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Renewable based distributed generation in Uganda: Resource potential and status of exploitation

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ABSTRACT

Uganda is gifted by nature with abundant energy resources, mainly renewables, which can potentially provide the country with sufficient capacity to meet future growth in energy demand. Surprisingly, Uganda has one of the lowest electricity penetration levels, with only 9–12% of the total population having electricity access; 2–3% of them living in rural communities. There is multitude of challenges facing the energy sector of Uganda, forcing energy demand to always exceed the supply. For decades, hydropower has been and is still the base electricity supply of the country with a supplement of limited biomass, diesel based thermal and solar electricity. The objective of this paper is to review the potential and progress of renewable based distributed generation in Uganda. The potential of the country's natural renewable resources and existing distributed generation is described and existing government policies are assessed. The challenges facing the energy sector and the suggested remedies are discussed. Various distributed generation systems that could be incorporated into the energy system of the country to improve renewable energy (RE) utilization and possibly contribute to the electricity needs of the population are also proposed and discussed. Exploitation of abundant RE resources through distributed energy generation around the region will not only improve the electricity needs of the country but also increase the economic welfare of the growing population.

Contents

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1. Introduction

Recent research showed that about 2% of world diseases is due to indoor air pollution emanating from solid-fuel cooking; the rate doubles in the poorest nations to 4%. As a result, approximately 1.6 million people die prematurely every year [1]. Solid biofuels provide nearly 50% of Africa's energy requirements and statistical figures show that about 94% and 73% of the rural and urban households in Africa are dependent on wood and charcoal for their energy needs, respectively [2]. Uganda is gifted by nature with abundant energy resources, mainly renewable, which can potentially provide the country with a sufficient capacity to meet the energy needs of the growing population. Despite this, the level of electricity supply and access by the population remains low. The abundant energy resources however have not been fully utilized, rendering the country to have one of the lowest electricity access levels, with only 5% and 9–12% of the total population reported to have access to electricity in 2005 and 2010, respectively [3,4]. In rural areas, the access levels are even lower, at only 2–3%. By comparison, Uganda's neighbor, Kenya, had connection rates of 18% for urban populations and 4% for rural populations in 2011 [5]. This can be attributed to various factors, but continued poverty is both a cause and a result. Uganda lacks energy access because it is poor, and remains poor because it lacks access to energy [6]. Electricity accessibility is vital to achieve the Millennium Development Goals on poverty reduction and environmental sustainability [7]. Where private industries try to supplement the existing grid power in Uganda, they mainly do so using electricity from diesel generators. For example, Muzizi Tea Estate had no connection to the national grid in 2007 and relied on two 200 kW and one 100 kW diesel generators for electricity [8]. This increases environmental pollution and greenhouse gases (GHG), leading to more global warming, while also exposing tea production to volatile fuel prices.

Research has been conducted on renewable energy resource exploitation in some countries across the African continent. The main purpose of briefly reviewing the energy status of some African countries is to show how different states have developed measures to boost the use of renewable energy (RE) in their individual regions, from which Uganda can draw lessons. Mohammed et al. conducted a study on the exploitation of local RE resources, including solar, biomass, wind, hydropower, and geothermal, in sub-Saharan Africa [9,10]. The authors covered the necessity to integrate power generation from RE in order to improve the energy supply of these countries. In another study, Mohammed et al. showed an increase in exploitation of wood-based bioenergy in the same region, especially in Ghana, Uganda, and Nigeria. From the study, the authors exposed massive consumption of bioenergy in the form of wood fuel resulting in deforestation, consequently affecting the environment [11]. An economic analysis for expanding RE to provide electricity access to rural areas in sub-Saharan Africa has been presented in Ref. [12], in which the study found that decentralized RE expansion is not the only solution to universal access; however, it is an important component of the global solution for universal access to electricity.

Subedi et al. performed research to assess the link between development of wood-based biomass energy and deforestation. The authors concluded that the biogas production has the potential to reduce deforestation by providing a source of energy that would otherwise be provided by wood fuel [13]. In another paper, Shaaban et al. reviewed the potential of RE in Nigeria. The authors described possible government policies to realize rural electrification based on wider RE applications [14]. It is revealed that a RE Master Plan was formulated to increase RE investment in Nigeria. The objective of this plan was to promote sustainable energy development in this country [15]. However, the objective of the plans has not appreciatively achieved due to inherent obstacles militating against the effective implementation of an orderly energy policy in Nigeria [16].

Mohammed et al. and Hensley et al. conducted a review of biomass energy potential and evaluated bioenergy resources for rural electrification in Ghana [17,18], showing that increased investment in renewable energy resources will in the long run balance the national energy equation, ensure energy security and promote sustainable development. Challenges for sustainable development in the same country have been studied by focusing on the rural energy sector [19], the most important of which were noted as technological constraints in relation to local food systems, traditions, and environmental protection issues. In addition, Kemausuor et al. conducted a review of national policy for increasing access of energy in Ghana focusing on RE [20]. In another sub-Saharan country, Malawi, small-scale hydropower has been developing over the last two decades. Chiyembekezo presented the latest status of potential and application of small-scale hydropower in the country [21]. A study on off-grid generation options based on PV and the micro-hydro hybrid system for a remote area in Cameroon was simulated in [22]. It is concluded that the micro-hydro hybrid system is the cheapest option for villages located in the southern parts, while the PV hybrid system is the cheapest option for villages in the northern parts of Cameroon with an insolation level of at least 5.55 kW h/m^2/day. This indicates that whereas some RE energy resources may not provide a sizable amount of enough in one location, they can work well in another location, necessitating the diversification of the energy supply with several RE energy resources available in the country.

