

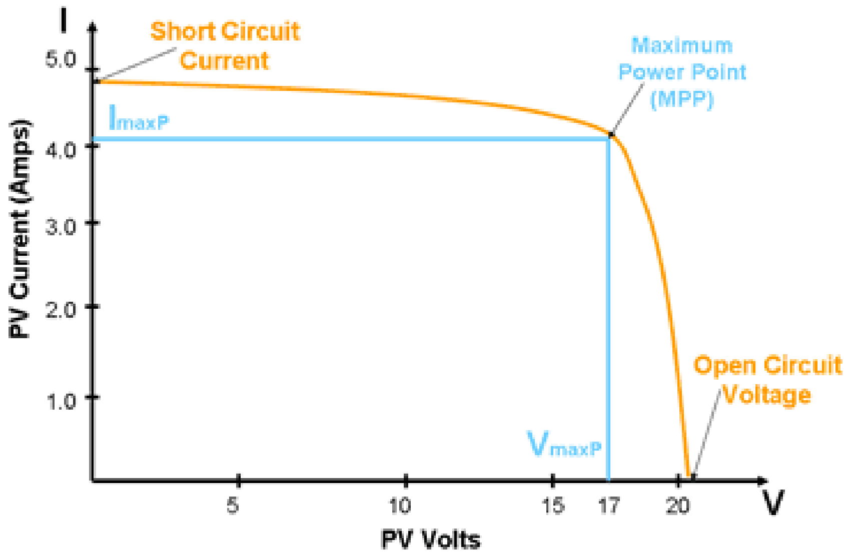

Figure 7: Current-Voltage characteristics (source: Electropedia 2012)

The efficiency η of a PV cell is characterized as the ratio between electrical power output and the irradiated power on the array under standard conditions. Crystalline silicon panels, for instance, have an efficiency of about 28 %.

Since the generated electrical field is weak, a number of solar cells is added up to strings and protected by layers made of glass and plastic. This compound builds the solar module (Krauter 2006). Where more voltage or current are needed, modules can be connected to form arrays (Messenger and Ventre 2000).

The key components of a photovoltaic power system are photovoltaic modules or arrays, an inverter, a storage battery and a charge controller as well as the connection of the load system to a generator backup.

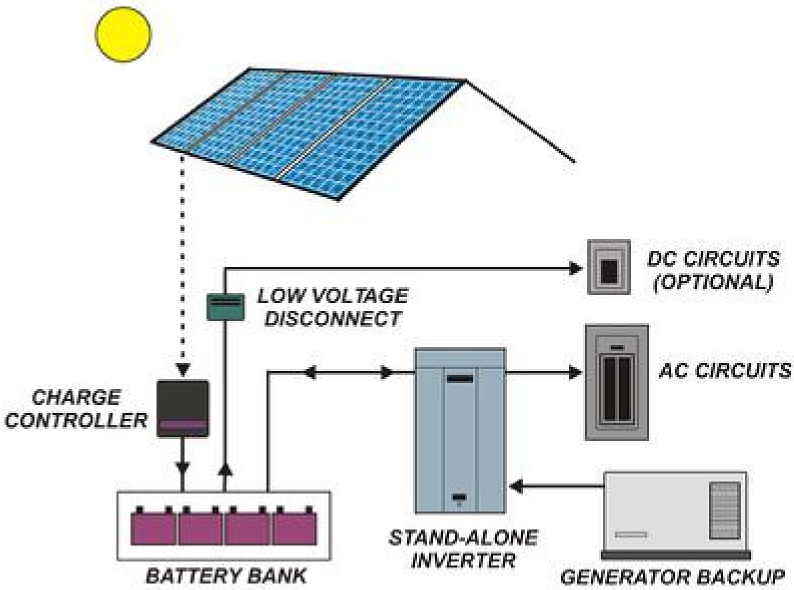

Figure 8: Stand-alone solar PV system (source: Aladdin Solar 2012)

The inverter converts DC into AC by switching the polarity with the frequency necessary for the AC or by coupling a DC motor to an AC generator. The charge controller regulates the charging and discharging phases of the batteries (Krauter 2006). It cuts the load as soon as the batteries are discharged and switches off the connection to the array as soon as it is fully loaded (Messenger and Ventre 2000). To store the generated electricity, mainly lead-sulphide acid (6.7 EUR/kWh), Nickel Cadmium (8.7 EUR/kWh), Nickel Hydride (14.6 EUR/kWh) or Lithium-Ion batteries (18.9 EUR/kWh) are used. Lead sulphide acid batteries are most common and comprise a lead cathode and a lead-oxide anode in a sulphuric acid solution. Its functional principle is based on the conversion of lead-dioxide into lead sulphate during discharging and the back-conversion during charging (Krauter 2006; Messenger and Ventre 2000; Battery University 2012):

$$PbO_2 + Pb + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_2O$$

Lead sulphide acid batteries are cheaper than other battery types, but are characterized by a shorter lifetime. A special type, the solar battery, uses thicker electrodes and excess electrolyte by which their cycle behaviour is improved.

Nickel Cadmium batteries have low energy density and are environmentally unfriendly due to their cadmium content. However, due to their relatively low price and long life, they are an economic solution.

Nickel Hydride batteries have high energy density, low maintenance requirements, a low memory effect and a long lifetime. They are an environmentally sound solution. However, their price usually lies two times over the acid-lead batteries and their efficiency is lower.

Lithium-ion batteries are expensive, but they have high energy density and efficiency (95 %). They operate at very low temperatures with almost the same level of efficiency. Regardless of which battery type is used, the devices should always be kept safely in a sealed case (Krauter 2006).

A generator can be introduced as a backup for the solar modules in regions where sunlight changes seasonally or where an important load needs to be served. In most cases, these needs are met by a gasoline, diesel or propane generator that generates between 0.65 and 11 kW and is available for 393 to 3,535 EUR. Efficiencies depend on rotation speed, fuel type, altitude effects or the generator size. Generators, however, entail disadvantages as their maintenance requirement, pollution and noise level are high. Fuel is expensive and not always available in every part of the world (Messenger and Ventre 2000).

3.4.1.2. Applications

PV systems are usually rugged and if adequate initial training is provided, simple to maintain. They can be designed for different sizes reaching from small electricity outputs of microwatts to large outputs of megawatts. PV schemes can be used in (1) off-grid SHS supplying electricity for low load applications such as lighting, (2) off-grid non-domestic PV installations for telecommunications, water pumping, vaccine refrigeration and navigational aids in places that have an urgent electricity need such as HCs and schools, (3) small grids to provide electricity to consumers or (4) centralized utility grids performing the function of a centralized power station (energypedia.info 2012). (5) Solar panels may also be used in power plants to enable reverse osmosis or (6) in satellite technology as a source of electricity to navigate (World Energy Council 2010).

3.4.1.3. Potential for solar PV systems in Uganda

In 2009, a total of 7,200 MWp of PV panels were sold worldwide and the market grew at an average of 47 % per annum within the last five years. The energy payback period of a PV panel has decreased to about 2-4 years while its lifetime has expanded to 25 years (World Energy Council 2010). Large areas in Sub-Sahara Africa including Uganda have a high potential for solar power and can produce twice the amount of high-potential countries in Central Europe (Belward et al. 2011).

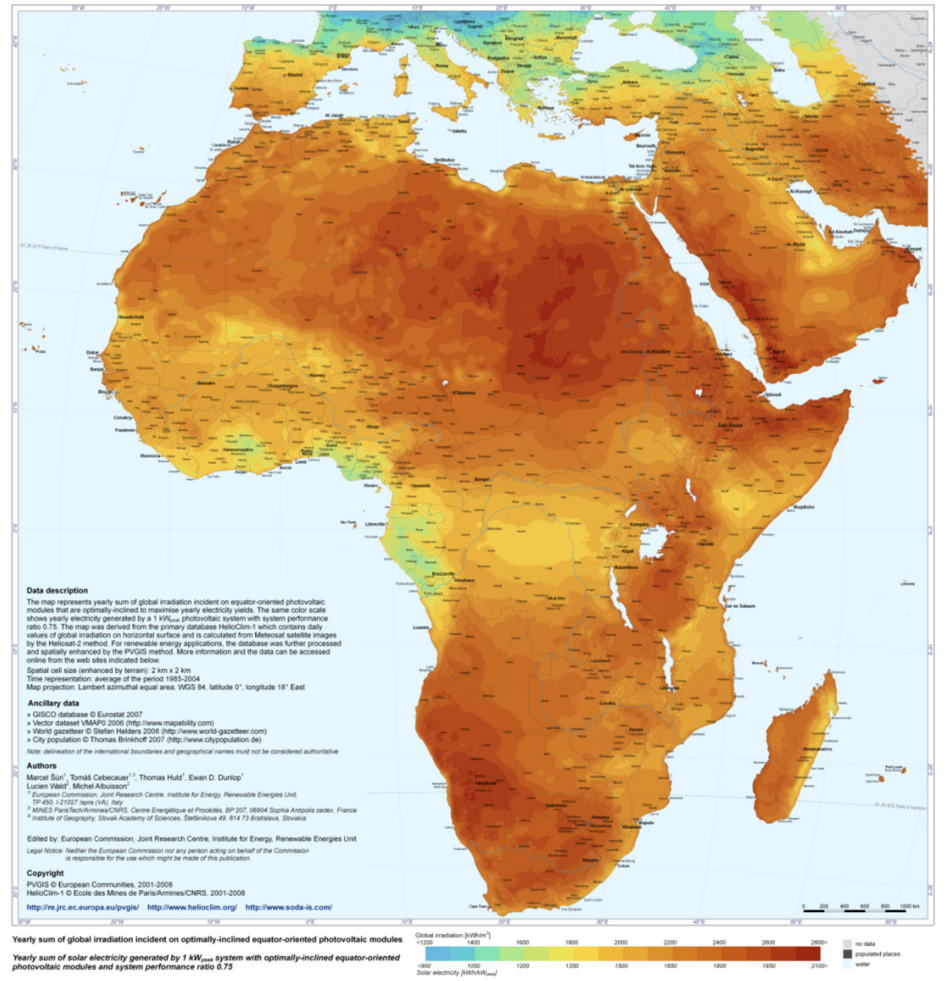

Figure 9: Solar Electricity Potential in Africa, South West Asia and the Mediterranean region (source: PVGIS 2011)

Since conditions are favourable, the Ugandan market for solar PV grows. The solar energy radiation is high and amounts to 5.1 kWh/m² per day. The usage time accounts up to 1.600 h/a. The rainy seasons from March through May and October through November are not perceived as being an obstacle for solar energy harvesting as many systems integrate batteries that can store electricity for three days (Migadde 2012). The conditions enable the application of solar technologies for basic electricity demand in MSMEs, social institutions and households. Solar water heating is especially beneficial for rural social institutions such as health centres or tourist facilities that need to provide sterilized water. However, it is also of great value in urban areas with electricity access since it is an inexpensive, reliable and environmentally friendly energy option (Wafula 2012).

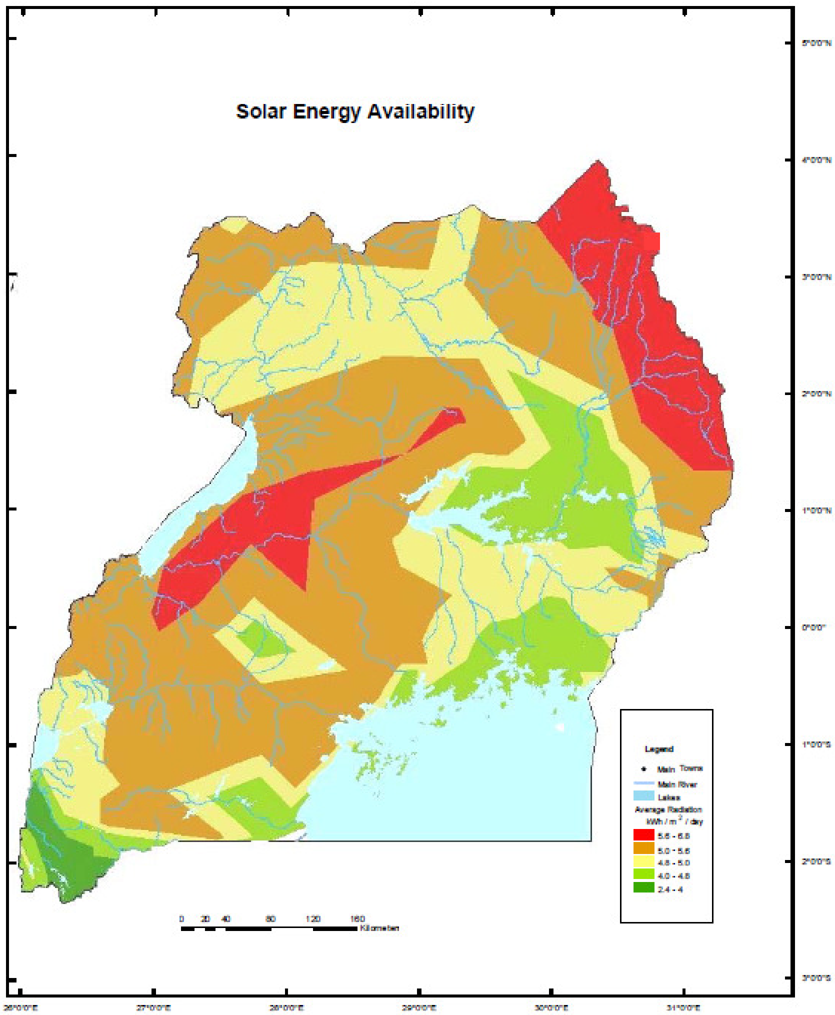

Figure 10: Solar Energy Availability in Uganda (source: MEMD 2007)

Nonetheless, tropical weather can pose a challenge to solar PV systems. The conditions may change fast. The panels are exposed to extreme conditions such as hot temperatures, high humidity and irradiance, dust, lightning overvoltage and strong winds. As a result, the modules must be fixed carefully. Often, the adequate equipment including UV-resistant cables may be not available. PV schemes are prone to failure caused by loose connections, corrosion or battery, module and controller collapse. The probability of failure, however, can be limited through good maintenance and operation (Krauter 2006).

Solar energy technology has remained largely untapped in Uganda so far. Currently, official numbers do not exist, but the ministry estimates that the share of electricity produced by PV systems lies below 1°% (Wafula 2012). The annually installed PV capacity accounts for a total of 200 kWp in households, social institutions and MSMEs (MEMD 2007). The sizes of solar home systems range between 14 Wp and 200 Wp.

The government's Rural Electrification Strategy and Plan aims to set up 700 kWp in SHS that will contribute 20 % to the energy access target of 400,000 households by 2017. Financial means for 2,000 large PV systems amounting to 2 MWp will be provided by the World Bank. During programme phase I (2002-2009), 3,800 household systems with a total capacity of 187 kWp and 1,930 institutional and 192 commercial systems with a capacity of 1,223 kWp were installed. Around 30 % of the installed systems were large systems with more than 200 Wp, while the major part provides electricity of below 30 Wp (GTZ 2009). The MEMD offered two year-loans enabling marginalized households to afford electricity for lighting. The loans were granted and monitored by village SACCOs, membership-owned groups, that offered a soft payment scheme with a low interest rate of 18 %. The programme was popular and quickly exhausted in some areas, but when batteries collapsed after four years on average, many households could not afford to replace them.

The advantages of PV systems are manifold: (1) The lumen output of electric illumination powered by pico PV is considerably higher than the output of a kerosene lamp or a candle and the monthly costs for kerosene or petroleum are avoided. (2) Lighting with the help of a PV system avoids respiratory diseases, burnings, fires and indoor air pollution due to hazardous gases. Especially CO and CO2 may cause fatal lung diseases. (3) PV systems, especially pico types, are simple to use, involve limited maintenance requirements and are thus feasible for rural areas (CREEC 2011). (4) Initial investment costs for pico PV systems are amortized within a few months depending on their size and the former kerosene or petroleum use. The upfront costs of a 14 Wp system of 200,000 UGX (63.5 EUR) will, for instance, pay off after 16 months if a family used 4 litres of kerosene for 12,000 UGX (3.8 EUR) a month (Wafula 2012; Kamese 2004; Uganda Radio Network 2012). (5) PV systems can be used for phone charging and thus avoid additional charging costs for households and institutions. (6) Pico PV systems can be simply extended by adding up further pico products. Moreover, they do not entail additional costs for maintenance, labour and installation. (7) PV systems avoid the use of dry-cells for torches. Due to the application of rechargeable batteries and if adequate disposal facilities are in place, the environmental impact of PV systems will be much smaller compared to other energy and electricity sources (CREEC 2011).

Nonetheless, PV systems entail disadvantages such as (1) high upfront costs and a lack in funding that keep many potential customers from purchasing them, even if the amortization can be quickly achieved. Households have 1.6 to 4 EUR for lighting and no buffer for savings available each month. (2) The current lifetime of solar batteries amounts to 6 to 8 years and for small systems to 1 to 1.5 years. After a battery collapse, the customer needs to replace it and spend 6.3 EUR for a small one included in a pico system. (3) In case of material failure, components may be expensive and difficult to procure. (4) Due to the absence of role models in many regions, there is often a lack of awareness for PV systems. Introducing solar systems in more social institutions including schools, prisons and health centres would entail a multiplying effect due to increased awareness and sensitization of pupils, prisoners or patients in terms of operation and maintenance (CREEC 2011). (5) Assessments by GIZ showed that half of the business sample using PV experienced problems such the replacement of bulbs, which are usually expensive (6.4 EUR) and of low quality (GIZ-PREEEP 2011c).

Solar PV systems are criticized by developing countries for being a donor driven technology, since it is does not provide enough electricity for all productive uses, but rather boosts the sales of modules in the exporting countries. The markets in developing countries have been driven by ODA. On one hand, experts argue that PV systems are applied where diesel generation would have been cheaper, while, on the other hand, oil prices have risen sharply and petroleum products are becoming unaffordable for the poor in developing countries. At the same time, prices of PV modules fell by 15-18 % resulting in a higher cost-efficiency of PV systems (Nygaard 2009). Furthermore, some system failures are caused by deficiencies in design. Critics state that donor organizations use developing countries as a test market and introduce new components without any prior adjustments to the domestic needs. People with limited technical expertise design systems, which results in low quality installations (Wafula 2012).

3.4.2. Wind

Wind generation uses the kinetic energy of wind with the help of rotors and transforms it into electricity. In the 1920s, Albert Betz found that the extractable kinetic energy is limited by the maximum wind turbine performance – “the Betz limit”, more precisely by the energy of the wind stream and it depends on the wind velocities before and after hitting the rotor. Modern wind generators transform 50 % of the airstream into electricity. The generating capacity starts at wind speeds of 2.5 m/s to 4 m/s (World Wind Energy Association 2012a).