In Ref. [5], the authors reviewed the potential of RE sources, i.e. hydropower, biomass, wind, solar and geothermal, in Kenya, a country in the East Africa region. Of the potential RE sources, biomass energy has huge potential to help meet the strong growth of energy demand in the country. A study on the potential of biomass energy in Kenya was also performed. It was concluded that the energy from biowaste residues can play a major role as a substitute for fossil fuel based electricity generation in the country

[23]. In addition to these efforts, Abdullah and Jeanty examined the willingness of households in Kusumu District, Kenya, to pay for energy and energy services. This was intended to promote electricity access in rural communities by showing that the price households were willing to pay exceeded the cost of electricity delivery [24].

In Tanzania, another part of East Africa, the planning and regulation of rural electrification were done in line with 2008 Electrification Act. One of the action plans was to diversify energy sources by exploiting wind and geothermal energy, as well as upgrading the existing hydropower, biomass, and solar energy sources [25]. This would provide a more secure energy supply to the country as well as benefiting from other advantages of RE.

A study of agricultural and forest residues based bioenergy potential and review of bioenergy technologies development in Uganda is conducted by Okello et al. [26]. It is indicated that bioenergy can make a considerable contribution to RE diversification and the use of improved bioenergy technologies is recommended to minimize the negative impact on the environment and to guarantee sustainable energy production from biomass [25–27]. Despite some efforts being underway to improve the biomass sector, much efforts are still necessary to improve the level of technology used in biomass utilization such as the use of sustainable technologies for small-scale biochar production [28]. This is one of the solutions that is likely to strengthen the bioenergy sector in the country.

Uganda's RE potential remains underused and underspecified. In this paper, the resources potential and status of exploitation of renewable based distributed generation in Uganda are investigated. The study covers biomass, hydropower, solar, wind, and geothermal energy resources as well as the existing policies on RE.

2. Background of Uganda and the energy sector in general

Uganda is a landlocked country located in East Africa, bordered by Kenya to the east, South Sudan in the north, Democratic Republic of the Congo in the west, Rwanda in the southwest and Tanzania in the south. Located on the basin of River Nile, this country is situated between latitudes of 4°N and 2°S and longitudes of 29° and 35°E. Almost a fifth of the country is made up of open water or swampland. This land varies in its physical features from plains to mountains and forests [29]. The population of Uganda is approximately 35 million [30]. The economy of Uganda is dependent mostly on agriculture. Uganda is bestowed with a variety of RE resources like biomass, solar, geothermal, wind and hydropower, which will be explored in detail in Section 3.

Since attaining independence in 1963, Uganda experienced low levels of Gross Domestic Product (GDP) growth from a low base, growing from less than US$100 per capita in 1962, to its maximum value of about US$500 in 2012 as shown in Fig. 1. This can mainly be attributed to the difficult political times and frequent political regime changes during this period. In fact Neelsen et al. stresses that tens of years of political disorder and fierce conflicts are partly responsible for making Uganda one of the poorest countries in the world [31].

Fig. 2 shows the comparison of GDP per capita for Uganda and other countries. It can be observed that in the 1960s, Uganda was at the same level of development as countries like Malaysia, Mauritius and Republic of Korea. However, the difference between Uganda's GDP and the other countries under comparison has widened for a number of reasons, the major one being the availability of energy to support economic and social activities in the country. For a long time it has been well understood that there is a direct relationship between insufficient energy supply and low levels of development [3]. For example, Malaysia with a total

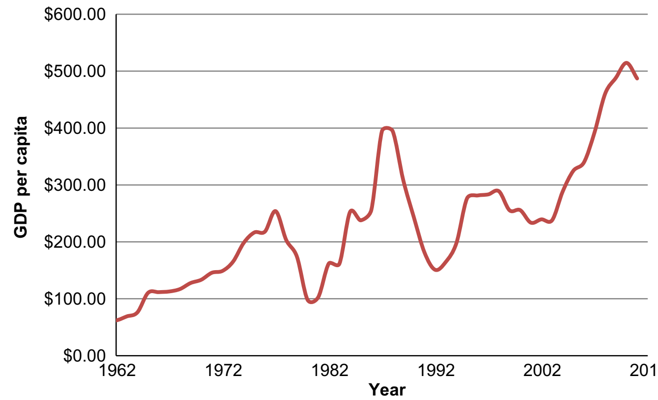

Fig. 1. The trend of Uganda's GDP from 1962 to 2012.

population of about 24 million generates 2091 MW from only hydro [32], which is already higher as compared to Uganda with about 37 million people (mid 2012) and a total generation capacity of only around 820.5 MW [33].

The total installed generation capacity of Uganda is around 820.5 MW and the available (usable) generation is 558.5 MW. Peak demand is about 487 MW and the annual average load growth is 10%. Currently, energy supply in Uganda is based on large hydropower (82%), thermal (10%), mini-hydro (5%), and cogeneration (3%) [34]. Uganda's current base power source is the power generated from hydroelectric power stations located at Nalubaale and Kiira Power Stations (formally Owen falls dam) in Jinja. In addition, there are thermal, mini- and micro-hydro power stations scattered around the country, some of which contribute to the national power grid and some that directly serve specific communities and individuals.

Hydropower is the predominant source of energy to generate electricity in Uganda. The main grid obtains its rest of energy from thermal generators and bagasse power plants. Some off-grid power plants supply power to some areas. Kisiizi Hospital, West Nile Rural Electrification Company (WENRECO) and Kihihi thermal generation plants are some examples. Power is also imported from Rwanda for Kisoro town, as it is near a grid from Rwanda that provides power more affordably than that from the Ugandan grid. Uganda also exports some power to nearby areas in neighboring Rwanda, Tanzania and Kenya [35]. Increase in cogeneration in collaboration with sugarcane industries, dissemination of PV systems in rural areas and supply of energy saving equipment are some of the policies under consideration. Uganda is also planning a nuclear energy program. The Atomic Energy Act 2008 was promulgated on 18th February 2009 which is paving the way for a nuclear program [36]. Uganda's nuclear potential has been championed since 2009 by IBI International and recently the energy ministry signed a five-year Framework with the International Atomic Energy Agency (IAEA) for safe application nuclear technologies. The Uranium Strategy proposes working with the Government of Uganda towards a nuclear electrical power generation program to meet the current and future needs of Uganda plus potential exports of electrical power to the East African region. However, some experts have cast doubt on the country's ability to develop nuclear technology [37].

3. Renewable energy resource potential in Uganda

3.1. Wind energy

Earlier studies show that wind speed in some regions of Uganda is moderate for wind to electric energy conversion, with

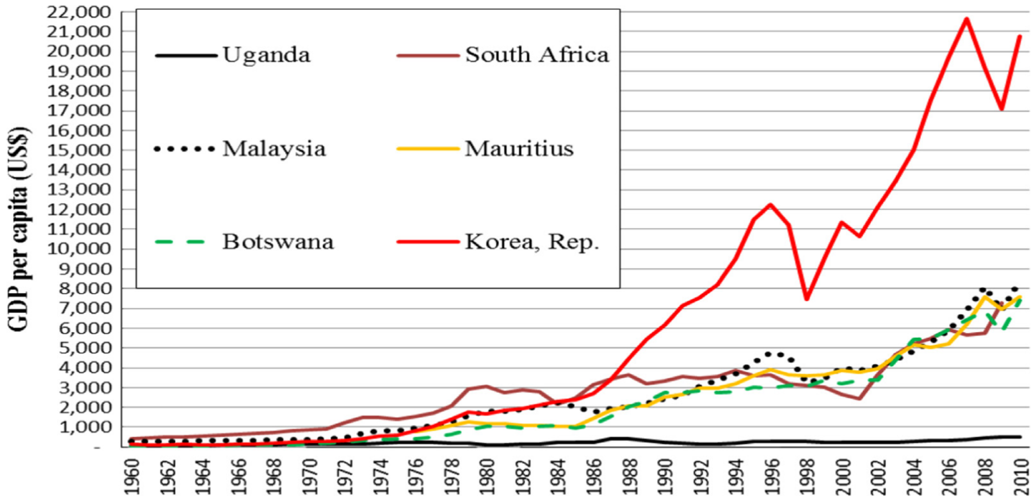

Fig. 2. Comparison of the GDP per capita for Uganda and other countries [32].

mean wind speeds at heights less than 10 m ranging from 1.8 m/s to about 4 m/s, while the optimal wind speed for typical 10 kW turbines at this height being 12 m/s [38]. Wind data collected by the Meteorology Department of the Ministry of Energy and Mineral Development (MEMD) reveals that the wind speed is merely appropriate to fulfill the energy requirement for special use such as water pumping, especially in the Karamoja area in remote, northeastern Uganda. Small industries with power capacity needs ranging from 2.5 kV to 10 kV in rural areas can be satisfied using wind energy if numerous small scale wind turbines are installed throughout the region where wind resources are available. However, wind energy has not received as much attention as solar energy as an alternative to hydro in Uganda.

3.2. Solar energy

Solar energy plays a significant role in the family of renewable energy. Generally, there are four ways of utilizing solar energy: (1) solar photovoltaic (PV) power generation, (2) solar thermal electric power generation, (3) solar water heaters, and (4) solar houses in building applications [39]. The unit cost PV is decreasing day by day and with technological advancement and efforts to boost efficiency, PV will ultimately become the dominant energy supplier in the world [40]. It is projected that PV will provide around 345 GW equivalent to 4% by year 2020 and 1081 GW for 2030 [41]. Uganda is endowed with abundant sunshine, which is a blessing that should be turned into prosperity by transforming the available solar potential into usable electric energy. Fig. 3 displays a map that shows solar energy availability in Uganda. Available solar data visibly demonstrates that solar energy is high all over the year, even during the rainy seasons. Generally, the country has peak solar radiation of 5–6 kW h/m^2/day on the horizontal surface, signifying an outstanding potential for solar energy use [42,43]. With a mean solar radiation of 5.1 kW h/m^2/day on a horizontal surface, it is reported that the country has a gross solar energy potential of about 11.98×10^8 MW h/[day/year]. At an estimated conversion efficiency of 10%, it is estimated that this provides 11.98×10^7 MW h of energy per [day/year] [44], which is about 3422 kW h per capita, a value more than the electric energy consumption of 2967 kW h per capita for Argentina in 2011 [45]. It can be observed from the map in Fig. 3 that the highest potential of about 5.6 to 6.8 kW h/m^2/day occurs in the western part in the districts of Hoima, Masindi and Kabale as well as in the North-eastern parts of Kotido, Moroto and Nakapiripit. The biggest area of the country possesses solar radiation between 4.8 to 5.6 kW h/m^2/day including the Northern, Central and Southern regions. Even the colder areas such as Kabale, Kisoro, Kanungu in the Southeastern part still have solar radiation between 2.4 and 4 kW h/m^2/day which is also attractive for some solar applications such as solar water heating.