A wind turbine consists of the tower that is between 40 and 130 m high, the foundation, three-bladed horizontal axis rotors, a nacelle that contains the machinery – the gearbox, the generator, coupling and brake – and electronic components. In areas with lower wind speeds small wind turbines that generate electricity of 300 to 10,000 W may be used (World Wind Energy 2012b).

In most regions in Uganda the wind speed is moderate and generally amounts to 1.8 to 3.2 m/s (fig. 11). Meteorological data lead to the estimation that the capacity is only sufficient to provide electricity for water pumping or MSMEs with a generator range from 2.5 to 10 kW (MEMD 2007). So far, wind has been completely untapped and its total potential has not been assessed yet. However, feasibility is currently studied and first conclusions showed that the best potential is located in Northern areas such as Karamoja, Nebbi-Gulu and Moyo (MEMD 2007; Wafula 2012).

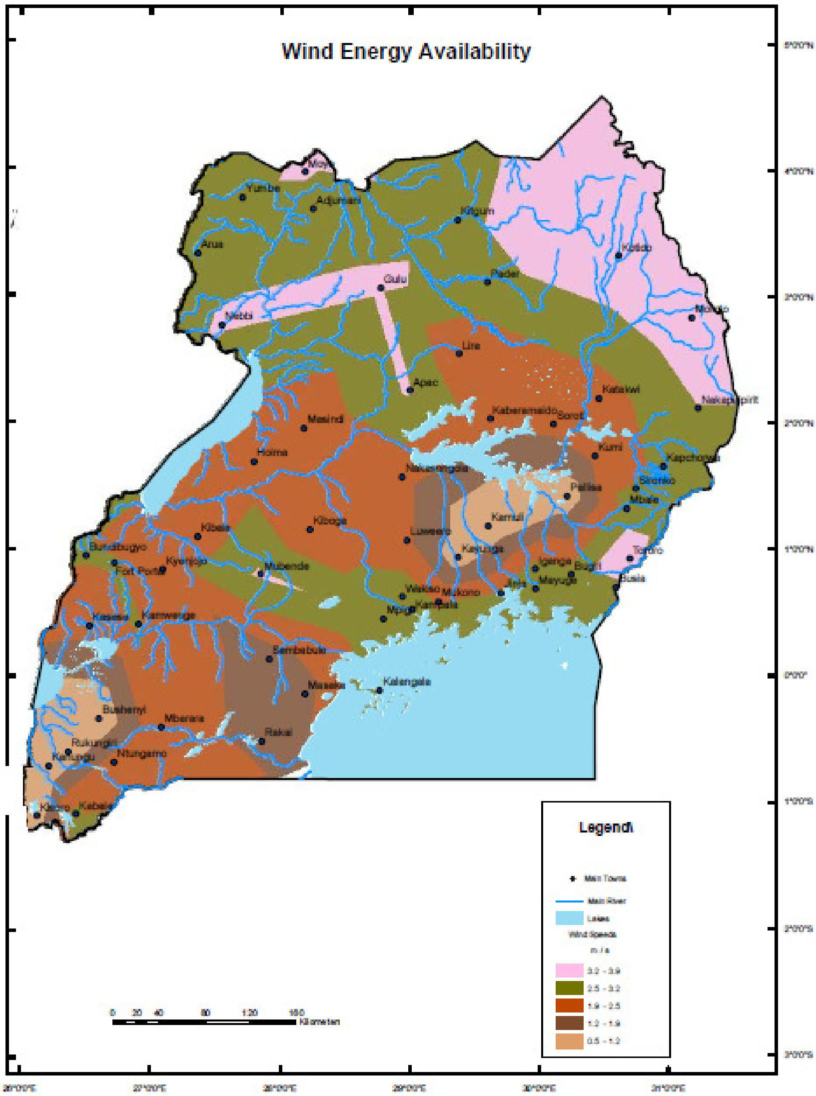

Figure 11: Wind Energy Availability in Uganda (source: MEMD 2007)

Also, an African-wide wind potential analysis (fig. 12) reveals that Uganda offers a relatively low capacity of 0-5 GWh/km². The result was calculated with the Betz formula:

$$E\ (v) = \frac{1}{2}\rho A v^3 C_p t$$

Where ρ is the air density (kg/m³), A = area swept by the rotor blades (m²), C_p = power coefficient, t = hours and v= wind speed at 100 m elevation.

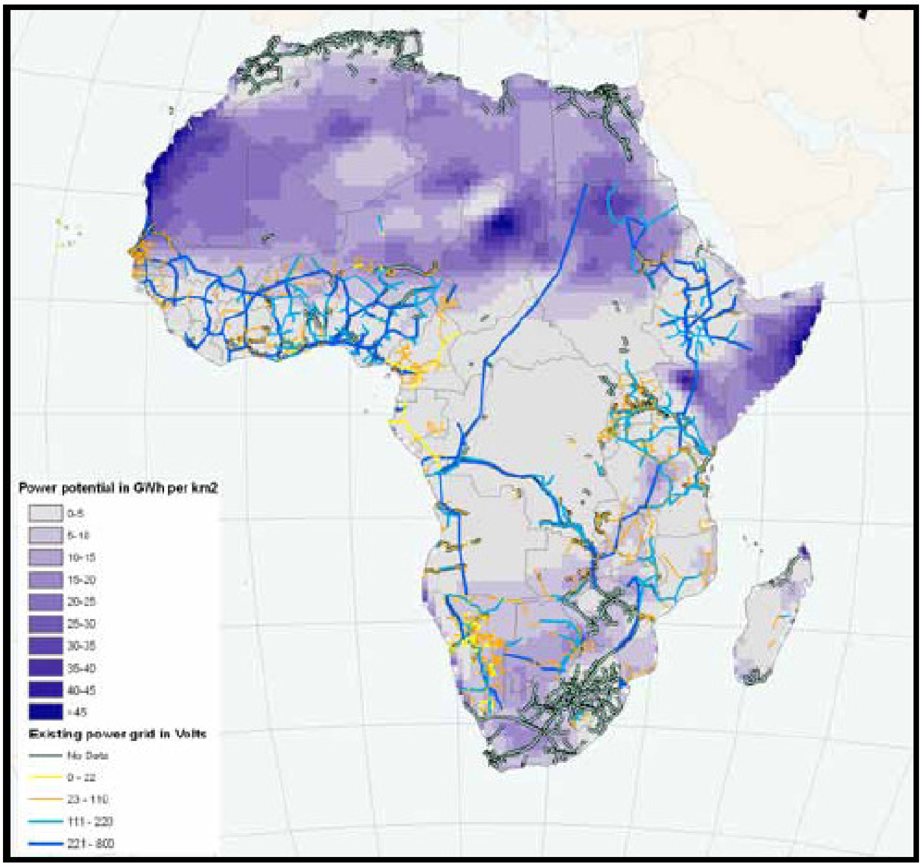

Figure 12: Potential wind power production in GWh per km² (source: Belward et al. 2011)

3.4.3. Small hydropower

Hydro-generation transforms a water flow into mechanical power that runs an electricity generator. The amount of electricity generated depends on the head and the volume flow rate and can thus be calculated with the formula (Brauner 2011):

$$P = \rho g h Q$$

Where ρ represents the water density, h the head, g gravitational acceleration and Q represents the flow rate. The total efficiency of a hydro-power scheme is the product of the hydraulic, turbine and generator efficiency and usually ranges between 60 and 80 %.

The functionality of a micro-hydro scheme is rather simple. Water, taken out from the river through a weir, flows through a settling tank, slows down and passes the penstock and forebay before it falls onto the low head turbine. When the valve is closed, water flows back to the river. Some small hydro-power schemes also involve the construction of a small canal.

Small hydro power includes mini-hydro producing up to 2 MW, micro-hydro up to 500 kW and pico-hydro up to 10 kW (Paish 2002). The schemes' costs lie between 1,960 and 3,930 EUR/kW.

Ugandan feasibility studies revealed the potential for 60 mini hydropower sites (fig. 13) accumulating to the capacity of 210 MW. Some of these are eligible to supply power for micro-grids or feed into the utility grid.

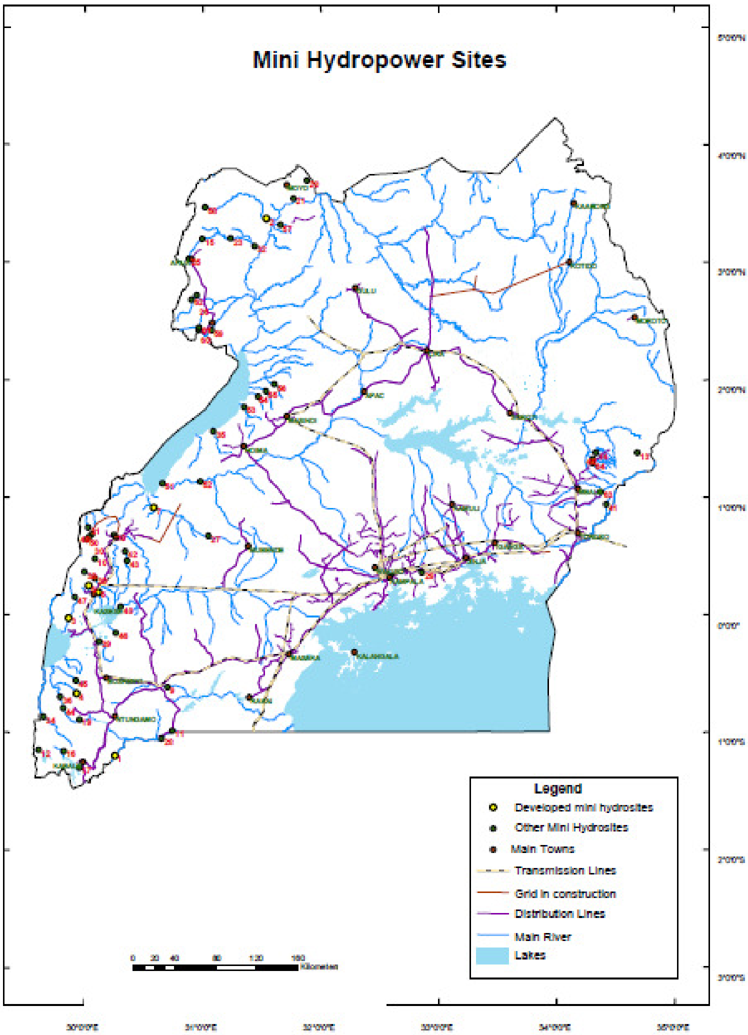

Figure 13: Existing mini hydro sites (source: MEMD 2007)

3.4.4. Biomass and biogas

Currently, three bagasse (fibrous remains from sugarcane and sorghum) co-generation plants are in operation. These are run by large sugar manufacturers and produce a total of 17 MW of which 12 MW are supplied to the grid. The rest is provided to the factories. The target for biomass electricity generation as set out in the RE Policy aims at the installation of 35 MW by 2012 and 67 MW by 2017. The technology may play a big role for distributed electricity generation since peasants are scattered in the entire country and agro-residues used for generation are available everywhere.

Biogas technologies are limited in demand. Around 50 % out of 500 existing plants are out of order. However, the potential for small household biogas systems comprises all 250,000 zero grazing households existing in Uganda (MEMD 2007; GTZ 2009).

3.5. Government policy framework

The issue of energy is a crucial or complementary part of many government plans and the policies of different ministries and institutions. First of all, it plays a major role in the Poverty Eradication Plan. The instrument repeats the government's stringent numerical aim as set out in the Rural Electrification Strategy and Plan: The republic aims to achieve a rural electrification rate of 10 % by 2012 through extending the utility grid, establishing micro-grids and introducing stand-alone systems. Another important instrument is the National Development Plan, which names an increase of electricity supply to 780 – 820 MW and a higher demand and awareness as central components for socio-economic development of Uganda. Furthermore, power losses are planned to decline from 40 % to 16 % (GIZ 2012a).

The electrification planning process of the government is mainly based on two components: (1) The Indicative Rural Electrification Master Plan concerned with on- and off-grid planning, financial and economic cost/benefit analyses and the technology selection. (2) On a district level, social institutions are selected for electrification by applying energy benefit points. The process aims at providing electricity to remote areas so that inequalities are reduced, while social welfare, education, health and income generation increase. As a result, schools and heath centres are first priority on the electrification list (GTZ 2009).

The Renewable Energy Policy 2007 describes the potential and targets in regards to RE utilisation and development. Furthermore, it sets stringent targets for their generation share.

The GoU aims at meeting the energy demand in the country. Closing the supply-demand-gap enables socio-economic development to take off. As a result, the government has built up its policy on five objectives:

a. To increase the availability of different energy sources in Uganda and develop energy potential and demand

The tasks in these terms include supply and demand management and local capacity building. Due to a broad availability of energy the countrywide needs will be fulfilled.

b. Enhancing the access to energy services in order to decrease poverty

To achieve this goal, the government aims to promote private capital and develop the market in technologies and services. The government makes use of subsidies on capital investment, optimizes business regulation, introduces differentiated tariffs in order to reflect different supply and investment costs, develops supporting tools for the consumer-side and introduces guidelines for rural groupings to facilitate their energy access. Furthermore, the government intends to develop the consumption by education on efficiency and awareness building. Finally, the financial institutions are guided in terms of financing mechanisms.

c. To optimize the energy governance and administration

The tasks of different institutions, the private sector, NGOs and communities need to be clearly coordinated. Moreover, the government targets at an improvement of regulatory framework capacity building and human resources.

d. To strengthen the role of energy in regards to economic development

The government promotes market competition to achieve efficiency, ensures energy supply, promotes investments and encourages energy trade with the neighbouring countries (GIZ 2012a). Since Uganda has been a member of the EAC customs union, it is beneficiary of the zero import duty on unsealed solar deep cycle batteries within the region (GTZ 2009).

e. To mitigate energy-caused environmental impacts

The GoU underlines the importance of a healthy environment which is a profound consideration in all energy-related decisions. As a result, the use of renewable sources and the promotion of energy-efficiency are central.

Furthermore, the REA Strategic Plan (2005/6 – 2011/12) contains five concrete energy objectives: (1) The annual connection growth of 1 percentage point in rural households shall be facilitated. (2) Priority is put on the most marginalized areas in the country. (3) A comprehensive database on Uganda's rural electrification sub-sector is established to facilitate informed decision-making. (4) The financial resource base for rural electrification is raised by an average of 31.4 million EUR annually. (5) The institutional sustainability of the REA will be improved (Rural Electrification Agency 2011).

3.6. Institutional bodies

The Republic of Uganda has identified main institutions to handle the country's energy agenda: (1) The Ministry of Energy and Mineral Development (MEMD) functions as the leading institution. Its main tasks include the creation of policies as well as their promotion, administration and evaluation. The ministry is the initiating body for energy legislation. The agenda is centralized (GIZ 2012a). Other ministries including the Ministry of Health, the Ministry of Education and Sports and the Ministry of Local Government established energy components focusing on reliable and renewable energy access of their institutions throughout the country.

(2) The Ministry of Finance, Planning and Economic Development (MOPFED) is an important actor in the energy market and is in charge of budget allocation and disbursement. The funding mechanism for the energy sector is organized by the Bank of Uganda and carried out by different lending banks. The parliament is responsible for passing these programmes.

(3) The Rural Electrification Board (REB) and Agency (REA) form the implementing body of the rural electrification strategy as set out in the Indicative Electrification Master Plan. The Agency monitors public funds that subsidize rural electrification projects.

(4) The Electricity Regulatory Authority (ERA) established by the Electricity Act 1999 controls the generation, transmission, distribution and sale of electricity in Uganda by

issuing licences. Furthermore, it is in charge of creating tariffs, charges and rates (GIZ 2012a).

(5) The Directorate of Water Development issues permits on water extraction for hydro power plants. The local governments accomplish approvals, planning, implementation and monitoring (GTZ 2009).

(6) The National Environment Management Authority (NEMA) carries out environmental impact assessments and permits projects.

(7) Finally, the Uganda National Bureau of Standards (UNBS) is responsible for the set-up and enforcement of standards in terms of industry, consumer protection and trade.

3.7. Donor initiatives

In order to promote energy access on a renewable source base, donors focus on several essential components such as (1) demand development in social facilities, homes and enterprises, (2) supply development targeted at electric service providers, investors and NGOs, (3) policy, legal and regulatory framework advice, (4) set-up of appropriate institutional frameworks and (5) incentive schemes (Shagir 2006).

(1) The World Bank supports Uganda by granting loans to finance the Energy for Rural Transformation Plan (ERT) with 84 million USD (66 million EUR), the Uganda Power Sector Development Project with 300 million USD (235 million EUR) and the Private Power Generation Project (Bujagali) with 115 million USD (90 million EUR) (GIZ 2012a). ERT is the main programme aiming to develop the renewable energy market. Therefore, it addresses multiple sectors to decrease poverty and achieve development. The tasks of the programme are twofold: On one hand, it intends to improve the energy access for rural households. On the other hand, it focuses on supplying energy to rural enterprises (GTZ 2009).

(2) One of the main pillars of the GIZ' support to Uganda is the energy sector. Energy projects are carried out by Promotion of Renewable Energy and Energy Efficiency Programme (PREEEP) on behalf of the German Federal Ministry for Economic Cooperation and Development and the co-donors, the Dutch Government and the ACP-EU Energy facility. PREEEP supports the lead executing agency, the Ministry of Energy and Mineral Development in developing decentralised energy and sub-sector strategies as well as in

promoting energy access and efficiency. The programme cooperates with the government, NGOs, private companies as well as training and research institutions. Its tasks include energy policy development, enhancing energy efficiency and improving energy access by introducing PV systems, micro-hydro power and improved energy efficient stoves. From 2007 to mid-2011 75 social institutions have been provided with PV systems and more than 600,000 cooking stoves have been distributed.

(3) Further donors addressing the country's energy sector include Norway with a focus on a large hydro power projects and Japan involved in grid extension. Additionally, the ADB and the European Union are involved in development cooperation (GTZ 2009).

3.8. Electricity market conditions in Uganda

3.8.1. Markets and players

The Uganda Electricity Transmission Company Ltd. (UETCL), a public company, is the only supplier and buyer of power for the national utility grid. Therefore, it is also the only buyer of independently generated power and it imports electricity from neighbouring countries. It issues standardized tariffs for renewable energy regeneration up to 20 MW. These tariffs are based on the avoided cost principle (chapter 3.8.3). UETCL has been created due to the dissolution of Uganda's national utility monopoly in 2003.