3.3. Hydropower

The country contains various water bodies including Lakes Albert, Kyoga, Wamala, Katwe, Bisina, Nakivale, Bunyonyi, Mburo, George and the largest Lake Victoria which is shared by Uganda, Tanzania and Kenya. Rivers include Kagera, Aswa, Nile and other small ones [35]. The main and base electricity supply is generated from the Nile River which is the major contributor of electricity, primarily from the Kiira, Nalubale and the New Bujagali hydropower stations [42].

3.4. Biomass energy

Biomass comprises of all biological material derived from living, or recently living, organisms. In the context of biomass for energy this is often used to mean plant based material, but biomass can equally apply to both animal and vegetable derived material [46]. With the inflation of oil prices, biomass based power generation is becoming increasingly competitive and considerably cheaper than thermal power based on fossil fuels. The need for modern biomass energy has become more essential due to the increasing scarcity of hydropower resulting from increased electricity demand in addition to unfavorable weather changes that have resulted in reduced water levels in the Lake Victoria catchment area.

The cogeneration/trigeneration systems are such systems which comprise an integration of primary and secondary subsystems that generates power, air-conditioning and refrigeration using a single energy source [47]. Energy cogeneration is one of the energy production technologies where biomass energy can be used as a clean form of energy whereby simultaneous production of two or more forms of energy such as heat and electro-mechanical energy from the same input source is possible [48]. A significant peat resources of about 25 million tons is feasibly available for power generation which is equivalent to 800 MW of potential capacity for 50 years [49]. This level of potential is quite high if well utilized with proper energy harvesting systems such as heating, ventilation and air conditioning (HVAC) systems which

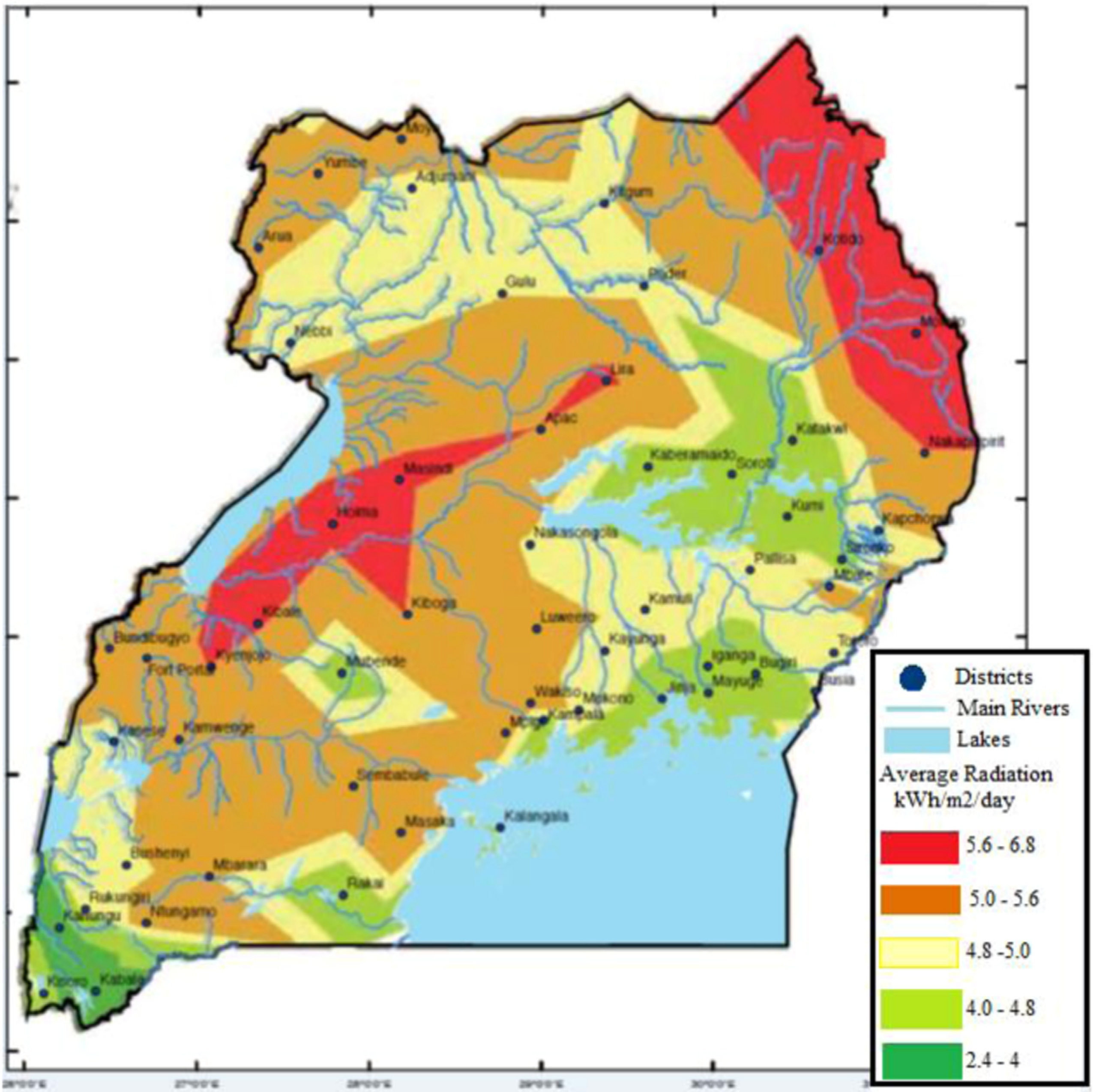

Fig. 3. Solar energy availability in Uganda.

are noted to constitute a major part of electrical energy consumption [50].

3.5. Geothermal energy

Geothermal energy, one of the potential RE sources in Uganda, is mainly concentrated in the western region. More than 40 geothermal sites were studied for their prospect parameters like reservoir temperature, chemistry of reservoir, natural heat transfer, and fluid characteristics to identify specific project areas and prioritize them for more detailed investigation [34]. Fig. 4 shows a map with identified sites for geothermal power generation in Uganda. From the study carried out, three major potential areas including Kibiro, Katwe, and Bulanga were found to have high potential for geothermal power generation with combined estimated power potential of 450 MW. These three area sites are characterized by high reservoir temperatures and high ground permeability resulting from their tectonic and volcanic features. These are located near the western Rift Valley of Uganda [51].

4. The status of RE application in Uganda

Uganda's energy sector is undeveloped and characterized by, among other things, extremely low levels of modern energy consumption and heavy reliance on biomass energy which accounts for 93% of total energy consumption. It is envisaged that this trend will continue in the foreseeable future. Petroleum accounts for 6% of total energy consumption, while electricity accounts for 1% of the total national energy balance.

Biomass is predominantly used at the household level for cooking and heating applications mainly in form of wood or charcoal. Wood and charcoal are respectively used on traditional “three bricks” stoves and improved efficient stoves which are

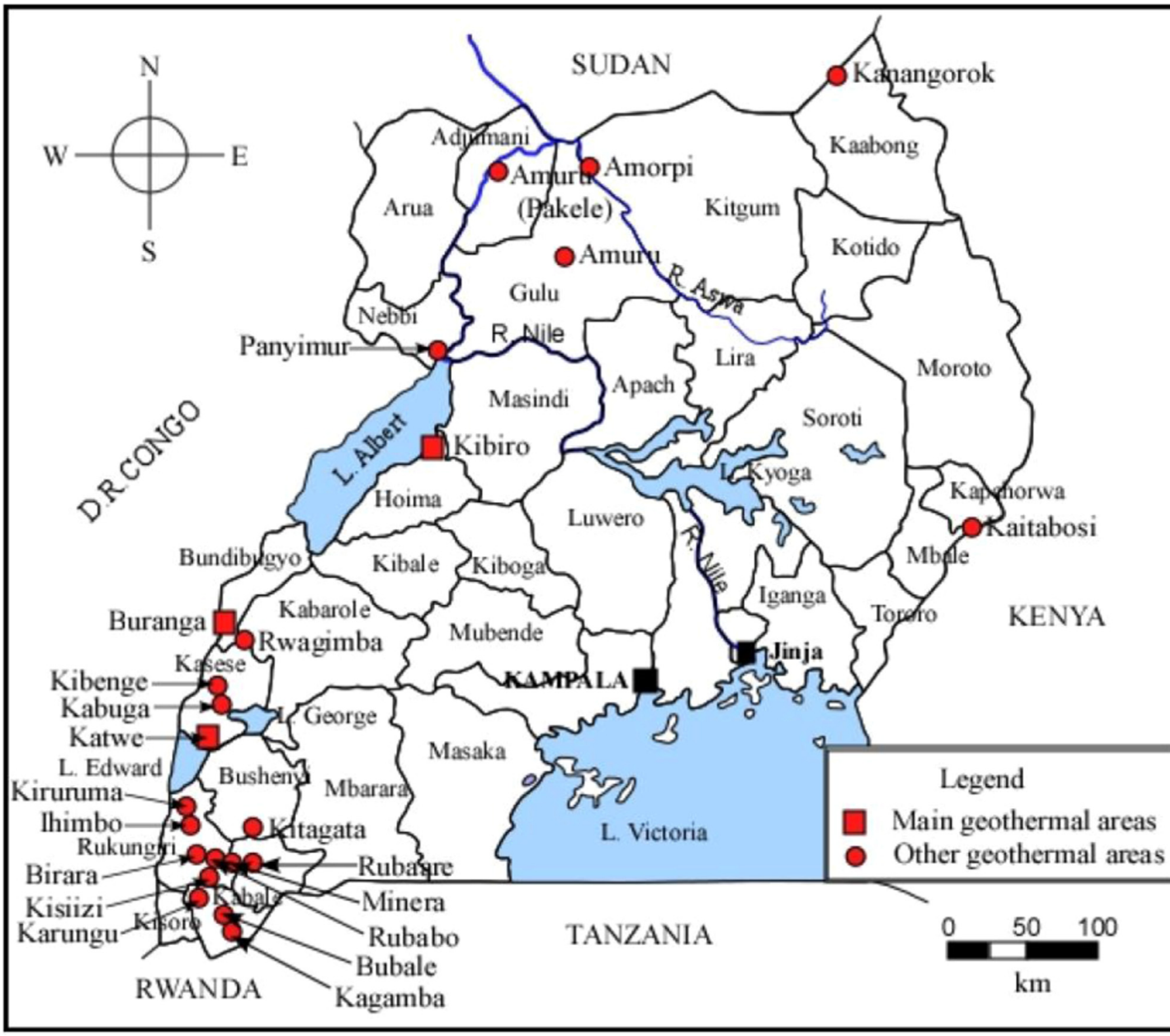

Fig. 4. Map showing identified sites for geothermal power generation in Uganda [50].

made out of steel and clay [52]. The traditional "three bricks" or "Jua kali" stoves are made of strong iron sheets, mainly collected from old dismantled buildings. In addition, a considerable amount of biomass is also used in the services/commercial, institutional, cottage industry and industrial sectors agro processing as fuel wood, and charcoal in restaurants and institutions, while bagasse is used in sugar factories. Use of biomass in other industries is relatively low but is on the increase with many industries switching from heavy furnace oil to vegetal wastes like coffee husks and rice husks for their thermal energy requirements [53].