Ueme Ltd. is the biggest electricity distribution company for 33 kV and below in Uganda. Further distribution actors supply several regions with the help of mini-grids. For instance, WENRECo, an off-grid generation and distribution company, is located in West Nile. In total, the current length of transmission and distribution lines is 14,312 km (GTZ 2009; GIZ 2012a).

The solar market in Sub-Sahara Africa has taken advantage of the decreasing global component prices. As they declined, an upward sales trend could be observed in Africa. Nevertheless, upfront costs are still too high for many marginalized households to be overcome and prices will have to decline further (Moner-Girona et al. 2006). The costs of solar systems lie at 12.5 EUR/Wp on average in Uganda. This includes already the government subsidy financed by the World Bank and leads to a total system price of 370 to 520 EUR for a 50 Wp SHS (GTZ 2009; GTZ 2010), while the GNI per capita amounted to 500 USD (377 EUR) in 2010 (World Bank 2012). The African system price is twice as high as the Asian price. Market development is crucial to achieve a high distribution of RE in

Uganda. As the prices are high compared to other parts of the world, local production may be one of the solutions to the problem. Costs for modules or batteries could be drastically reduced (Moner-Girona et al. 2006). Furthermore, jobs would be created through starting manufacturing, marketing, packaging, and recycling (TERI 2010). The MEMD promotes engineering courses at technical institutes. On the long-run the technical know-how shall be increased.

The number of solar businesses, NGOs and institutions promoting the market will grow in the future. Regarding to a market analysis by GIZ, an estimated share of 60 % of the households could afford to acquire micro-solar systems of 2 to 20 Wp. The costs of such systems are usually amortised within 6 to 10 months (GTZ 2010; CREEC 2011). Today, around 25 companies are active in the field of solar PV. So far, it has been difficult for the providers to create markets in the rural areas (GIZ 2012a). However, some bigger ones such as Barefoot Power develop local retailing and reparation networks and enhance the rural accessibility and affordability of purchasing and maintenance (CREEC 2011). A part of the solar companies is united in an association, whose members have signed an initial Code of Ethics. The government's strategy aims to introduce more transparency to the national solar market by creating list prices to give people confidence in the technology and its economic aspects (Wafula 2012).

3.8.2. Consumer tariff setting

The electricity tariff is charged for electricity consumption per kWh in domestic, commercial, medium and large industry applications as well as for street lighting. Additionally, a monthly fee per customer is levied. It covers costs such as metering and meter services, customer information, billing and service (ERA 2012a; ERA 2006). The charges are listed in the table below:

Table 2: Average total energy tariff per kWh and consumer group 2012 (ERA 2012a)

Consumer group	Unit cost per kWh UGX (EUR as of 22/04/2012)	Fixed monthly fees UGX (EUR)
Domestic	524.5 (0.16)	3,360 (1.02)
Commercial	487.6 (0.15)	3,360 (1.02)
Medium industry	458.9 (0.14)	22,400 (6.79)
Large industry	312.8 (0.09)	70,000 (21.21)
Street Lights	488.7 (0.15)	-

In comparison to the Ugandan tariffs, the Austrian distributor Wien Energie charges domestic consumers a gross unit price including the grid usage fee of 0.1694 EUR (Optima). The basic fee accounts for 44 EUR per annum (Wien Energie 2012).

In 2012, Ugandan unit prices rose by 36 % to 69 % depending upon the consumer group in comparison to 2011. The price increases were caused by the removal of government subsidies to distributors and generators that had amounted to 396 billion UGX (121.5 million EUR) per annum (Wesonga 2012). Some experts argued that the subsidies only helped a small part of the population, mainly the upper and middle income classes. This belief was based on the fact that only higher income households could afford the connection to the utility grid. However, the subsidy removal will hamper the development of the Ugandan economy since companies that use Ugandan raw materials and intend to process them in-situ cannot compete any longer with importing companies procuring from neighbouring countries such as Kenya, where power is cheaper. Moreover, the poor population is endangered to become even poorer as maize milling becomes more expensive. Some small scale companies might even switch back to diesel generators, which may not only lead to a higher alimentation price, but also to environmental problems (Byekwaso 2012).

3.8.3. Feed-in tariffs

Uganda has introduced RE feed-in tariffs in 2009. In the second price period (2011-2014), tariffs for hydropower projects vary for sizes between 1 and 8 MW. The government has introduced a cap per technology and year. Owners of installations exceeding the caps negotiate separate contracts with the operator. Tariffs are based on investment estimations and assumptions about each technology’s capacity to influence generation costs. They are funded through carbon credits, official development aid and private capital (GIZ 2012b).

Table 3: RE Feed in Tariffs and Maximum Technology Capacity Limits (2011-2014) (source: ERA 2011)

Technology	Tariff (US$)/kWh	O&M %age	Cummulative Capacity Limits (MW)				Payment Period (Years)
			2011	2012	2013	2014	
Hydro (9 ><= 20 MW)	0.073	7.61%	45 MW	90 MW	135 MW	180 MW	20
Hydro (1 ><= 8 MW)	Linear tariff	7.24%	15 MW	30 MW	60 MW	90 MW	20
Hydro (500kW ><= 1 MW)	0.109	7.08%	1 MW	1.5 MW	2 MW	5 MW	20
Bagasse	0.081	22.65%	20 MW	50 MW	75 MW	100 MW	20
Biomass	0.103	16.23%	10 MW	20 MW	30 MW	50 MW	20
Biogas	0.115	19.23%	10 MW	20 MW	30 MW	50 MW	20
Landfill gas	0.089	19.71%	10 MW	20 MW	30 MW	50 MW	20
Geothermal	0.077	4.29%	10MW	30MW	50MW	75 MW	20
Solar PV	0.362	5.03%	2 MW	3 MW	5 MW	7.5 MW	20
Wind	0.124	6.34%	50 MW	75 MW	100 MW	150 MW	20

4. Case study – rural electrification of social institutions in Arua district

4.1. Situation in Arua district

Arua district is located in the sub-region West Nile in Northern Uganda. Arua town is the administrative and commercial capital of the district and lies 520 km away from Kampala. 565,300 (2010 est.) inhabitants live in the district, 59,400 of these stay in Arua town (2011 est.). The district comprises 5 counties (Arua Municipality, Ayivu, Vuraa, Madi-Okollo and Terego), 27 sub-counties, 119 parishes and 939 villages (Arua District Local Government 2010).

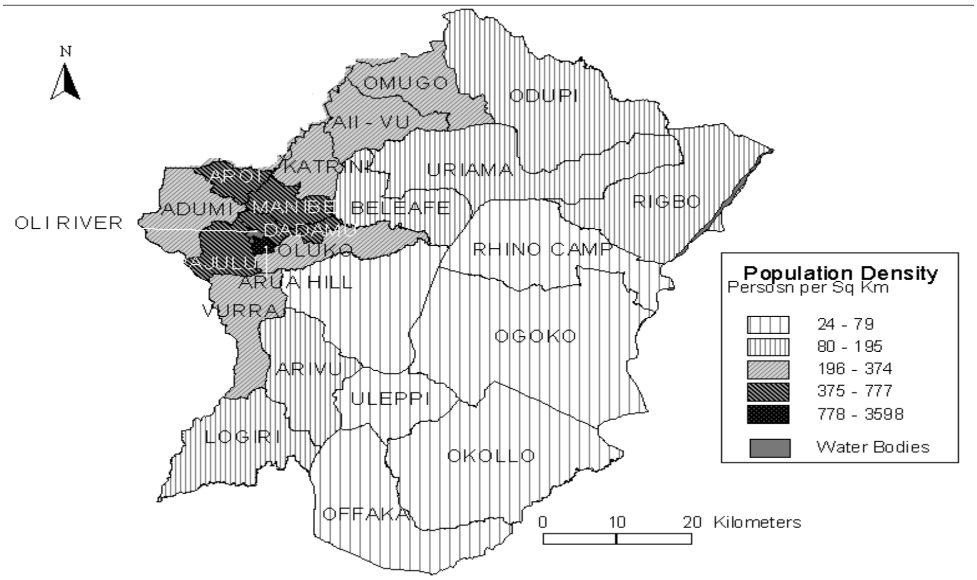

Figure 14: Map of Arua district (source: District Planning Unit Arua 2010)

The district borders the Democratic Republic of the Congo and South Sudan (Arua District Local Government 2010). The local economy is largely based on cross-border trade. 87 % of the district's total area of 4,274.13 km² is arable (Lübbert 2010). The area has a bi-modal rainfall pattern with light rains between April and October and heavier rainfall in August and September (Arua District Local Government 2010).

4.1.1. People and population

The Lugbara are the biggest ethnic group in the district. Further ones include Kakwa, Madi in the South and Alur and Lendu in the West. From 1991 to 2002, Arua's population grew by 3.3 % per annum. If this trend continues, the population will double by 2030. In 2002, 101,650 households with a mean household size of 5.5 people were counted in Arua district. The population becomes increasingly younger. 56 % of inhabitants are under 18 years, half of these are even under 14 years old. The high population growth, based on high fertility rates of seven children per woman, is putting pressure on education, health, energy and water supply. The population density of the District has increased overtime from 95 inhabitants/km2 in 1980, to 118 in 1991 and 180 inhabitants/km2 in 2002 (Lübbert 2010).

4.1.2. Economy

The population of Arua district relies to 80 % on agriculture. The activity mainly takes place on smallholdings of 2 acres average. Only 0.5 % of the population is engaged in commercial agriculture. The economy relies on both food and cash crops. Food crops harvested include cassava, groundnuts, millet, beans, simsim and maize. The main cash crop and source of livelihood of the population in the highlands is tobacco. The cultivation of cotton has been given up due to marketing problems. In the South, a small proportion of coffee is grown.

Another 9 % of the population rely on formal employment, 3.8 % and 0.7 % on petty and formal trade respectively. The remaining proportion relies on family support and other activities (Arua District Local Government 2010).

4.1.3. Development challenges and bottlenecks

Several issues pose challenges to the development plans and strategies of the district. These include (Arua Municipality 2010; Arua District Local Government 2010; CREEC 2011):

- HIV/AIDS: Due to a lack in reporting mechanisms, reliable statistics concerning the rates of HIV/AIDS do not exist. However, it is common knowledge that the infection rate is high. Unlike in other regions, the rate did not experience a downward trend.
- Poverty: Over half of the district's population lives below the poverty line. 90 % of inhabitants of Arua town earn 3,000 to 5,000 UGX (0.96 to 1.6 EUR) per day, while a meal including meat is about 2,500 to 3,000 UGX (0.8 to 0.96 EUR). Since most of the inhabitants depend on agriculture, people are particularly dependent on soil conditions, which are degraded due to poor farming, deforestation and waste disposal problems.
- Climate change: Weather events such as drought, flood and hailstorms have been occurring frequently within the last years. Additionally, the district is vulnerable to climate change.
- Deforestation: 99 % of households depend on wood fuel for cooking. Therefore, 40 to 60 % of gazetted forest reserves have been cut. Inhabitants spend more time on collecting wood fuel and costs for cooking grow.

4.1.4. Energy

Inhabitants of Arua mainly depend on petroleum and biomass as energy sources.

Petroleum products

Kerosene, diesel and petrol are used for transportation, lighting and power generation. As a result, fuel prices have a great impact on daily life, socio-economic development and poverty. There are some initiatives to change the usage of petroleum, however alternative forms of lighting still have problems to compete with petroleum products.

Biomass energy

Biomass is the major source used for cooking and process heat. The population is involved in all steps of the value chain: production, transportation and conversion. Particularly production and conversion entails prospects for improving quality of life for many inhabitants – however, only when sustainable methods and pricing schemes are used. Proper methods limit emissions, boost local revenues, public health and improve the work load of women. According to the district administration, emphasis is put on planting trees and the distribution of efficient cooking stoves (Arua District Local Government 2010).

Electricity in Arua district

The district administration points out the strong correlation between the amount of electricity used and the development status of the area. Reliable supply would raise the living standard of the population drastically. Improvements of power supply, grid extension and transmission are thus of high priority.

Uganda's energy sector is still very centralized. Arua and two further districts are engaged in pilot decentralization projects. As a result, a District Energy Office has been installed and energy matters are handled in a concentrated way (Arua District Local Government 2010).

WENRECo, the West Nile Rural Electrification Company, a subsidy of the Aga Khan Fund for Economic Development, provides parts of Arua town and the neighbouring Nebbi with 18-hour electricity a day. For this purpose a 1.5 MW heavy fuel oil plant has been constructed and prudent load management is applied. The company is involved in the planning of the 3.5 MW Nyagak Power Station that has been commissioned in 2006. The project additionally includes the set-up of a 33 kV line from Nebbi to Arua town.

Current tariffs amount to 367 UGX/kWh (0.12 EUR/kWh) for domestic and 421 UGX/kWh (0.13 EUR/kWh) for commercial and industrial use (ERA 2012b). Due to the high prices, only a few households are connected to the utility grid (Nordic Folkecenter for Renewable Energy 2011). Villages beyond the borders of the district town are not supplied. There, only a few households are able to afford diesel generators or solar PV systems.

4.1.5. Education and Health

Education

In the Northern region, the primary school enrolment rates are high since education is understood as post-conflict transition component. However, the quality of education in the North is widely low and drop-out rates are high. Many schools can still be found under trees and teacher accommodation is often insufficient resulting in absenteeism.

The completion of primary school entails the same income and employment chances as not attending school at all. Therefore, secondary education becomes increasingly important to escape poverty (Bird and Higgins 2009). Additionally, students from the neighbouring DRC and Southern Sudan are approaching Arua to go to school. As a result, branches of five universities, two teacher's colleges and one nursing school have settled in the district.

Currently, 162,200 students are enrolled in schools and 2,470 teachers are employed. The 70 secondary schools counted 18,811 students in the school year 2010-2011. 27 secondary schools are full grant aided government schools and 43 are community-owned. 19 technical schools offer practice skill courses in carpentry and joinery, car mechanics, tailoring and cutting. These schools can be attended after concluding the final senior 4 year at secondary school. Moreover, 18 vocational training institutes are offering basic skills education in agriculture and handicrafts to school drop-outs.

The education sector in Arua district has to face several severe constraints: the classroom/pupil ratio is high (1:140) as well as the pupil/teacher ratio (1:66). Furthermore, the drop-out rates are alarming. Many head teachers do not comply with the data submission deadlines. This might be due to the fact that photocopiers, generators and computers are not existent or break down (Arua District Information Portal 2012; Arua District Local Government 2010).

Health

The health sector of Arua district includes several clusters. Health promotion, disease prevention and community health initiatives play a big role. Emphasis is put on maternal and child health, prevention of child to mother transmission of HIV, family planning services, nutrition promotion, growth monitoring and adolescent and reproductive health services. The estimated number of deliveries accounts for 34,915 per annum. However, the estimated infant population is 29,084, which suggests a high infant mortality.

The district counts three hospitals with full service, four HC IV with a comprehensive package, 31 HC III with a basic package, 27 HC II with a limited package and 600 HC I offering only community mobilization and reporting on maternal deaths.

Service utilization is low. However, health facility deliveries have increased to 40 % within the last three years. Furthermore, the human resource situation is difficult in many HCs. The current staffing norm is only fulfilled by 54 %. A further challenge is the inadequate staff accommodation. Only 25 % of medical workers and 60 % of midwives are accommodated in the health centres. As a result, a big part of staff is not available for emergencies during night hours. Some other challenges include the low involvement and participation of local leaders in health issues, shortages in commodities, equipment, funding, community awareness and a lack of female involvement (Arua District Local Government 2010).

4.2. Project description

The electrification of social institutions is one of the main tasks of GIZ-PREEEP's work. From 2007 to mid-2011 the project has provided 75 institutions with solar-PV systems (GIZ-PREEEP 2011b). It chooses to electrify schools, HCs, orphanages, sub-county headquarters and vocational institutes that have according to the REA's plans little prospect of being connected to the utility grid within the upcoming 10 years. The criteria for selecting an institution include a great expected benefit, for instance, in boarding schools that are reliant on lighting or schools that run computer labs (GIZ-PREEEP 2010; GIZ-PREEEP 2011a). As the beneficiaries have a limited budget, the project subsidizes the procurement with 80% of the installation costs. Schools and sub-county headquarters provide their 20 % contribution on their own, whereas for HCs the district authorities assist in terms of the budget. Following the installation, the institution is responsible for operation and maintenance including replacing system components such as batteries (GIZ-PREEEP 2011b; Migadde 2012).

4.2.1. Beneficiary applications and project proceedings

When the project was started in 2006/07, PREEEP contacted the district Chief Administrative, District Education and District Health Officers in order to obtain a list of eligible schools, HCs and SC-HQs as well as the permission to contact and discuss the electrification proposal with them. After the word had spread, institutions contacted PREEEP proactively asking for participation in the project. Nevertheless, upon the first system designs, some potential beneficiaries bailed out as they could not afford the upfront costs (Migadde 2012)

The project process is standardized: After selecting an institution, its site is surveyed. During this phase, electricity requirements are assessed and a sketch of the premises is drawn. Then, the costs are presented to the institutions and district authorities. If they exceed the budget, the institution selects priority buildings and confines the project. A Memorandum of Understanding agreed between the institution/district and PREEEP is signed. It includes the description of responsibilities, amounts of money contributed by each partner and payment schedules. An exceeding of the schedule renders the MoU null and void.

Upon reception of the institution's contribution, the procurement phase is started. Since solar panels are usually expensive in Uganda, GIZ procures certain items in bulk through the headquarters. The remaining components are purchased in Uganda. The selection of solar companies conducting the installations is managed with the help of tenders calling for the installation, user trainings and energy efficient equipment such as DC fridges, computers from Inveneo and printers. In first place, PREEEP put emphasis on selecting local suppliers. However, limited response, capacity and bidding were observed. Thus, Kampala-based companies were selected.

After installation, PREEEP conducts follow-up visits, checks on the technical performance of the system and conducts impact assessments. PREEEP advises the institutions on how to manage system problems that might come up after expiry of the warranty (GIZ-PREEEP 2011b; Migadde 2012).

4.2.2. Technical project design and costs involved

A needs assessment is conducted to reveal the demand for lighting, phone charging, research equipment, eventually refrigeration, PCs and printers. If staff houses or dormitories are included, the system should also provide for running medium sized radios and additional lighting (GIZ-PREEEP 2011a).

The average size of PV systems in social institutions accounts for 630 Wp. The range lies between 160 Wp and 2,580 Wp. The majority of installed systems are AC systems, because DC systems have proven to be less cost-effective due to the vulnerability and availability of adequate bulbs and adapters. Moreover, DC systems are more prone to total black-outs in case if devices with high energy consumption such as kettles were plugged in (Migadde 2012; Harsdorff and Bamanyaki 2009). PREEEP uses mainly the following components:

Table 4: Components regularly used in PREEEP projects and their prices (Migadde 2012)

Component	Procurement price	
Inverters	**In UGX**	**In EUR**
300 W	600,000	190,74
600 W	1,000,000	317,90
1000 W	1,800,000	572,23
1500 W	2,500,000	794,77
Regulators		
10 A	200,000	63,58
15 A	250,000	79,47
20 A	300,000	95,37
30 A	400,000	127,16
Batteries		
100 Ah	750,000	238,43
200 Ah	1,400,000	445,07
Panels	**(10,000 per Wp)**	
85 Wp	850,000	270,22

The system set-up is usually standardized and consists of similar or same components adding up to different sizes. The 85 Wp mono-crystalline panels are procured in bulk and shipped in from Germany. Their price amounts to 2.7 EUR/Wp. The further components are procured from Ugandan companies, which buy them from Germany, the Netherlands and China (Migadde 2012). The total average cost for equipment and installation accounts for 11 EUR/Wp (Harsdorff and Bamanyaki 2009).

A large system such as in Okufura SS, which supplies 1,350 Wp for five buildings, accounts for a total cost of 44,438,800 UGX (14.400 EUR). A smaller system such as at African Child Care providing electricity for two buildings accounts for an initial installation cost of 14,820,800 UGX (4,800 EUR).

The lifetimes of the system components installed are estimated to be 5-7 years for batteries, 20-25 years for modules, 7-10 years for regulators and 10 years for inverters. Most of the systems have been installed in 2009 to 2011 and so far only a few technical failures occurred due to, for instance, technical faults or invading cockroaches (Migadde 2012).

4.3. Impact Assessment

Within the upcoming years, PREEEP plans to electrify 36 schools, 24 health centres and 20 sub-county headquarters in Arua district (Migadde 2012). In order to gain insights in benefits and problems related to the project, field assessments are conducted regularly. This survey was carried out qualitatively and may serve as starting point for a quantitative assessment and to derive implications for upcoming project phases.

4.3.1. Sample of institutions

During the two weeks of field assessment in Northern Uganda four SC-HQs, four HCs and seven schools equipped with solar PV were visited. The PV systems are all located in Arua district and were installed between 2008 and 2011. Additionally, three HCs and one school in the bordering Moyo district, one school in preparation to receive a PV system from PREEEP and two health centres having received systems from the ERT component of the Ministry of Health in cooperation with the World Bank were visited to elaborate some differences. The guiding questionnaires (to be found in Annex I) elaborated on the prior situation, the installation process and the situation after installation. They were adopted for each type of institution.

Whenever it was possible, the visits were announced before and interview dates were set. In all of the institutions, the interviewees were present and ready to answer the questions. However, not always, especially in the HCs, the in-charge was available. Language problems only occurred in four of the HCs. At one school the director took up his post after the installation of the PV system and thus could not answer questions about the prior situation. One of the schools visited, Ocea Vocational Training Institute, had been closed in 2011. According to the guard, the solar PV systems in staff houses and the classroom compounds were still installed and working.

4.3.2. The situation before

The main part of the schools had no access to electricity at all. Students had to bring their own lamps for the evening reading hours. Some students, who could afford to bring the reading equipment, shared their lamps with others.

Figure 15: Reading time at Okufura SS before solar PV was installed

Petroleum fuel contained in the lamps affected the health of the eyes of the children and caused breathing diseases due to harming CO and CO2 emissions. A kerosene lamp can only provide 1 to 6 lux and is thus inappropriate for reading, which actually would require 200 to 500 lux (Mills 2003). Moreover, entailing the risk of causing fires, the lamps posed danger to the school buildings. In HCs, medical staff used halogen lamps for nocturnal emergencies. In some cases, the patients brought them themselves.

All of the institutions suffered from a difficult security situation due to the absence of outdoor security lights. In-charges were afraid of theft as well as unauthorized people and wild animals, such as snakes, approaching.

Due to the absence of modern communication equipment and possibilities to charge mobile phones, working conditions were difficult for staff of the institutions. To copy or print bulky documents or to charge phones, employees had to travel to the next town or trading centre resulting in increased absenteeism.

Two schools and three SC-HQs used fuel generators for illumination and providing electricity for electronic equipment, which was sometimes damaged due to charge overloads. However, fuel was not always available and affordable.

4.3.3. Contribution fee

Raising the 20 % contribution to the installation costs was difficult especially at schools. Most of the schools dealt with the problem by raising a solar contribution fee from the parents. It mostly accounted for a sum between 1,000 UGX (0.32 EUR) per term and child and 20,000 UGX (6.2 EUR) as a onetime payment. Additionally, some teachers abstained from a welfare payment and one school could save some money on wood fuel due to the prior installation of an efficient cooking stove. A technical institute sold furniture built by the students. The SC-HQs raised the contribution from their annual budget. The HCs received it from the district.

4.3.4. Application of energy and electricity

All of the institutions use the electricity for indoor, outdoor lighting and phone charging. Each of the schools and SC-HQs runs PCs and a printer procured through the PREEEP project. Some of them also use radios or TVs.

The compound buildings provided with electricity include classroom, dormitory and partly staff blocks at schools, office buildings at SC-HQs and maternity wards, patient treatment rooms and staff houses at HCs.

Figure 16: Ajia SC-HQ

All of the institutions additionally use other sources of energy, for instance, wood fuel for cooking or boiling instruments in the HCs. Some of the institutions acquired efficient cooking stoves that save around up to two thirds of wood. In compound buildings that are not connected to the solar PV system kerosene lamps are still in use. HCs additionally need gas to run vaccine refrigerators. Gas is not always available in sufficient amounts. In case of a shortage, HCs take the vaccines to the neighbouring institution to keep them cool. Some HCs indicated that the use of gas for vaccine refrigeration is determined by law. The common wish is, however, to also run refrigerators on solar PV soon.

4.3.5. Benefits

Direct observable benefits at schools included an increase in boarding school applications. Total enrolment in the schools, which counted between 200 and 600 students before, rose by 50 to 120 students from the sub-county and beyond. Sending their children to a boarding school with solar PV available enables the parents to save money and spend it on other things than kerosene or petroleum. The increased student enrolment caused institution expansions such as the construction of additional dormitories.

The reading time and quality enhanced. Some institutions extended the evening reading time by an hour and students do not have to use fuel lamps any longer. Some day scholars return to the schools to read after having their supper at home. Some teachers give extra lessons during evening hours. Due to the improved quality of preparation for exams, the students' performance at the nationwide senior exams increased. This led to a better image of the schools in the eyes of the District Education Office and the Ministry of Education and Sports. However, this assessment result demands further elaboration, because the greatest improvements were observed in the schools that now count more students.

Figure 17: Reading time at Okufura SS with solar PV installed

The teachers' working conditions have improved. Teachers can make use of lights, PCs and printers for their preparation and administrative tasks. Nevertheless, at many schools, the PCs cannot be used for lesson preparation or exam typing due to a lack of PC skills and the low number of available devices.

Figure 18: Okufura SS at night

At Omugo Technical Institute many students abstain from visiting the nearby trading centre during evenings since a TV-set has been acquired and students can watch sports and TV shows at the school. As a result, drop-out rates are also declining.

Some schools and SC-HQs offer services including printing and phone charging to the community members. For some of them the institutions charge fees, others are provided for free.

Figure 19: St. Theresa SS prints for the community

At the SC-HQs the efficient use of time for planning, documentation and reporting has increased. Reports are delivered on time. Targets as set out in the strategic development plans have become easier to achieve.

The communities use the halls of the SC-HQs for evening meetings or cultural gatherings. Security lights outside of the office compound create a nice atmosphere for youth parties. However, the additional uses of the facilities do not entail economic benefits as the institutions do not charge the parish for any of these services.

At HCs the staff especially benefits from better working conditions during night hours. Emergencies and deliveries are much easier to handle since the wards can be illuminated adequately. The treatment quality and the image of the institutions have increased. The staff members can easily finish paper work during the evening hours. As a result, reports are delivered on time. Due to illumination, the staff can use the evenings for continuous medical education and professional discussions.

In most of the visited HCs the radio call for emergencies does not work, because of empty batteries. Since the staff members can charge their phones at the HC now, they can use them to call the ambulance. Moreover, the staff personally saves money on kerosene and phone charging at trading centres. Some HCs had used fuel generators before. Where printers are available, absenteeism of staff members has decreased. Printing and copying of small documents in town has become obsolete and money formerly provided for it can be saved.

Due to the 20 % contribution to the installation costs, ownership of students and staff has developed. The beneficiaries look carefully after the systems and no case of theft or vandalism has occurred. Moreover, the motivation amongst the staff rose. Its work conditions have improved and the welfare at the staff quarters has increased tremendously. With the lighting system in place, staff members can play with their children during evening hours.

4.3.6. Disadvantages

On one hand, the enrolment figures have increased in many schools. On the other hand, the number of teachers remained the same. Omugo Technical, for instance, has 200 students more than before, but did not employ additional teachers. As a result, the pupil/teacher ratio has increased in all schools but one that has employed seven new teachers.

Due to extra-lessons during evening hours, the day scholars are inequitably treated. As they return home in the late afternoon, many cannot participate in these lessons. Therefore, a difference between day and boarding scholars can be observed when it comes to performance in exams. The best grades in the last senior exams were all achieved by boarders.

Some of the HCs receive more patients since the systems have been installed. People from neighbouring districts and South Sudan decide to go to the HCs providing electricity to deliveries or disease treatment. More night emergencies can be treated and the patients do no longer have to bring kerosene lamps.

4.3.7. Technology-related problems

Some of the technological problems were experienced at several institutions. They are listed and explained below:

- Bulbs

A commonly mentioned problem was the frequent replacement necessity of bulbs, especially during the dry season. The procurement of the bulbs is perceived as challenge by some in-charges, because adequate quality is both expensive and sometimes not available in the district. This holds also true for the procurement of other PV components. Some of the HCs lack in financial means to replace broken bulbs.

- Batteries

At one HC staff quarter, the battery bank broke down. There is no budget to replace it and the staff members have to buy paraffin to light their rooms. At one of HCs provided with the system in 2008, the OPD system has been out of order since August 2011. The batteries seem to have collapsed as well.

- PCs and printers

Several institutions experienced problems with the printers. Some had to be replaced after some months. Some in-charges noticed that the printer cartridge runs out fast.

- Under sizing

Some institutions named the low capacity of the system as a problem. Some buildings were left without electricity. One school also had problems with a too small power regulator and the reading room is equipped with too few lamps. Especially if staff houses are not connected, the employees become discouraged. Moreover, some of them plan to use the money saved for paraffin on acquiring entertainment equipment such as VCRs. This might lead to a system overuse in future.

- Blackouts and charge drops

At several institutions electricity blacked out as a result of overload. This usually happened during phases of long working hours, or because rats bit cables. At one school, the charge dropped to 20 % in a compound. After the holidays, the charge went up again and the system has been working very well since then.

4.3.8. Sustainability of operation and maintenance

The in-charges act as focal point for all concerns related to the PV system. Usually, support staff, physics teachers or cleaners are responsible for the maintenance of indoor components and panels. They were usually trained when the system was installed. The panels are cleaned in different periods between every two weeks and once a year. However, especially during dry season a lot of dust settles on them. In many cases, the panels would require more frequent cleaning. However, problems occur where no ladders are available. Some institutions refuse to buy some in order to avoid theft of the arrays (Migadde 2012).

The brochure (fig. 20) produced and distributed by GIZ should help the beneficiary to keep in mind how operation and maintenance should be conducted.

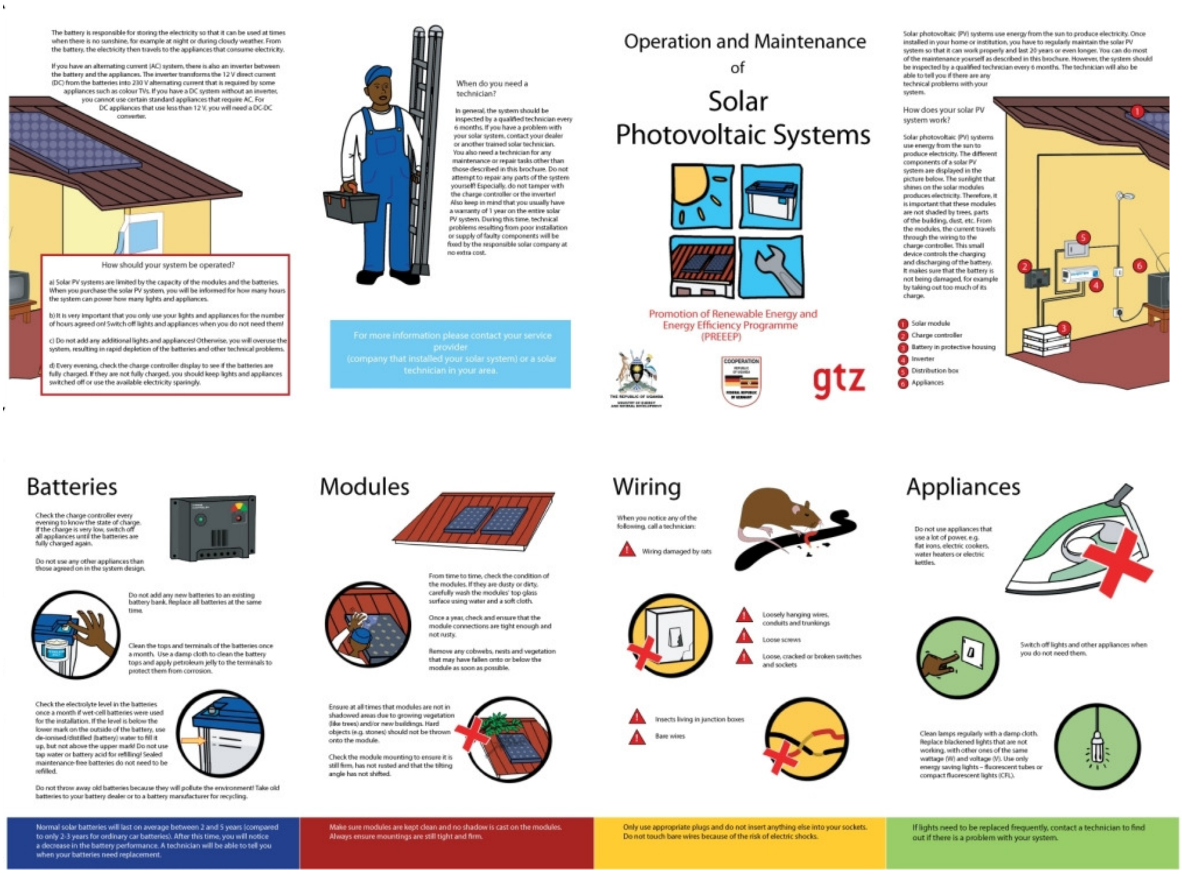

Figure 20: Operation and maintenance brochure (source: PREEEP 2012)

Even though the donor gives recommendations on operation and maintenance, the compliance depends upon the in-charges of institutions. Systems are over-used, because appliances that require high loads of electricity are plugged in (Migadde 2012). Moreover, PREEEP advised the institutions to set up a separate solar PV system account and save money on a regular basis to accumulate enough financial means to renew components. So far, only one institution has saved 400,000 UGX (142.4 EUR) on a separate account by raising a solar fee from the parents. Other institutions collected charges and saved up to 1.2 million UGX (373.2 EUR) for the general maintenance account. Many in-chares argue that bank charges are too high to set up a separate account. As a result, some institutions take the solar budget from the general budget. The HCs are especially prone to long-term outages as they have no budget for replacement available and fully rely on the district budget in this regard.

Furthermore, PREEEP noticed that in-charges of health centres had started to re-arrange the wiring of the PV systems. At the end of the warranty after three years, some institutions try to fix problems on their own. Moreover, maintenance know-how is lost as soon as in-charges leave the institution (Migadde 2012).

4.3.9. Further developments and energy plans

- Efficient cooking stove

Some of the schools and HCs are planning to apply for an efficient cooking stove since large amounts of expensive wood fuel have to be used every day.

- Extension

Many institutions would like to extend the system to illuminate the staff quarters and other buildings that have not been connected yet or were newly built. A couple of SC-HQs and HCs are planning to refurbish buildings, build additional staff quarters and extend the solar PV systems.

One of the SC-HQs plans to install additional sockets so that the community can use them for charging their phones in the secretary's office. For charging a small fee for phone charging a by-law has to be passed.

- Science and PC labs

PCs play an important role in education. As a result, some of the schools plan to build PC labs.

- Communication devices

Some institutions provided with common printers are planning to acquire 2-in-1 printers so that the teachers do not have to travel to town to copy anymore. Furthermore, other social institutions think of purchasing additional PCs to facilitate the working conditions. However, these plans might lead to an overload of the system and should be advised by a solar company or PREEEP.

- Solar water pumps

Manual pumping of water is a time-consuming problem. The acquisition of solar water pumps is thus of interest for some schools.

- Curriculum at schools

Omugo Technical Institute is planning to introduce IT training and an electricity course within the next two years.

- Assisting other institutions in terms of solar PV

Some SC-HQs act as role model in terms of solar PV system management. Offices and schools interested in acquiring a system visit them to inform themselves informally on the progress.