Uganda's power sector is suffering from a shortage of generating capacity due to lengthy drought, inadequate investment in least cost-generation capacity and a relatively high load growth; the power deficit is currently estimated at 130 MW. This has resulted in massive electricity rationing and has forced the country to resort to expensive thermal generation. The country currently depends on hydroelectricity for around 60% of its total power generation output; the remainder of Uganda's power generation comes from thermal power stations, fired by bagasse and diesel, and a small percentage of other renewable electricity (making 4%) [51].

4.1. Wind energy

Generally the wind energy resource has not been used mainly due to limited awareness of the technology behind the functioning of wind energy systems. Another reason according to our analysis is because the wind energy resource is overshadowed by the vast solar RE potential available in almost all areas in Uganda. In addition, solar products are becoming cheaper day by day and are mainly made available at various sales outlets especially in urban centers in the country. Hybrid DG systems are proved to be more reliable and effective in performance than single source power systems especially for microgrid operations. For example, a study on the application of a micro-hybrid solar PV/hydro/wind system was conducted in which six sites with small-scale hydropower potentials were identified [54]. The analysis of the results indicated high capability of hybrid systems to cater for the electricity needs of small communities. We have observed that in the Karamoja region both wind and solar potential is available while in some other areas, wind, solar and hydro energy resources have attractive potential for hybrid systems application. In our previous research in [55], a method of determining the best hybrid renewable-based DG system with feed-in tariff (FIT) and ranking technique was presented. It was clearly observed that a hybrid wind/PV/hydro exhibited better performance compared to the PV/hydro system with storage in terms of improved reliability and increased RE penetration levels. Similarly, wind energy can be utilized if hybrid systems are adopted especially those operating on microgrid integrations in different locations in Uganda. Giannoulis et al. conducted a study on DG systems in an isolated island in Greece and the results indicated that the integration of RE through microgrid can result into increased environmental benefits with relatively high cost of energy (COE) compared to that of the main grid [56]. However, they suggested that the COE can be lowered by advocating for technologies and strategies of reducing electricity surplus in the power system, thereby rendering RE resources exploitable more efficiently.

4.2. Solar energy

Currently, solar energy is used primarily for off-grid electrification in rural communities, as well as for solar cooking, and providing water heating and power to public buildings and hospitals. Over 30,000 PV systems are installed throughout the country representing about 1.1 MW of capacity. This includes both institutional and solar home systems with the former accounting for a greater portion of that installed capacity. Currently, a 50 MW solar thermal plant, at Namugoga in the Wakiso District outside of Kampala, is being investigated by a private firm, Solar Energy for Africa [57]. The Feed-in-Tariff (FIT) scheme has attracted some investors in the solar RE development and in January 2014, the Electricity Regulatory Authority (ERA) announced the construction of eight RE projects with a total capacity of 83.7 MW which were to begin soon [58]. An on grid hybrid solar project/diesel of 1.6 MW was completed by the Premier solar company under the sponsorship of Kalangala Infrastructure services project (KIS), a company which develops environmentally sensitive infrastructure services to serve Kalangala island residents with improved access to water, safer transportation, and more reliable, renewable (solar powered) electricity. KIS is a subsidiary of InfraCo Africa Ltd. which is an international NGO that funds various projects in Africa [59].

Solar cooking also holds a significant potential in the country, with a large number of the population living in well-radiated areas, without access to energy services [42]. There have been efforts to sensitize people to the use of solar energy and small PV in the country. Joint Energy and Environment Projects (JEEP) Uganda Nordic Folk center for RE, Denmark is one of the NGOs that have sensitized the masses in areas of Arua, Luwero and Tororo [60].

The major share of the installed solar PV systems is usually project or donor supported through the government. The applications are mainly in the health, water, education and local government sectors. The World Bank-supported rural electrification program referred to as "Energy for Rural Transformation (ERT)" is the core driver behind most of the government initiated projects [51]. The solar PV market in Uganda has steadily grown over the last 15 years with new players entering the market, including foreign investors. While 10 years ago there were a handful of solar companies mainly engaged in institutional solar PV installations, there are now over 30 companies involved in the solar business (both PV and solar thermal). Table 1 gives a list of some of the private solar companies in Uganda that provide sales and services [61–66].

4.3. Hydropower

As noted in Section 3 above, Uganda has a sizeable amount of hydropower potential which is favorable for large and small scale hydro power stations. Fig. 5 shows a map highlighting the proposed, ongoing and operational hydropower sites within the region. The map has been extracted from an interactive map that shows the energy utilities of the country. An interactive map was developed by the Energy Sector GIS Working Group (E-GIS) and received an award from the parliament of the Republic of Uganda for producing the best map in support of their contribution towards the energy sector [67]. The E-GIS is a collaboration of the major players in the energy sector in Uganda such as Uganda Electricity Transmission Company Limited (UETCL), UMEME, Rural Electrification Agency (REA), MEMD and German Agency for International Cooperation (GIZ) [68]. UMEME, named for the Swahili word for lightning, is the largest electricity distribution company in Uganda. It is mandated by the government to: operate, maintain, upgrade and expand the distribution network; retail electricity to its customers; and to improve efficiency within the electricity distribution system [69].