Figure 21: Maternity ward of Olujobo HC with light bulbs

4.4. Evaluation matrix

In an optimal case, energy access entails poverty reduction by improving conditions in the health and education sector as well as the income and environment. Kanagawa and Nakata (2006) have formulated main development factors influenced by energy:

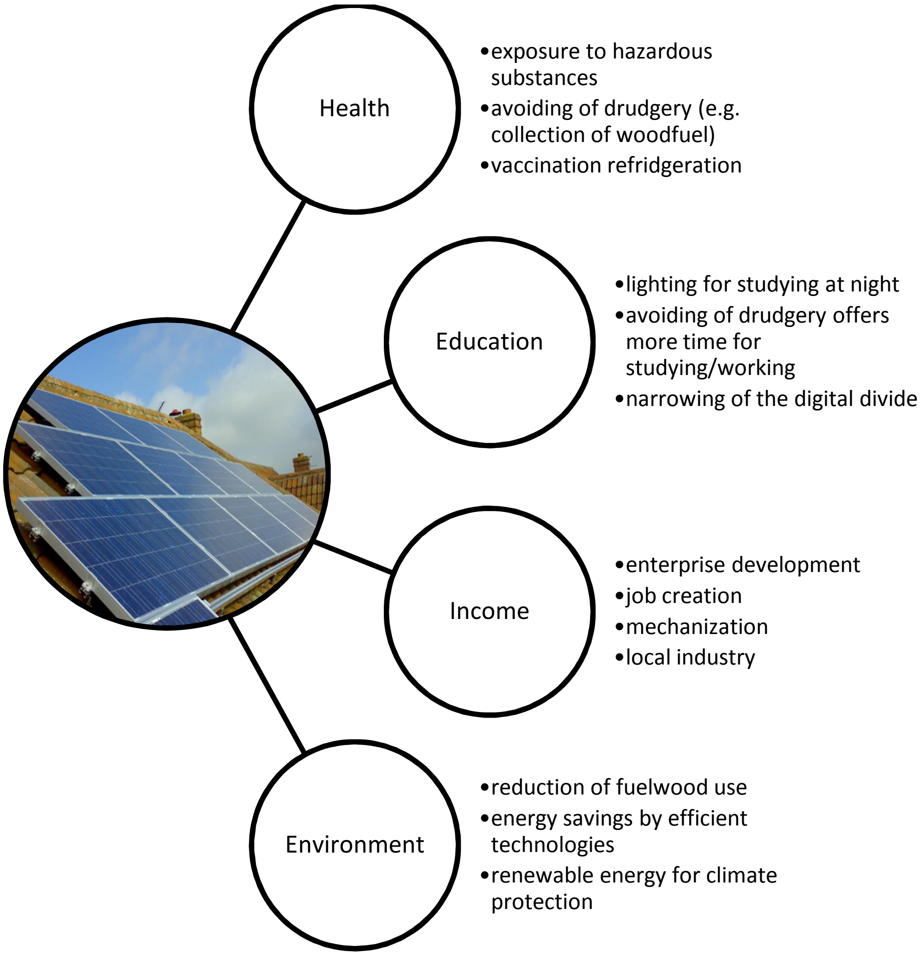

Figure 22: Energy influences on development factors (adapted from Kanagawa and Nakata 2007; Solar Trade Association 2012)

On the basis of these factors an evaluation matrix (table 5) is created and the project is analysed by identifying advantages and disadvantages for each type of institution.

Table 5: Evaluation Matrix (adapted from Kanagawa and Nagawa 2007)

Factor/Question	Schools	Health Centres	Sub-county headquarters
Health			
Decline of exposure to hazardous substances	+	+	+
Avoiding of drudgery			
Improvement of health services		+	
Education/Work			
Lighting for studying/working at night	+	+	+
Avoiding drudgery results in time for studying/working			
Avoiding long ways to trading centres/town results in more working time	+	+	+
Narrowing of the digital divide	+	(+)	+
Income			
Enterprise development / local industry	(+)	(+)	(+)
Job creation	(+)		
Working time is more efficient	+	+	+
More services can be offered	+		

Environment			
Reduction of fuel wood use			
Reduction of petroleum products use	+	+	+
Reduction of emissions	+	+	+
Renewable energy in use	+	+	+
Energy efficient devices in use	+	(+)	+
Closed-loop (recycling) is available for all components	-	-	-
Socio-economic impacts			
Inequality has emerged	-		
Households save money	+	+	
Decrease of accident occurrence (e.g. no hazardous kerosene lamps need to be used anymore)	(+)	(+)	
Savings can be spent on other projects	(+)		(+)

The evaluation shows that electrifying schools, HCs and SC-HQs influence the factors that contribute to poverty reduction strongly. Nevertheless, negative aspects arise from the absence of an adequate recycling system for batteries and panels. Furthermore, performance inequality occurs in secondary schools between boarders and daily scholars who do not have access to electrical illumination to read at night. There is no impact on the use and collection of biomass since it has to be used for cooking in any case.

4.5. Comparison to the ERT projects of the health and education ministries supported by the World Bank

The overall aim of the ERT component of the Ministry of Education and Sports is to provide energy access to post primary education. The second phase of the programme focuses on the quality improvement of education by providing electricity. To electrify schools the ministry has developed 13 solar PV packages. Some were not sufficient for the applications, mainly because the use of computers was not incorporated as an application. The systems were only designed for indoor illumination, security lights, heating for physics laboratories, chemistry, biology and information technology as well as the preparations of meals. At technical institutes electricity is needed for training in electrical installation, electronics, plumbing, motor vehicle mechanics and bricklaying. The daily energy requirement for common classroom lighting is 240 Watt-hours, which results from 60W times 4hrs.

An evaluation of the design packages let the ministry conclude that many classrooms systems were undersized and did not provide enough illumination. As a result, the performance of the systems was dissatisfying (Ministry of Education and Sports 2010). The project team realized that providing electricity to the teacher's house was a crucial success factor, because not having electricity while other parts of the compound had, was discouraging. In contrary to the PREEEP project, some beneficiaries did not develop ownership for the system. The Ministry noticed that theft occurred during holidays. In Arua, the highest occurrence of theft and vandalism was observed. In response, the management is now better trained and the community more involved. As a result, it should be avoided that students take parts of PV systems back home to sell them. In comparison to the PREEEP project the schools do not have to pay any installation contribution, but they also carry the full operation and maintenance costs after five years (Migadde 2012; Ssenozi 2012).

The maintenance is cared for by the supplier. In the beginning, a focal point in each school was planned. A person in charge is trained and reports to the supplier in case of problems. Challenges occur when people are transferred to other places. Know-how is lost, because many fail to pass it on to their successors.

Similar to the schools electrified by PREEEP, the ERT schools reported better performance of the students, increased enrolment, longer reading hours at night and a better security situation.

During the field assessment, two HCs electrified by the ERT component of the Ministry of Health were visited. In one of them the system had been installed four years ago and has not been working for two years. The ministry sent inspectors, but still the problems were not fixed. The second HC had been using the system for two years. It is working well in the treatment rooms, but has collapsed in the staff quarters. However, similar problems were noticed in some of the PREEEP HCs since the district is the budget authority and needs to plan well in advance. As a result, sustainability is a challenge for both of the programmes.

4.6. Cost analysis example and cost aspects of solar PV systems in Uganda

A simplified cost/benefit-analysis of a fictional 820 W solar PV system in a Ugandan school operating 36 weeks a year is calculated. The calculations include the total system costs of 11 EUR/Wp according to Harsdorff and Bamanyaki (2009), estimations of maintenance costs per year according to the current component lifetimes and prices according to Migadde (2012), savings according to the principals of Okufura SS and St. Theresa, who were visited during the impact assessment, the average inflation rate over the last five years of 13 % and the deposit rate of 3.5 % according to the Bank of Uganda (2012) to calculate the real interest rate. In terms of benefits only the directly related savings and in terms of maintenance only the directly related costs excluding bulb exchange are accounted for to achieve a rough amortization analysis. Due to the absence of appropriate inflation estimations, it is not possible to derive a reliable benefit analysis. Moreover, a quantitative and statistical analysis is necessary to express benefits such as rising enrolment figures, printing and staff labour costs as well as bulb replacement numerically and include them into a more detailed a cost-benefit analysis. Furthermore, a more detailed inflation and interest rate forecast should be included. A detailed cost-benefit-analysis could, however, be a topic for further research.

Installation costs:	UGX	EUR
Installation costs for a 820 W system (36500 UGX/Wp or 11 EUR/Wp):	**5,986,000**	1,903
Maintenance costs (per year):		
6 batteries a 200Ah:	1,400,000	445.07
Average lifetime: 6 years		
Cost of one battery: 1.400.000 UGX		
2 regulators	94,118	29.92
Average lifetime: 8,5 years		
Cost of one regulator: 400.000 UGX		
2 inverters (300 and 600 W)	160,000	50.87
Average lifetime: 10 years		
Cost of one inverter 600.000 / 1.000.000 UGX		
Total:	**1,654,118**	**525.86**
Savings (per year):		
Operation of fuel generator (600.000 UGX per term)	1,800,000	572.24
Maintenance of fuel generator (400.000 UGX per term)	1,200,000	381.49
Phone charging for employees (1.000 UGX per week)	36,000	11.44
Total:	**3,036,000**	**965.17**
Net savings per year:	**1,381,882**	**439.31**

$$n = \frac{\ln\left(\frac{r}{q \cdot r - b \cdot (q-1)}\right)}{\ln(q)} + 1$$

Period of amortisation without interest rate/inflation (years):	**4.3**
Period of amortisation with inflation (years):	**3.6**
Period of amortisation with inflation and interest rate (years):	**3.7**

The calculation is based on total cost of the system and the fact that the system owner does not take out banking loans. If it was so, the amortisation period would be much longer, even more than 21 years, since the current lending interest rate accounts for 25 %.

In case of the PREEEP social institution electrification project, the beneficiary institution carries 20 % of the initial and the full maintenance cost. As a result, a system with an 820 Wp capacity would amortize after 4.3 years without inflation considered, after 3.6 years with inflation or after 3.7 years with the real interest rate taken into account.

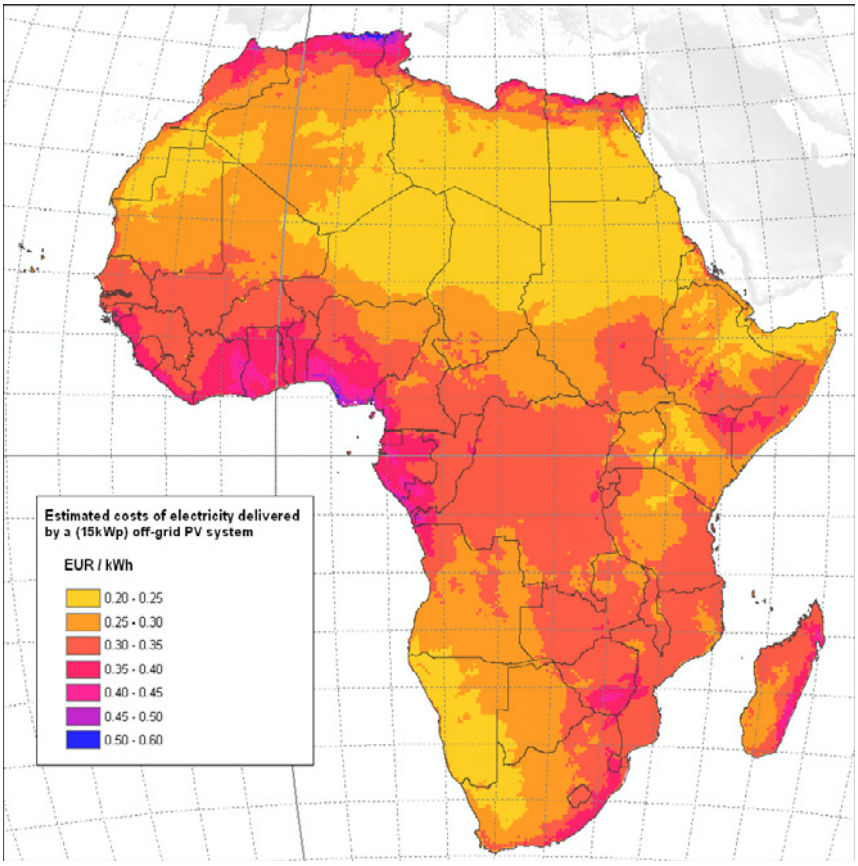

Figure 23: Estimated costs of electricity (EUR/kWh) delivered by a (15 kWp) off-grid PV system (source: Szabó et al. 2011)

Figure 23 gives an overview of PV systems generated electricity costs based on solar radiation and technological system assumptions (Szabó et al. 2011). Large parts of Uganda have relatively low costs that reach from 0.25 to 0.30 EUR/kWh. These calculations are based on factors such as system sizes, energy consumption, array sizes, battery discharge, prices and discount factors.

The most suitable and affordable type for rural homes with a low income are pico-PV systems. This small equipment is usually based on a solar panel, a rechargeable battery and a lamp and can be used for lighting only or also for phone charging or running a radio. The cost-benefit relation thus depends on several factors. For instance, the panel capacity may vary between 0.3 Wp for a solar lantern and 12 Wp for a combined system. Most of the used systems, however, have a capacity of 1 to 3 Wp. The technologies used may also vary widely: lead-acid, NiMH or Li-Ion batteries, CFL or LED and an optional charge controller may be included. Moreover, affordability, quality, output, charging duration and durability influence the system's efficiency. The upfront costs for pico-PV systems amount to a cost between 15 and 95 EUR. However, since kerosene lamps entail running costs of 1.5 to

4 EUR a month, these costs can be compensated soon upon procurement. Nevertheless, financial services are difficult to access which makes it not easy for many households to meet the initial costs all at once.

To be affordable for private households, PV systems have to be manufactured at low cost and fulfil quality standards. However, failed systems are no curiosity. A 2009 GIZ assessment showed that 50 % of the systems installed in households and small companies do not fulfil the expectations (CREEC 2011). Larger systems used in enterprises amortize after four to five years. The monthly savings ratio lies at 2 %. Enterprises that use PV spend more on stock and devices for their business (GIZ-PREEEP 2011c).

Solar PV is usually not used for production processes, but by the service sector. 7 % of enterprises, bars, shops, hair dressers and phone charging stations, have procured a system. Manufacturing companies face high upfront costs of systems that could run their heavy machinery. Moreover, enterprise owners carry on using other energy sources such as kerosene and dry cell batteries. The habits of many users only change slowly (GIZ-PREEEP 2011c). Thus, PV does not have a direct influence on economic growth in the country. The number of customers of electrified MSMEs initially increases, however when markets become saturated, the overall economy stays at the same level. The size of the system does not have an impact on attracting customers. The attraction is simply based on the fact that there is light, but not on its quality. Therefore, only productive use of systems for basic purposes can be economic. New markets, however, benefit from solar PV right away, leading to a faster skimming of potential (GIZ-PREEEP 2012).

5. Potential for decentralized grid generation in rural Uganda

5.1. Introduction

Distributed generation is a decentralized form of energy generation and integrates local renewable energy sources according to their availability under a single control unit. As a result, inefficiencies of distributed energy resources (DER), for instance, solar PV or wind generation, are compensated and load peaks are smoothened out. Micro-grids can operate both in connection to a utility grid or autonomously and are designed upon total system energy requirements.

The integrated generation technologies can be solely renewable ranging from micro-hydro plants and wind generators over fuel cells to solar PV and biomass plants or they can be coupled with conventional generation methods in a hybrid system. Storage devices such as batteries or flywheels can be introduced to serve peak loads and backup the supply. The consumers account for the load that should be managed and controlled (Berizzi 2011; Baharuddin et al. 2009; Brauner 2011; Pointon and Langan 2002).

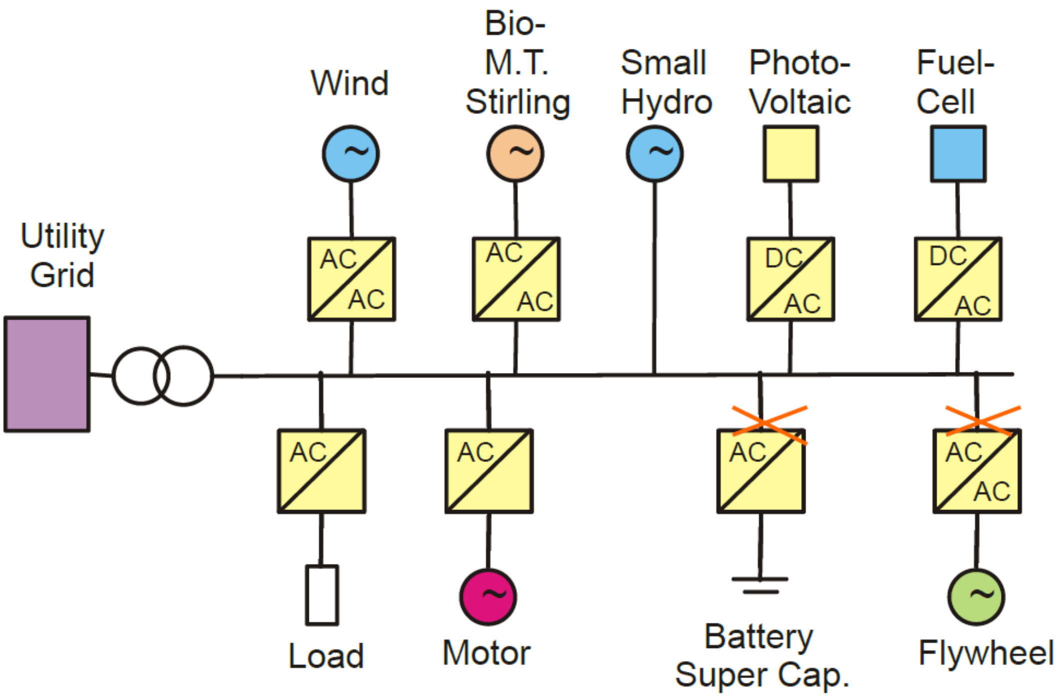

Figure 24: Sample structure of decentralized grids (source: Brauner 2011)

Uganda features low population densities and low energy consumption. As a result, decentralized generation is a more favourable and cost-effective way to achieve energy access (Levin and Thomas 2011).

Due to the utilization of renewable, locally available free sources operational costs are relatively low (Berizzi 2011). The current capital cost for extending a low voltage line is 5 EUR/m. Additionally, generation technologies need to be acquired and set up (Nfah et al. 2008). The Life-Cycle Costs (LCC) of a micro-grid depends on the cost of electricity generation, availability of resources, operation and maintenance, electricity consumption per household, the number of households connected, the penetration rate, capital cost of the lines and connection costs. The total cost of a micro-grid decreases disproportionally with the penetration, respectively the number of households connected. A lower grid penetration results in a more scattered network and a longer line length per household (Nässén et al. 2002). Small mini-grids have a levelized cost of energy of 0.20 to 0.80 EUR/kWh (Simonet 2012).

A comparison of grid extension with PV and diesel off-grid option costs (fig. 25) leads to the conclusion that decentralized PV integrated into diesel mini-grids as well as grid extension are the best choices in Uganda to stay below a threshold cost of 0.30 EUR/kWh (Szabó et al. 2011). However, in some areas, where the utility grid is far and settlements scattered, only stand-alone systems are economically feasible. Mini-grids will become relevant for trading centres or local government districts (Wafula 2012).

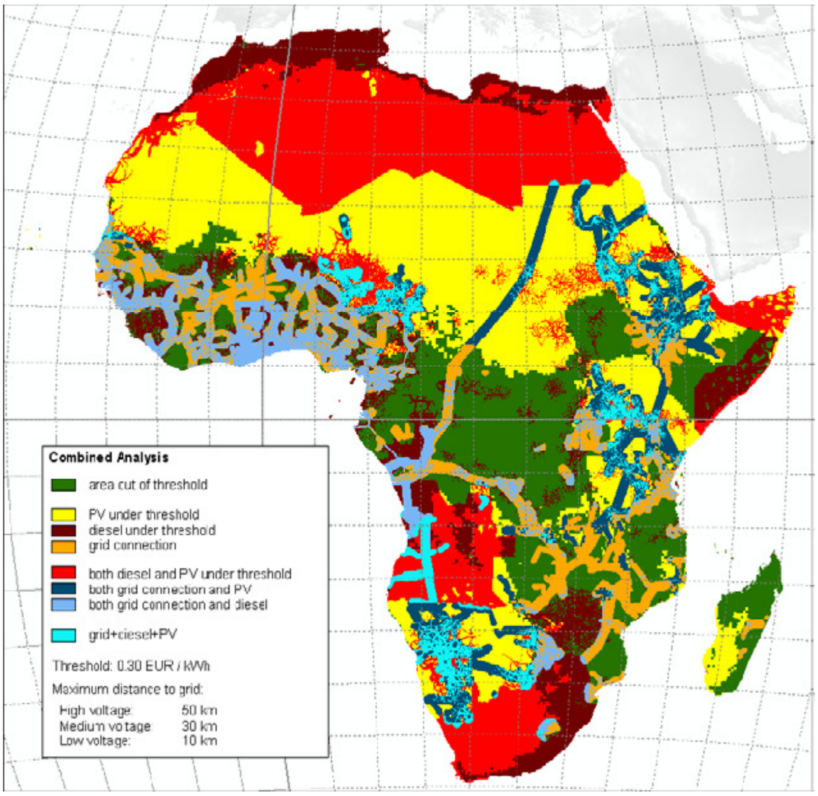

Figure 25: Overall distribution of PV, diesel and grid extension electricity options compared with average assumed willingness to pay of 0.3 EUR/kWh (source: Szabó et al. 2011)

An economic analysis of solar-fed hybrid grids conducted in Cameroon, which has a similar solar radiation as Uganda (5.5 kWh/m² and day), showed that micro-grids are more cost-efficient than PV stand-alone systems and diesel generators. A micro-grid entails costs of 0.692 to 0.785 EUR/kWh – while diesel generators amount to 0.812 EUR/kWh. Hybrid stand-alone systems entail 0.785 EUR/kWh (Mbaka et al. 2010).

5.2. Technological micro-grid planning

First, an important party involved in a local micro-grid is the operator. The operator is obliged to deliver a specific amount of reliable electricity and thus is allowed to set tariifs under certain guidelines as set out by the regulatory body. The consumers build the second important group. They might be private households or commercial users. In rural areas in developing countries their demand is usually small, however, it still leads to morning and evening peaks. Third, a regulatory body is in charge of controlling the market and protecting environmental efficiency as well as consumer rights (Sendegeya 2009).

5.2.1. Sizing

Basic requirements for introducing a micro-grid include an adequate population density, the set-up of a community profile, building of awareness and acceptance, involvement of the community, the evaluation of risks and environmental impact analyses (Sweczuk 2007).

A mix of considerations for planning needs to be taken into account:

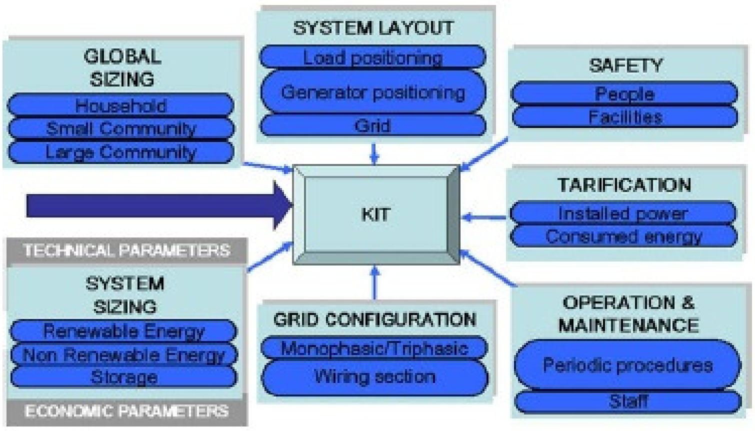

Figure 26: Methodology for the definition of the micro-grid kit (source: Alzola et al. 2009)

Sizing is the first and most critical task in micro-grid designing. First, the entire load must be served with the adequate amount and quality of electricity. Second, load dispersion and variations must be accounted for. As a result, the electricity storage must be adequately planned (Berizzi 2011). Demand and supply need to be balanced (fig. 27). On one hand, the production must be adapted to the demand of the village. On the other hand, the consumers need to adjust their demand patterns to the grid capacity and use energy efficiently. Energy storage opens space for variations on both sides. Additional capacity might be necessary, for instance, if a cloudy day limits the energy output of the PV system (Brauner 2011).

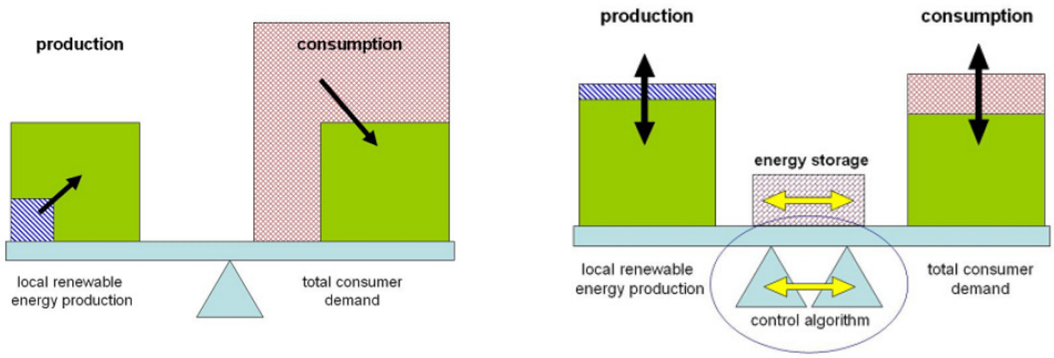

Figure 27: Balancing supply and demand in a micro-grid (source: Brauner 2011)

Solar and wind profiles, fuel costs, component costs, load information and economic aspects are taken into account in a prior simulation (Alzola et al. 2009). If lacks in sufficient data are observed, continent- or region-wide GIS data on resource, water supply and meteorology may be used (Belward et al. 2011) and can be combined with national data on demographics and development issues (Szewczuk 2007). Finally, to achieve a good demand estimation of the village, household surveys are carried out (Camblong et al. 2009).

5.2.2. Layout

In a conventional grid electricity flows in only one direction: from a large generation source via transmission and distribution networks to the end-user. The flow is controlled by central facilities (European Communities 2006). In a micro-grid, however, the line between a transmission and distribution grid is blurred and only one system connects generation and load on a medium- or low-voltage level with a frequency of 50 or 60 Hz (Katiraei et al. 2008).

The system layout depends on the location of users and generators, the distances between them, the plan for expansion and economic implications (Alzola et al. 2009). Blyden and Lee (2006) have developed the principle of the "Olympic Ring", a bottom-up approach developed for the specific needs of African villages that includes a power network control. This converter system enables the interaction of the different electricity sources to share and regulates voltage/frequency regulation. In response to the characteristics of load and resources, the operator may create a double or a single node.

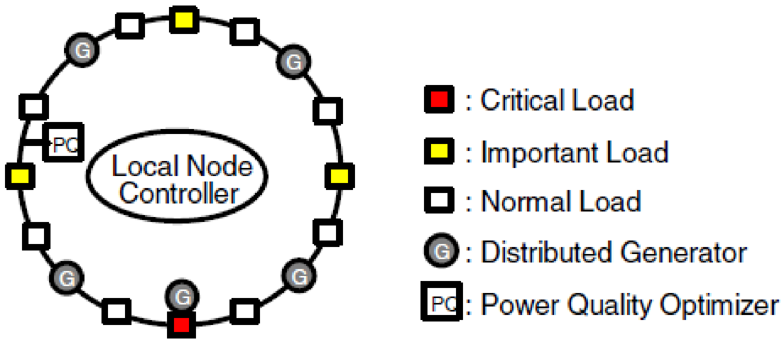

Figure 28: Single ring local node (Blyden and Lee 2006)

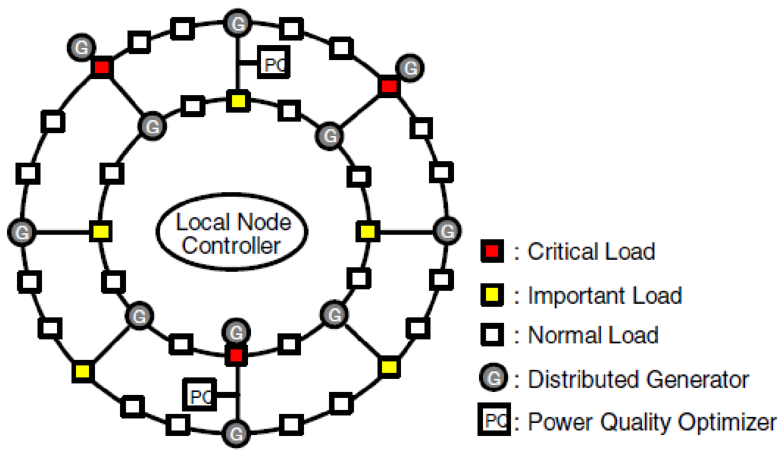

Figure 29: Double ring local node (source: Blyden and Lee 2006)

The grid may distribute AC or DC current depending on the type of energy sources (Berizzi 2011). Several nodes are accumulated to form a super node operating autonomously or independently from the national utility grid. Due to its modular character, the system is flexible and can be easily expanded in case the village develops a greater demand for electricity or additional sources can be exploited. The circle formation is important since it enables a higher reliability of the electricity supply (Blyden and Lee 2006).

5.2.3. Control mechanisms

Special control mechanisms have been developed so that distributed energy resources contribute efficiently to the stability of the micro-grid. These take the variability of renewable generating sources such as wind and solar PV into account. In order to keep a stable level, the supply should be secured at a maximum. Voltage and frequency may increase over a defined level, but only to a small extent and a short while. If so, communication measures shall be taken to reduce it again. Control and monitoring can be central, distributed and based on available communication tools such as the mobile phone network or the Internet. They are built on two stages:

1) Primary droop control

This stage is in charge of securing the operation of the grid by implementing the droop characteristics and aims to improve the power quality. It handles frequency and voltage deviations that might occur after load changes (De Brabandere et al. 2007). An off-grid inverter allows different generation devices to be connected and regulates the electricity flow from the grid to the battery and vice-versa (Braun 2008). Furthermore, it regulates energy loads and sources by starting/stopping the generator or switching off loads. As a result, energy losses can be minimized (Tapanlis and Wollny 2009). The monitoring kit should be retained in a container.

2) Secondary power quality optimization

At this stage the frequency and voltage deviations as measured. All DER units use the same droop parameters to achieve optimization (De Brabandere et al. 2007). Inverters are connected to each generating unit to handle generation specific tasks:

Solar inverters transform DC into grid-acceptable AC, track the MPP and control the frequency. They should have a high efficiency of about 95 %. Induction generators or wind induction inverters in combination with PME generators transform variable frequency voltage into AC voltage and recognize 50 or 60 Hz frequencies automatically avoiding over voltage. Hydro-electric schemes use either synchronous or PME generators combined with an inverter. Finally, battery inverters are introduced to control backups such as fuel generators (SMA 2012; Tapanlis and Wollny 2009; Alzola et al. 2009).

5.2.4. Configuration and safety

The next step of the system designing is the grid configuration taking into account generation equipment, inverters, chargers, batteries and measurement devices: First, the decision whether the grid shall be monophasic or triphasic has to be taken. Monophasic systems are easier to install, while triphasic allow greater load units and result in smaller losses. The optimal wiring size needs to be developed and electrical resistance that may lead to voltage drops or power losses should be avoided.

The integrated diesel generator is directly connected to the grid as it should be able to provide electricity in emergency situations and thus should not be dependent on any other component.

Safety issues need to be considered. Potential hazards and threats need to be minimized. Overload may result in overheating, voltage drop and component break-down. In response, current limiting devices such as fuses and circuit breakers need to be included. To achieve a high safety standard, users should be well educated. The contact with wires has to be avoided (Alzola et al. 2009). In case of load shedding to balance the power and stabilize the voltage, important loads such as health centres that need to have lighting for emergencies or to cool vaccines still have to be supplied (Katiraei et al. 2008).

5.2.5. Tariff setting and metering

A tariff plan needs to be set-up. It is based on maximum quantity and variable quantity of electricity available dependent on the load schemes. An inexpensive and simple option is the use of contracted power that uses the same control devices as the safety control. In case of a higher load, the unit price becomes higher. As a result, the user will be educated to use more energy when the load is lower (Alzola et al. 2009).

A study by Kirubi et al. (2008) concluded that community-led micro-grids can recover a large part of their operating costs from internal revenue of electricity sales and other charges. This is due to the fact that charges can be set in a cost-effective way leading to a return on investment. Cost recovery triggers local revenue and improves the system's load factor. During the day, when it is easy to generate electricity through, for instance, solar PV, the tariff should be set lower, while during the night, when electricity has to be drawn from the storage system, higher fees are charged.

Smart meters can be installed in every household. They track the electricity consumption and send the data back to the utility for monitoring and invoicing. The communication is bi-directional so that the consumers can keep track of their usage and an exact measurement of the load profile is possible. It gives the provider the possibility to communicate tariff variations influenced by the total load over the day directly to the consumer. The consumer realizes when it is the cheapest time to use power for certain power-intense tasks. A pre-paid system can be introduced to facilitate the paying-method for the consumers (e-control 2012). Shared Solar, a research initiative of institutions and individual scholars, has developed a pre-paid aggregated metering method for 1.4 kWp micro-grids for up to

20 consumers in developing countries based on the use of scratch-cards and mobile phones. Its system shall be managed semi-autonomously. SMS containing the code arrive at a SMS centre that communicates with a server activating the electricity connection. In each household the electricity use is measured with an own pre-paid metering system. So far, the idea has been tested in Mali, but also two projects in the Ugandan Western region supplying power for a school and a trading centre have been completed (Shared Solar 2012; Simonet 2012).

5.2.6. Operation and maintenance planning

Operation and maintenance planning is crucial since it is the major influencing factor for the sustainable success of a micro-grid. A technician should be in charge of regular maintenance, control of availability and supply, regular inspections, fee management and training on energy efficiency (Alzola et al. 2009).

5.3. Impact on the local community and economy

To achieve electrification that operates in a sustainable way, the area should have potential for economic activity ready to pay for the service of energy. In return, enterprises earn higher profits due to enhanced sales figures, yields and revenue. According to Szewczuk (2007), the achievement of environmental improvements, energy access and economic growth is only possible if certain strategies are applied and crucial factors are taken into account:

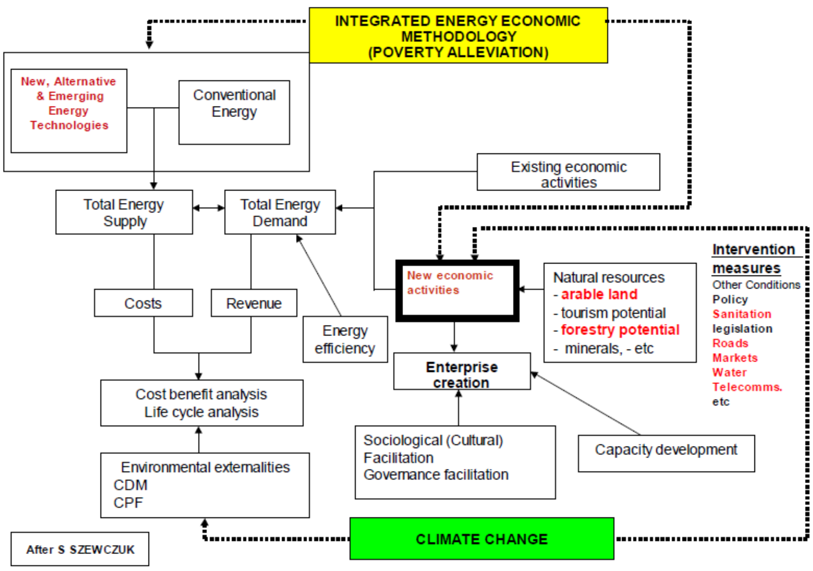

Figure 30: Integrated energy economic framework (source: Szewczuk 2007)

Case studies analysing micro-hydro schemes in Sri Lanka and Nepal have shown that the deployment of micro-grids creates small grain milling businesses, radio repair shops and carpenters. Additionally, social institutions, especially HCs, benefit from inexpensive or even free electricity (Nfah et al. 2008). As a result, micro-grids retain capital in the area and provide local jobs (Moner-Girona 2009).

The use of modern energy services may also decrease the total costs of energy in each household since purchasing paraffin or kerosene becomes redundant (Zerriffi 2011). In order to ensure the optimal benefit gaining for the community, social and economic mechanisms should be created to introduce micro-grid projects. These might reach from the establishment of local committees, the involvement of inhabitants through manual labour, the set-up of a local skills catalogue, the procurement at local dealers wherever possible and trainings of the beneficiary community (Sweczuk 2007). Quality standards and a legal framework need to be created to open a market for investors, operators and developers. Local technical expertise in micro-grid operation and maintenance is important to secure high quality supply and community engagement (Yadoo and Cruickshank 2011).

5.4. Drawbacks to micro-grids

Certain barriers might hamper the construction of micro-grids. First of all, RES-based micro-grids compete with off-grid diesel alternatives that may be initially cheaper, but less reliant. Second, awareness for micro-grid options is often lower than for stand-alone options. Low awareness is even observed in government bodies responsible for electricity planning. Moreover, the upfront costs for micro-grids are high. As a result, initial government subsidies, donor grants or loans are necessary to construct such projects (Yadoo and Cruickshank 2011).

Low population density entails high energy delivery and maintenance costs. Low consumption of the rural population makes private investment unattractive in many cases. Inhabitants are mainly poor and cannot afford large investments in new technologies or services (Zerriffi 2011).