4.3.1. Large and small hydro

The operational hydro capacity along the river is 380 MW developed at Kiira and Nalubaale, and 250 MW at Bujagali, meaning that the unexploited potential is about 1300 MW. The large hydropower projects being developed include Karuma-600 MW, Isimba-180 MW and Ayago-600 MW.

4.4. Pico, Micro-hydro

There are micro-hydropower sites but they are not located on the Nile, and although they possess potential resources, they have not been fully exploited. These are important sources of electricity for Uganda. Over 50 potential sites for small hydro have been identified near rivers with a capacity of more than 164 MW of electricity [34]. Table 2 shows the estimated capacity of a number of identified sites which have the potential for development.

Table 1
List of some of the private solar companies in Uganda: Internet sources.

Company	Location	Items	Nature	Date of establishment
Power Trust Uganda Limited	Kira Road Ntinda, Kampala	Solar panels, Solar Batteries and Appliances [61]	Private	Sept 2011
UltraTec (U) Ltd.	Kabalagala, Kampala	Solar PV, Solar water heating and Solar cookers [62]	Private	1999
MAK Power Systems Ltd.	Namungoona, Kampala	Solar Systems Sales and Services	Private	–
Suntopway Solar (U) Ltd.	Portal Avenue, Kampala	Solar systems	Private	–
Energy Systems		Solar system sales and services [63]	private	2000
Solar Construct Ltd.	Kibira road, Kampala	RE	Private	–
Solar Energy for Africa	Kampala, Mbarara. Soroti, Mbale	Sales, installations, maintenance and servicing all types of solar [64] energy/power systems, equipment and appliances	Private	15 years in existence
Davis & Shirtliff	Uganda	PV modules, hot water heaters, pumps, lighting accessories, inverters and controllers [65]	Private	1945

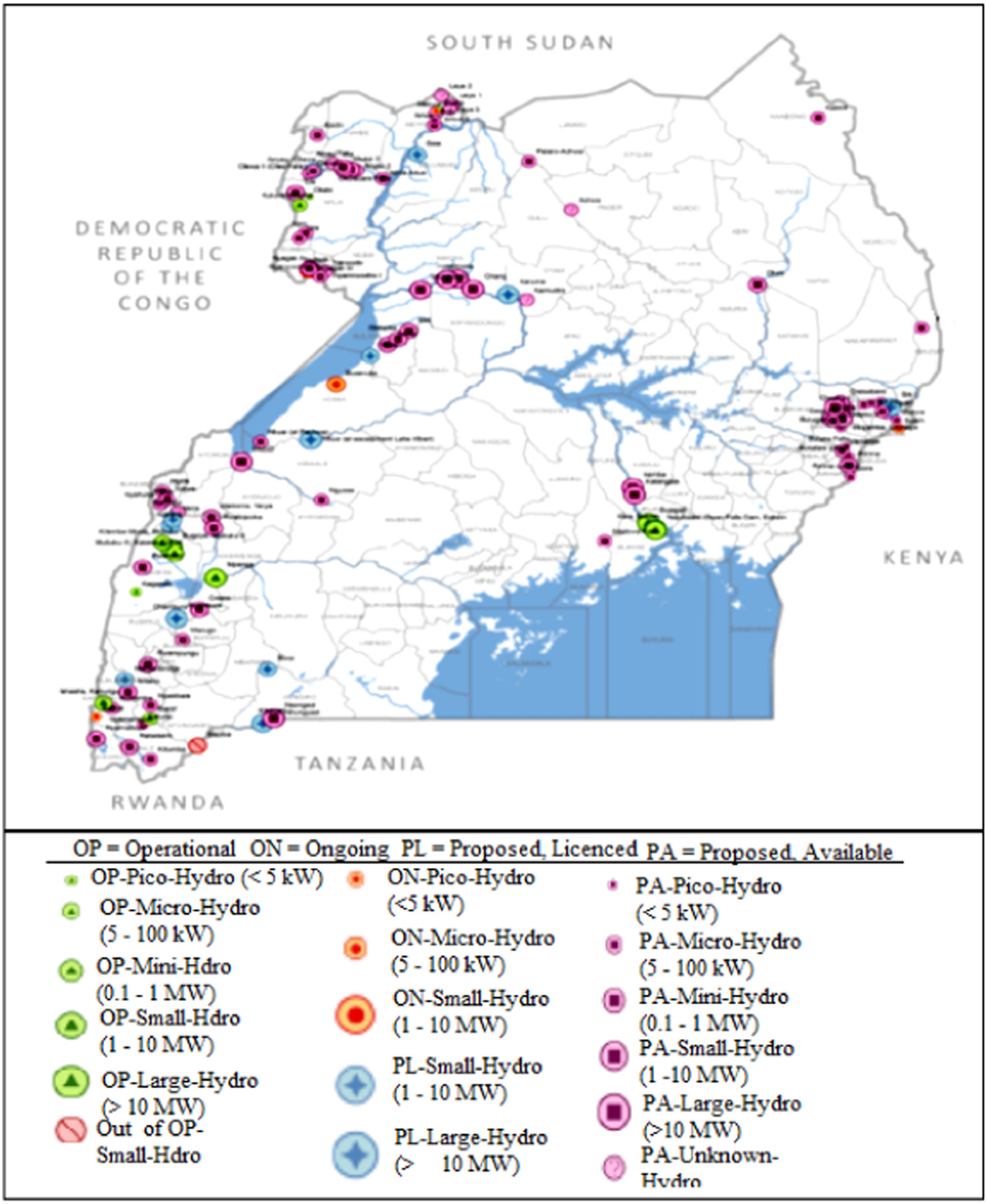

Fig. 5. Proposed, ongoing and operational hydropower sites in Uganda.