5.5. Recommended micro-grid configuration and implementation strategy for Uganda

5.5.1. Generation technologies and energy storage

Considering the fact that electricity demand grows by 6 % per annum and the low rural electrification rate of 3 % is hampering economic growth, strategies on demand and supply matching need to be developed. Even though electricity demand per capita is still low and load equipment limited, the growing number of units electrified enhances the overall economic growth. Micro-grids coupling different RES offer a good compromise since they can be developed where demand is high and they entail lower costs than grid extensions. Different generation technologies depending on the local conditions may be introduced. Micro-grids offer the possibility to merge the benefits of different sources in one system to provide reliable electricity that can meet peak loads. Uganda has potential for different RES that can be merged in decentralized systems (table 6). Additionally, many components for building decentralized grids can be acquired on the Ugandan market. These include equipment for solar PV, hydro-generation, fuel generation, biogas-digesters and batteries. As a result, the government's Rural Electrification Strategy and Plan has defined micro-grids as one strategy to achieve a 10 % rural electrification rate by 2012 (MEMD 2007).

A case study from South Africa was successful in introducing a 86 kW hybrid system by coupling solar arrays with 6 m wind generators, battery banks, a control system by grid lines and premise equipment components. The grid provides enough energy to supply a village of 220 households (Szewczuk 2007). A micro-grid based on these technologies might also be eligible for Uganda. However, to enable an economically feasible wind generation option, the speed should at least reach 2 – 4 m/s. This speed can only be harvested in a few regions such as Karamoja. In other regions, it might be better to choose hydro-power, biogas or biomass instead of a wind turbine. In any case, it is important to back up the system with the help of a diesel generator that smooths out generation lows in order to guarantee the supply for sensitive consumers such as health centres (Beaudin et al. 2010).

In Uganda, additionally to two systems mentioned in chapter 5.2.5, one micro-grid has been installed in a donor school in Bulyansungwe, Western Region, in 2004. The system produces 485 AC kWh a month and comprises 3.6 kWp solar panels, two 1.7 kW PV inverters, a 21.6 kWh battery bank, a 3.3 kW island battery inverter as well as a 4.6 kW gasoline generator. In a first phase, several school compounds were connected to the micro-grid. A further expansion is planned to a social centre and a HC that already have generation systems in place. Furthermore, the schools shall be able to run PCs with the help of stand-alone energy production through solar arrays. In peak production hours, a water pump is run and transports water upwards to a tank. This water can be bottled and drunk after passing through UV-purifiers. This strategy avoids an overcharging of batteries in low generation periods (Brandt 2005).

Table 6: DER technologies and their general potential in Uganda (adapted from Berizzi 2011; MEMD 2007; Brauner 2011; Blyden and Lee 2006; Alzola et al. 2009)

Technology	Features	Potential
Biogas	Cooking, CHP and electricity Bio-digesters: 30 to 1,150 EUR Usable on different scales	250,000 households
Biomass	Cooking, CHP and electricity Usable on different scales Steady source, prognosis easy	1,650 MW Good potential
Diesel	High availability → secures power supply as backup technology Not renewable, noise and pollution Low initial investment, easy installation High operation costs (fuel) Used for short periods	
Small hydro	Capacities reach from 10kWs to MW Large upfront, but low maintenance costs If coupled with further uses (e.g. mills), costs are decreased Precipitation must be reliable	210 MW
Solar PV	Generate DC current that can be converted to AC Different scales O&M costs, especially replacement costs Thefts Coupled to wind fluctuation, prognosis difficult	200 MW Great potential in Uganda: 5.1 kWh/m^2/day
Wind	Small scale Costs decrease over time due to low maintenance costs Not constant → storage required Coupled to solar fluctuation, prognosis difficult Wind analysis needs to be conducted first	No wind mapping available Wind can only be used for small scale applications in the North

Energy storage is important in any rural micro-grid that is not connected to a macro-utility grid. The easiest and cheapest possibility is to introduce a bank of deep-cycle rechargeable batteries. Such types of batteries are easily available, also in rural areas since they are used for vehicles, communication and other applications. Their costs lie at 178 to 354 USD/kW. They are reliable and efficient. However, deep-cycle batteries need regular maintenance, have a short lifetime and threaten the environment, especially in countries, where recycling facilities are not in place. For micro-grid applications it might be better to use a type of battery that is less environmentally harming and more economically feasible (Beaudin et al. 2010) such as lithium-ion or Nickel-metal-hydride batteries that are efficient and have a long lifetime. Lithium-ion is still very expensive and thus not suitable for the Ugandan market. Nickel-metal-hybrid, on the other hand, are cheaper, affordable and do not have a memory effect (TERI 2010).

Another storage device considered for energy generation in Uganda is the small-scale flywheel that can store up to 6 kWh. It might be applied additionally or instead of a battery bank. A flywheel stores or retrieves electricity by rotational speed applying torque to it or connecting it to a mechanical load. The initial costs of a flywheel are high, but its lifetime ranges from 15 to 20 years (Beaudin et al. 2010). As a result, a study by Okou et al. (2009) concluded that the application of a flywheel may be more cost-efficient than the use of a lead-acid battery bank and may thus be feasible in Uganda.

5.5.2. Preparation, planning and implementation of micro-grids

5.5.2.1. Budgeting and financing

The sustainable management of a common village micro-grid in an African country has not sufficiently been researched so far. Nevertheless, the cooperation amongst villagers needs to be shaped, patterns of electricity consumption assessed and mechanisms for conflict resolutions defined (Kirubi et al. 2008).

Financing methods of energy projects in developing countries can be based on available, modern business factors such as improved credit facilities, venture capital or NGO support, consumer side finance options, leasing models or micro-credits. International aspects such as CDM schemes influence the local or national conditions. In some cases, banks decide to acquire generation equipment and lease it to the developer (Zerriffi 2011).

Transparency of financing mechanisms shall be guaranteed by involving all community members involved in the process and clarifying the importance of the project. Each member is allowed to inspect the books. Therefore, the hazard of corruption and budget misuse is lowered. Budget facets are approved by a group consisting of several members so that spending on trivial activities is avoided (GIZ 2011).

Contributions can be financed with the help of SACCOs (Savings and Credit Cooperative Organizations). This is particularly appropriate for financing parts of a decentralized power system such as generation or storage equipment. In a SACCO members share a common bond such as belonging to the same labour union or church. Members save their money in the group and offer loans to each other at reasonable interest rates. A board is in charge of day-to-day business decisions. Since it is rooted in the community, it is aware of cultural and special conditions such as delayed contributions from villagers before religious holidays such as Christmas or during dry season as little income can be generated. SACCOs are united under the Uganda Cooperative Savings and Credit Union Limited (UCSCU) that offers training and services to the cooperatives and communities (UCSCU 2012). Nevertheless, SACCOs can be started by almost everyone, even villagers who might not have financial expertise. Therefore, SACCOs should aim at sustainability, be reliable and assessed in terms of corruption (GIZ 2009).

Another finance alternative, an expanded SACCO approach, may be an adopted Grameen Bank Model developed by the Nobile Prize Laureate Muhammad Yunus (1997). A bank unit is set up covering an area of 15 to 22 villages. The bank managers then visit the villages to familiarize themselves with the conditions and needs. Groups of borrowers are formed. Only two villagers are allowed to take out a loan at first place. Only after a period of 50 weeks and when they have paid back the full sum including an interest rate, further villagers are allowed to take out loans. The system is based on a substantial group pressure and collective responsibility that emerges since members try to keep their records clear.

Micro-grids, however, might need a more capable finance-scheme than common micro-financing. The price is higher and the tenure is usually longer resulting in a higher risk. In cases where SACCOs cannot meet the demand for loans or they may not exist, other microfinance institutions may step in. In Uganda, FINCA Uganda, Postbank, Opportunity Uganda, United Bank of Africa and Uganda Finance Trust grant energy loans to clients after visiting them at home and assessing whether they will be able to pay it back. They directly cooperate with solar companies. The programme is based on a group-lending scheme. Moreover, a NGO in Kenya has developed a micro-grid shareholder scheme reflecting the increasing assets of the community and the NGO. To boost investments it has included a carbon finance scheme based on the CDM. This idea could also be assessed for the Ugandan market (Kebir and Heipertz 2010).

5.5.2.2. Roll-out

Kirubi et al. (2008) formulated three strategy components to plan micro-grids, which include (1) the installation of a onetime subsidy for the installation, (2) an integrated infrastructure development approach including the set-up of roads as well as social institutions and (3) the set-up of a criteria catalogue for selecting and prioritizing areas. This may be conducted with the help of the Rural Electrification Agency (Kirubi et al. 2008).

GIZ (2011) made available some lessons learnt from the installation and management of pico- and micro-hydropower schemes that might also be applied to the implementation of micro-grids. The first step taken should be a preliminary assessment. In order to understand the socio-economic context and relations fully, a village survey should be carried out before the planning phase starts. Studies might reveal, for instance, that the income generating capacity of households is limited, on one hand, but on the other, some of the units might achieve higher purchasing power due to remittances from emigrated family members influencing their willingness to pay and take out loans in order to be electrified. Furthermore, the overall acceptability and willingness of the community to engage need to be assessed (Camblong et al. 2009).

Sustainability of micro-grids can only be assured if the community is involved in planning, financing and implementation. At first, micro-grid planning requires ethical reflection. (1) The fact whether electricity can be provided to the entire or only a part of the village needs to be considered. Extension may be planned over time. However, a priority plan needs to be set up and well justified towards the community in economic and socio-developmental terms. Otherwise, parts of the population may intervene, which can result in conflicts. (2) During the planning and implementation period corruption may become imminent. To find an adequate response, it is important to understand interrelations of groups and develop a strategy well in advance. (3) Equality should be promoted wherever possible. If the extension should be limited due to budgetary constraints or sparse population density, all parts of the population shall have energy access in one way or the other, for instance, through phone charging services in community centres, water purification or restaurants, shops, health and administration buildings having electricity (Geirbo 2011; Nygaard 2009).

The second step includes the system design. The planning considers the local availability of resources and replacement parts and materials. In-situ amendments should be possible and the design rigid. Alterations may become necessary in response to logistic bottlenecks and geological or hydrological site restrictions.

The third step is to plan the organisation. A community committee is set up. To limit corruption, the community chooses its most reliable members as representatives. To gain advantage from group dynamics, locals will design the working schedule. It should be taken into account that villagers are less occupied during the dry season since they are not involved in agricultural work. To boost participation in meetings, it is advisable to offer the attendants food or a small monetary compensation. In these meetings the project management needs to remind the community regularly of the aim, benefits and expected difficulties during the technical implementation. Only when large awareness is achieved, the community can develop ownership for the project. Therefore, the community should also be included in the decision-making process and choices between cheaper upfront costs or more cost-effective solutions.

The district officials and parish chiefs can support the identification of optimal locations. Sub-counties delegate some of the work to the Local Committees, which usually have an excellent insight in the area conditions. Workloads and labour intensity should be clarified and the possibility of eventual alterations announced (GIZ 2011).

Furthermore, an operator is appointed and involved in the installation. As a result, he will be able to conduct small repairs as soon as the system is installed (GIZ 2009). In order to ensure the sustainability of operation and maintenance, tariffs are charged. One principle to set-up a tariff is the renewable energy premium tariff. It pays in response to the renewable electricity produced. If the grid involves independent power producers, the generation facilities are owned by them, the grid by the local energy utility and the latter purchases from the generator based on feed-in tariffs. A subsidy per kWh may be paid by the REA or a fund through the utility to the generator. Since the locals mostly cannot afford a high price for electricity, the utility company charges below the production cost. If a cooperative and thus the customers own the grid, it does not require a specific profit (Moner-Girona 2009).

5.5.3. End-of-life recycling of components and closed loop

5.5.3.1. Problem

So far, recycling of components for electricity generation has not played a large role in Uganda. Closed loop schemes are not a common culture in the country (Migadde 2012). Donors and solar companies include information on battery maintenance in manuals and advise the beneficiaries to return the battery to the dealer. However, the manuals usually do not propose actions related to the disposal of other components (Sandgren 2001). As long as recycling and disposal facilities for system components are absent, an improved environmental soundness of micro-grids is not secured.

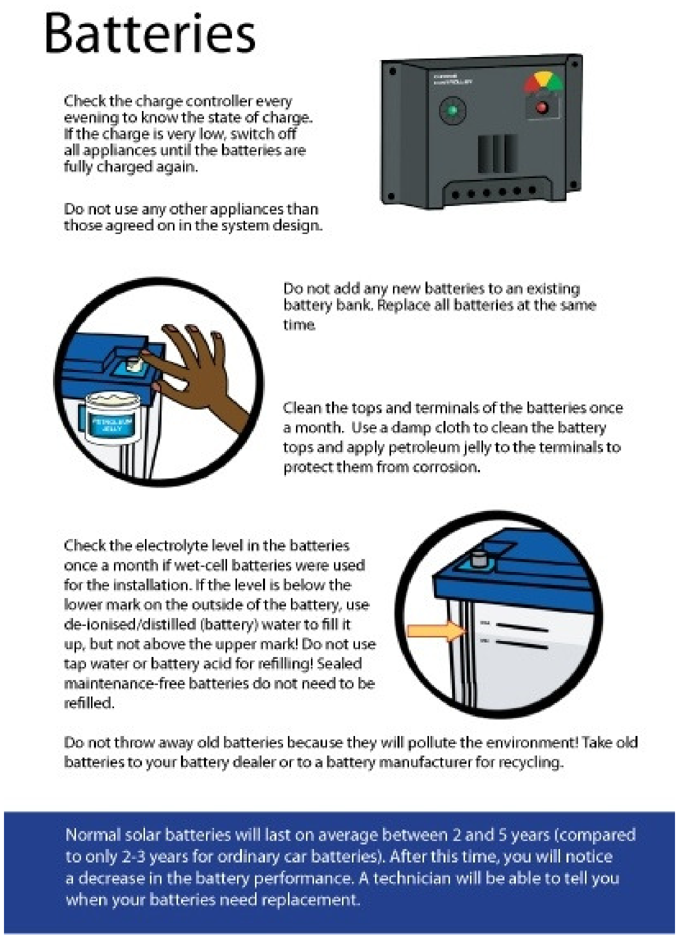

Figure 31: Manual example for battery maintenance (source: PREEEP 2011)

One company, Uganda Batteries Ltd. (UBL), is known for buying used lead batteries, recycling the lead contained and disposing the waste safely (UBL 2012). The lead is used again for production. Compensation payments amount to 185 UGX/kg (0.0588 EUR/kg) for batteries and 230 UGX/kg (0.073 EUR/kg) for plates. UBL indicates the recycling efficiency of amounting to 70 %.

A research (Sandgren 2001) conducted by the University of Lund showed that Ugandan domestic PV users use either lead solar, modified car or truck batteries in their SHS. However, lead has severe impacts on health and environment by contaminating soils, water bodies and agricultural land. The electrolyte used in the batteries is sulphuric acid, a substance that is highly corrosive. However, the risk awareness is low amongst the population. Some users do not know what lead even is. In many households replaced batteries can be found next to the new ones. In some cases the owners remove and pour the electrolyte including diluted lead particles outside in the garden or give it to somebody else such as a neighbour or friend. Other batteries end up in charging stations.

During the research, no example of solar module recycling could be found in the Ugandan context. Households, commercial users and institutions install a capacity of 200 kW annually. These modules will be replaced and disposed in 20 to 25 years at the latest. Similar to the global scale, waste from solar modules will increasingly accumulate to large amounts from the year 2022 (fig. 32):

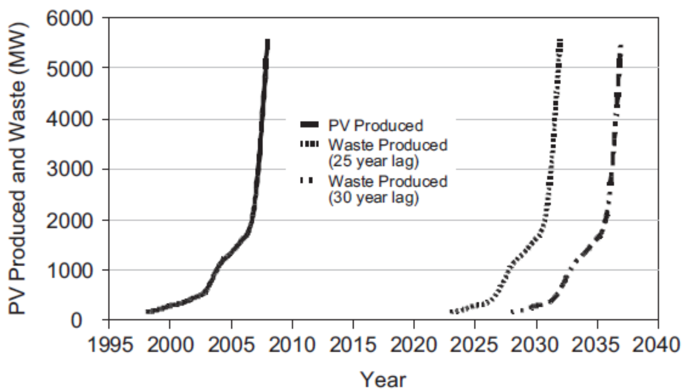

Figure 32: Global PV production and projected waste from 1998 to 2038 (source: McDonald and Pierce 2010)

Solar panels contain hazardous materials such as lead, selenium, tellurium and cadmium. The latter is highly toxic, volatile and accumulates in soils, water and thus the food chain (Fthenakis and Zweibel 2003). Governments should create recycling strategies for all common types of solar panels in use, but especially poly-crystalline-silicon and mono-crystalline-silicon panels that have the highest global market penetration.

Recycling is based on mechanical, thermal or chemical delaminating (Fthenakis 2000). The importance of thin-film cells have been increasing for the last years (Eberspacher et al. 1996). A study conducted by McDonald and Pierce (2010) led to the conclusion that the value of certain elements – selenium, indium and gallium – incorporated in the panels is enough of an economic incentive to start recycling on large scale. As for the other types of cells recycling costs for collection, energy, substances and tools used as well as the working time outweigh the profit being made by re-selling semi-conductor materials. Even in developed countries there have been few and only voluntary initiatives to recycle solar cells, although the Polluter Pays Principle is of priority (McDonald and Pierce 2010).

5.5.3.2. Suggestions for recycling strategies

Even though, waste regulations including hazardous waste paragraphs have been adopted by the GoU in 1999 and solar companies agree with the text, compliance is difficult. The lack of disposal and treatment facilities hampers the proper handling of the components. Considering the fact that the batteries used for solar PV systems are only a small fraction in comparison to the use for vehicles, it is necessary to develop disposal and recycling facilities. Moreover, it is important to increase the awareness of battery components posing a threat to health and environment by including the topic in trainings and manuals.

In order to reduce the environmental impact of PV systems, batteries and modules need to be disposed and recycled at the end of their lifetime. Estimations indicate that recycling rates of lead batteries will increase from 10 % to 90 % even in developing countries, because the lead price will further rise. Technologies will improve so that the lifespan increases, which results in a decreasing deposition of lead (Bader et al. 2003). Until then, governments and donors will have to introduce regulations and incentives in order to convince manufacturers and distributors of the importance of recycling measures (Eichner and Pethig 2001).

Several recycling policy tools were successful in different countries over the last decades and might also be applied in Uganda: First, posing a higher tax on virgin materials reflects the social value of resources and lowers their use. This might go hand in hand with a lower taxation of labour (Bruvoll 1998). Second, deposit or refund programmes such as bottle bills might be an incentive additionally to the price of selling old batteries to the manufacturer. A deposit programme creates a pull effect and convinces the customer to bring back the battery to not lose any money. Third, federal subsidies for recycling are another way to accomplish the target. However, this alternative may not be eligible for developing countries as the budget may not be available. Fourth, recycled content standards legally require new products to be composed by a minimum amount of recycled materials (Sigman 1992). As only one battery manufacturer is active in Uganda at the moment, this strategy may not be helpful to achieve the target. Fifth, tax deductions may be applied on the purchase of recycling equipment (Palmer and Walls 1996). To find the right policy mix for Uganda, the conduction of a detailed market analysis is recommended.

As for the companies involved in the recycling process, a collection system for used batteries and modules could be organised with collection vehicles visiting the big district towns a few times a year to pick up batteries or panels. In case of recycle shops, a deposit system additionally to the recycling payback can be introduced and the shop can achieve revenues by separating the lead plates from cases and selling them to manufacturers or dealers. This system can be set up for both modules and batteries. The strategies should include awareness campaigns to fully inform customers and manufacturers.

6. Conclusion

The use of renewable energy sources to accelerate electricity access has proven to influence the socio-economic development of Uganda positively. Solar photovoltaic systems are well suitable for this East African country since weather conditions are favourable and a small market already exists.

Donors such as GIZ make use of this generation technology to electrify social institutions including schools, health centres and sub-county headquarters. The introduction of solar electricity schemes causes more pleasant working conditions, better academic and work performance as well as target compliance, a higher quality of education and health services, a better security situation and more quality time for the staff to spend with their families.

However, some disadvantages related to the application of photovoltaic systems in social institutions need to be overcome. Attention should be paid to the sustainability of the systems. Budget strictly used for operation and maintenance of PV systems is not accumulated in all institutions and its unavailability results in lengthy system blackouts. Many institutions perceive the frequency of bulb replacement as a problem. Good-quality and energy efficient bulbs are expensive to acquire and not available everywhere. Some beneficiaries also added that the system installed did not fully meet the institutions' demand, because some important buildings or devices were not connected to the electricity source. Overuse may occur when employees plug in additional devices anyway. For instance, some health centre staff members plan to purchase TV-sets using money saved through the reduction of their personal paraffin bill. Finally, the lack of adequate disposal and recycling facilities for system components, in particular for batteries and modules, poses a threat to the health of citizens and the environment in Uganda.

Despite of the positive socio-economic impacts of PV systems, electricity distribution needs to intensify and achieve a higher reliability to enable mechanized processing and boost economic growth. Decentralized grids combine several renewable energy sources, fossil backup systems and energy storage devices. As a result, they are able to offer high-quality electricity to rural villages. Uganda is a good playground for such grids since it offers different possibilities to produce renewable energy and connect solar, hydro and biomass electricity generation in ring-formed distribution line configurations. First examples of such systems can be found in the Ugandan Western region, Ghana, Cameroon and Kenya. These projects show that micro-grids are a cost-effective alternative to national grid extensions and can be cheaper than stand-alone systems. However, high upfront costs and low household budgets hamper their diffusion. These obstacles may be overcome through financing options such as community saving schemes or grants from international donors. Electricity tariffs can be raised with pre-paid cards of mobile networks to offer a simple and projectable payment scheme to poor households.

During the implementation phase of micro-grids, it is important to achieve a high grade of community involvement to ensure their long-time sustainability. System components should be procured domestically whenever possible. Moreover, recycling strategies for parts, in particular for batteries and solar panels, should be developed to secure the environmental soundness of their disposal.

Finally, it is important to conduct further research as well as concrete feasibility and market studies to elaborate more closely on the potential of decentralized grids and component recycling in Uganda. Nevertheless, solar stand-alone systems and decentralized grids based on a mix of renewable energy resources can be the right generation option to increase social welfare and scale up the domestic production in Uganda.

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10. Annex

10.1. Annex I: Guiding Questionnaires Arua Field Assessment

Guiding Questionnaire Schools

1. Tell us a bit about the school's history.
2. What was the situation before the school got solar electricity?
3. How did you hear about solar electrification?
4. What made you decide to get your school electrified?
5. How long has the school used this electricity? What do you use it for exactly?
6. Was the process of acquiring solar difficult? How did you deal with the challenges?
7. What benefits have you seen so far?
    a. Enrolment figures (before – after)
    b. Reading time (before – after)
    c. Motivation for studying
    d. Situation of lesson preparation and revision of teachers (before – after)
    e. Attendance of students (before – after)
    f. Performance: UCE (before – after)
    g. Any other extra-curriculum activities
    h. Other bonus activities from other institutions (e.g. conferences, meetings, etc.)
    i. Any savings from energy use? (Impact on electricity bill)
8. Are other energy forms still in use? Why?
9. Were there any problems with the system so far? Any faults?
10. Who is responsible for maintenance? How many people?
11. Could any challenges in regards to maintaining be observed?
12. Do you know any local Technical Engineer?
13. Did you open an account for operation & maintenance costs so far?
    a. What is the amount saved so far?
    b. What are the plans?
    c. How high is the energy fee?
14. Which impact on the institution's status in comparison to other institutions in the area could be noticed?
15. How did the students / teaching body generally react to having electricity?
16. How else did the quality / efficiency of education change?
17. Are there any other developments that are worth being mentioned?

Guiding Questionnaire Sub-county headquarters

1. How did you hear about solar electrification?
2. What was the situation like before?
3. How long has the office had solar? What is it used for?
4. Are there any marked benefits that you can see, from having solar electricity?
    a. Productive use of time for planning, documentation and reporting (time saved for printing, etc.)? (before – after)
    b. Security situation
    c. Communication (phone charging, PCs, etc.)
    d. Any reductions of the electricity bill?
    e. Did solar PV make it easier to achieve targets (SDP planning, reporting, reliability) in time?
5. Which economic benefits since the installation of the system could be observed?
    a. Was money saved due to solar and can it now be used for other purposes in development? Prioritization?
    b. Time?
    c. Incentives?
    d. Bonus uses of facilities?
6. Are there other energy sources in use? Which? Why?
7. Were there any problems in regards to the system so far? Any faults?
8. Who is responsible for maintenance? How many people?
9. Do you know any Technical Engineer?
10. Did you open an account for operation & maintenance costs so far?
    a. What is the amount saved so far?
    b. What are the plans?
    c. How is money collected for this?
11. Could any challenges in regards to maintenance be observed?
12. How and in which areas has the performance in comparison to other sub-county headquarters changed?
13. Can an impact on absenteeism be observed?
14. How did employees react to having electricity?
15. Are there any other developments that are worth being mentioned?

Guiding Questionnaire Health Centres

1. Tell us a bit about the health centre's history.
2. What was the situation before the HC got solar electricity?
3. How did you hear about solar electrification?
4. What made you decide to get your HC electrified?
5. How long has the HC used this electricity? What do you use it for exactly?
6. Was the process of acquiring solar difficult? How did you deal with the challenges?
7. What benefits have you seen so far? (Get actual figures concerning reduction in the electricity bill, refrigeration, etc.)?
    a. Productive use of time
    b. Reduced absenteeism of staff
    c. Communication
    d. Efficient work (quality and time for treatment)
    e. Accessibility of HC at night
    f. Security
    g. Status quo of the HC in comparison to others in the area
8. Are other energy forms still in use? Why?
9. Were there any problems with the system so far? Any faults?
10. Who is responsible for maintenance? How many people?
11. Do you know any technical engineer?
12. Could any challenges in regards to maintaining be observed?
13. How did the motivation of the employees change?
14. Does the HC attract more patients than before? (actual numbers)
15. How and in which areas did the overall HC performance change? (more patients, more successful in treating patients, etc.)
16. How did the staff / patients generally react to having electricity?
17. Are there any other developments that are worth being mentioned?

10.2. Annex II: Summary Matrices

Summary Matrix Impact Assessment GIZ-PREEEP Solar Electrification Secondary Schools

	Electricity situation before	Current energy/electricity situation	Savings	Benefits	Problems	Developments
St. Theresa SS 01.05.2011	220V-generator paraffin lamps for reading brought by students	• solar PV, 820 Wp • wood fuel for cooking • diesel for grinding mills • paraffin for lab experiments	• 600,000 USH (fuel) per term • 400,000 USH for generator repairs • the money saved was used to build a new classroom block	• + 180 students • reading time increased to 3 hours and night preparation courses were introduced • teachers find it easier to prepare classes and stay longer, exams are typed and printed, grade lists were introduced • students attend more regularly • more 2nd-grades and for the first time a 1st-grade at the senior-levels • printing and copying services for the community • the district inspectors were impressed by the progress the school had made	• bulbs had to be replaced, the procurement of good-quality bulbs is difficult in Arua • printer broke and a new one was acquired	• the school would like to acquire an efficient cooking stove
Aria SS 01.06.2011	paraffin lamps for reading brought by students	• solar PV, 1650 Wp • wood fuel for cooking	no savings for the school	• reading time was prolonged by 1 hour • after-supper-teaching has been introduced • exams can be processed and consultative meetings be held after sunset • neighbours and community members can charge their phones for 200 USH	• lights in the girls' dormitory are flickering • one important reading room has too few lights • one power regulator was renewed • two bulbs were renewed • printer does not have a 2-in-1 function • no separate account was set up so far, but 505,000 USH saved for O&M • students and community developed ownership	• the system should be expanded to six staff quarters • improvement of the science lab situation • a 2-in-1 printer shall be acquired

Oluko SS 01.09.2011	paraffin lamps for reading brought by students	• solar PV, 680 Wp • wood fuel for cooking	no savings for the school	• +180 students, share of day scholars has increased • reading time was extended by 1.5 hours • reading culture has improved • teachers can charge their phones and photocopy documents • the number of 1st and 2nd-graders at the senior-level has increased • during the holidays the parish can use rooms to meet • the ministry awarded it a better grade than before • health conditions of the students improved (paraffin lamps were health-damaging)	• the charge of the system has dropped to 20%, but has recovered after the holidays • some students were caught reading during night hours. This led to overuse of the system. • no separate account was set up so far, but 5,000 USH per child and term were saved for O&M	• a new girls' dormitory was built expansion of system planned • expansion to teachers houses planned • solar water pump planned to be acquired
Okufura SS 01.06.2011	paraffin lamps for reading brought by students	• solar PV, 1350 Wp • paraffin for lighting the blocks that are not connected	• 60,000 USH (used for phone charging) can be saved • parents save money, because they do not have to provide paraffin anymore	• +50 students, more applications for the boarding school • reading time was extended by 1 to 2 hours • reading culture, motivation and performance at senior-levels improved • teachers stay longer to prepare their lessons • extra evening lessons are held, some day scholars return after supper • the school's national rank has improved • the students developed ownership • the improved performance was noticed by the ministry and it set up a fund for Okufura students in need	• inequality between boarders and day scholars in performance can be observed • four buildings are still without electricity • one PC is too few • the printer runs out of cartridge fast • 15 out of 70 bulbs needed replacement • no separate account was set up yet, but 1.2 mio USH saved on the development account • no separate account was set up yet, but 1.2 mio USH saved on the development account	• the school needs a photocopier soon • 1 dormitory, 1 lab and 1 classroom block will be built • a PC lab is planned

Sartori SS 01.06.2011	• paraffin for lighting the blocks that are not connected	• solar PV, 1100 Wp • wood fuel for cooking	• parents save money, because they do not have to provide paraffin anymore	• +50 students • reading time has become more efficient • teachers teach evening lessons, the reading and discussion culture improved • administrative lists can be used now	•boarders perform better than day scholars • some bulbs had to be renewed • no account was opened and no money saved for O&M so far	• additional teacher quarters are built • a lab and a classroom block are planned
Omugo Technical Institute 01.06.2011	• generator • paraffin for lighting the blocks that are not connected	• solar PV, 735 Wp • wood fuel for cooking	• 200,000 USH per month that were spent on fuel for the generator can be saved completely	• +200 students • reading time has increased and day scholars come back to school after supper • the security situation has improved, no thefts occur • teachers introduced evening lessons • a TV was acquired and keeps the students from going to the next trading centre • neighbours come to charge their phones • performance of students has increased • the attention of the MoES was attracted. After a visit, the ministry sponsored new building blocks. • students developed ownership and protect the system	• no extra teachers were employed • some bulbs constantly blew. The contractor fixed the problem. • the printer broke • no separate account was created, the money is saved from the annual budget • no lights in the dormitories	• introduction of an electrician and IT course is planned
Ocea Vocational Training Institute 10.10.2009	When we arrived there, we realized that the school had been closed one year ago. The panels were still in place and the guard told us that the system was still working.					

Summary Matrix Impact Assessment GIZ-PREEEP Solar Electrification Sub-County Headquarters

	Electricity situation before	Current energy/electricity situation	Savings	Benefits	Problems	Developments
Ajia 04.01.2011	no electricity at all no PCs/printers	• solar PV, 780 Wp	• printing costs: per bulk app.. 1,500 USH + fuel costs had to be paid	• working time can be used more efficiently • fewer long trips to Arua • in emergency cases, community members can charge their cell phones • absenteeism of the staff members has decreased • team spirit improved and the staff consults more often	• two blackouts happened so far. More employees (interns) used the system for laptops then. • no account for O&M was set up so far. The money needed is taken from the general fund account. • high-quality bulbs could only be ordered in Kampala and sent on bus	• head teachers of schools nearby came to see the system and applied for one later on
Ogoko 04.01.2011	generator 1 PC	• solar PV, 780 Wp	• 80,000 USH a week for fuel can be saved • money saved will be used for O&M	• the office performs better, 70% of reports are delivered on time (50% before) • fewer long typing and printing trips to Arua • better security situation for the entire community due to security lights • work can be finished in the evening hours if necessary • sometimes SC chiefs from Rhino Camp and other SCs come to type and print • the staff's motivation increased • absenteeism of the staff members has decreased • community meetings can be held until 8 pm	• the printer runs out of cartridge fast • no separate account has been set up so far, so nothing was saved on paper only for the purpose of solar	• the renovation of the building will be a challenge. The system has to be removed and re-installed. • new staff houses will be built

Pajulu 04.01.2011	generator 1 PC, 1 laptop, 1 printer	• solar PV, 780 Wp	• 100,000 USH a month for fuel can be saved • money saved is spent on co-funding production, education and health projects	• work can be done quicker • improved efficiency • work can be finished in the evening hours if necessary • since everyone approaching can be seen now, the security situation is better • communication is more efficient since phone charging and printing is done at the office • reports are delivered on time and targets can be achieved easier • lighting during rainy season • community members can charge their phones	• no separate account has been set up so far • no money was saved yet. Money for maintenance will be taken out of the general maintenance fund	• the SC has become a role model for other SC-HQs • the SC wants to add sockets to offer a phone charging service to the community • the SC-HQ wants to extend the system to staff houses
Adumi 04.01.2011	generator 1 PC, 1 printer	• solar PV, 780 Wp	• 40,000 USH can be saved	• documents are delivered on time, printed in the office instead of in Arua town, reports can be typed instead of written by hand • the guards can recognize approaching people easier during night hours • batteries of phones are always charged due to plugs at the office • youth parties held in front of the building are better, because of the security lighting • staff absenteeism has improved	• one PC broke after some months. The contractor had a look at it, but did not replace or repair it. • not all the blocks are connected • the system had a blackout, when a rat bit through a cable. A staff member with technical background repaired the damage. • one time a line between two houses was disconnected, but repaired soon • the SC-HQ did not open a spate account for the PV system yet. But 1 mio USH were saved from the annual budget. • one staff room is completely in darkness now, which has a negative impact on the motivation of the staff member staying there	• the SC-HQ would like to acquire more PCs • a printer including a photocopying function is planned to be acquired

Summary Matrix Impact Assessment GIZ-PREEEP Solar Electrification Health Centres

	Electricity situation before	Current energy/electricity situation	Savings	Benefits	Problems	Developments
Lefori HC III 30.06.2011	halogen lamps for lighting	• solar PV, 1110 Wp • gas for vaccine refrigeration • charcoal for instrument boiling and cooking • paraffin for light in staff houses	• 10 - 15 l of paraffin a quarter provided by district • staff saves approx. 2,500 USH paraffin costs a week	• more efficient use of time for treatment • continuous medical education in the evenings • phones are always charged and can be used for emergency calls and office communication • treatments are easier with light • better accessibility and security at night • staff lifestyle has improved: (1) no paraffin has to be bought any more, (2) more family quality time during evening hours • more patients and more staff (+5)	• replacement of three bulbs • sustainability: (1) no monetary capacity of the HC to renew things, (2) early planning will be necessary	• staff plans to purchase a TV • one staff quarter has to be renovated and the PV system extended
Munu HC II 30.06.2011	solar lamps for lighting halogen lamps for lighting	• solar PV, 300 Wp • gas for vaccine refrigeration • charcoal for instrument boiling and cooking	• paraffin a quarter provided by district • staff saves approx. 3,000 USH paraffin costs a month	• paper work can be finalized at night • phones are always charged and communication is easier • emergency treatment has become more efficient • better accessibility and security at night • staff performs better	• one bulb blew and needs replacement	• staff plans to purchase a VCR • new staff houses will be build • potential upgrade to HC III

Goopi HC II 30.06.2011	halogen lamps for lighting patients also had to bring their lamps	• solar PV • gas for vaccine refrigeration • charcoal for instrument boiling and cooking • paraffin for burning waste	• paraffin a quarter provided by district • when it ran out of paraffin, the HC bought paraffin on its own. Each time 6,000 USH were spent.	• staff can write reports until 10 pm • reports are delivered more timely now • communication has become easier • emergency treatment has become more efficient • the HC is easier to access now during night hours • security is better, because snakes can be recognized easier now • continuous medical education in the evenings • staff performance increased • patients do not have to provide paraffin anymore	• 3 bulbs were replaced • one lamp in the maternity ward broke during a delivery, the contractor checked on it, but did not repair it yet • during the rainy season, the charge is lower •cleaning is a problem, because the HC does not have a ladder • the sustainability of the system will become a problem, because the district would have to provide a new components	• an additional staff quarter will be built • gas refrigeration is problematic. The HC would like to have a solar-driven one. • the comprehensive nurse would like to purchase and plug in a private PC soon • the staff would like to acquire a TV in future
Ocea HC II 10.10.2009	n/a	• solar PV, 705 Wp • gas for vaccine refrigeration • charcoal for instrument boiling and cooking • paraffin for lighting the staff quarters where the system does not work anymore	• no paraffin has to be bought by the staff	• possible to work during night • emergency treatment has become more efficient • communication has become easier • more emergencies are approaching the HC during night	• the battery of one staff house has collapsed • in the same staff house 4 bulbs blew and cannot be replaced (in the past the comprehensive nurse got new ones from GIZ Arua) • two security lights broke and cannot be replaced • one time a line between two houses was disconnected, but repaired soon • no one is really in charge of maintenance • one staff room is completely in darkness now, which has a negative impact on the motivation of the staff member staying there	n/a