4.5. Biomass energy

Biomass contributes 85% of the total energy of the country in which 72.7% of the households use three-stone stoves and 14.8% use traditional charcoal stoves. Beyond cooking, five digester plants were installed by 2004 [26]. The traditional stoves are typical agents of indoor air pollution mainly smoke particulates, CO and CO_2. Energy-saving stoves, based on the rocket stove principle, are being promoted by the government with the support of GIZ. Under this program, more than 500,000 improved stoves have been distributed since 2005. However, despite these efforts, the current level of adoption of improved biomass combustion technology is still low in the country with about 8.7% of Ugandan households using improved biomass stoves. The major causes for

Table 2
Estimated capacity of a number of identified small hydro power sites.

Site	Estimated capacity	District
Estimated Pico hydro capacity and technical feasibility studies done		
Kakaka	7.2	Kabarole
Nyamabuyo	2.2	Kisoro
Yerya, Mahoma confluences	3	Kabarole
Siti	2.5	Kapchorwa
Nyahuka	0.65	Bundibugyo
Nkusi (at Pachwa)	0.6	Kibale
Sezibwa	0.5	Mukono
Tokwe	0.4	Bundibugyo
Ngiti	0.15	Bundibugyo
Myembe/Sirimityo	9	Mbale
Ririma	1.5	Kapchorwa
Estimated Pico hydro capacity without technical feasibility studies		
Mvepi	2.4	Arua
Sogahi	2	Kabarole
Ela	1.5	Arua
Haisesero	1	Kabale
Rwizi	0.5	Mbarara
Rwigo	4.8	Bundibugyo
Narwodo	4	Nebbi
Agoi	0.35	Arua
Kitumba	0.2	Kabale
Amua	0.18	Moyo
Leya	0.12	Moyo
Nyakibale	0.1	Rukungiri
Miria Adua	0.1	Arua
Nkusi (At escarpment/Lake Albert)	11	Kabale

Table 3
Consumption of bioenergy in Uganda.

Sector	Wood (TOE/year)	Charcoal (TOE/year)	Residents (TOE/year)
Residential	5957976	406756	488106
Commercial	1242267	195855	0
Industrial	999213	0	0
Total	8199456	602611	488106

the low adoption of these stoves are due to limited sensitization of the masses about their importance, as well as poverty. Okello [26] reported that energy-saving stoves, based on the rocket stove principle, were being promoted by the government with support of German Agency for International Cooperation (GIZ) under the “promotion of renewable energy and energy efficiency” program, but this is limited to a small portion of the population. On the other hand, those with low incomes prefer to use the traditional stoves which are generally cheaper than the improved stoves. Table 3 shows the share of bioenergy consumed every year for each sector in the country. Kakira Sugar Works Limited and Kinyara sugar mills are officially allowed to generation and supply electricity of 12 MW and 5 MW, respectively to the national grid.

4.6. *Renewable energy application in rural areas*

Despite the rapid urbanization that has been experienced, most people in Africa still reside in rural areas [70]. In Uganda, the majority of the population lives in rural areas with limited access to electricity. The rural electrification agency (REA) was formed by the MEMD in respect to the 2001 statutory instrument to improve electricity access to rural communities [71]. The projects under its mandate include grid extension, RE generation and developing microgrids for rural areas. The government has set out various strategies to improve energy access to the rural population. REA is mandated in the “REA Strategy and Plan (2013–2022)” with the task of fulfilling the government's goal of increasing rural electricity access to 22% by 2022, up from the current rate of 2% [72]. The REA board recently announced the bids for consultancy for the development and access expansion of electricity to seven towns, which is part of the implementation of the financial assistance received from the OPEC fund for international development [73]. Although the grid extension exercise is one of the major tasks for REA, the critics of this exercise say that the connection costs in rural areas are high and consequently the cost of a kW h of energy is high and power consumption is low due to few connections per kilometer [74,75]. Murphy et al. carried out the analysis of grid reliability by comparing grid extension and use distributed energy resources (DER) and they discovered that installing micro-DER systems were more cost-effective and provide more reliable energy than grid extension [76]. This is because the mean time between failures of the grid system in Uganda is high which prompts the use of other sources of electricity during frequent grid outages. However, some efforts have been made to utilize the use of solar systems especially at the roof tops for individual households. Although some solar PV projects are in operation and others in the offing, the progress of RE utilization in rural areas is too slow mainly due to a lack of financing and ignorance about the usefulness of RE systems. Therefore, the REA and the government-private in general should intensify efforts to sensitize the masses especially on the use of solar systems. Limited data about RE energy resource is another challenge. For example solar data such as global solar irradiation, diffuse radiation, etc. for different parts of the country is not usually recorded. This makes the selection and operation of renewable energy system difficult. For instance it is difficult to predict the tilt angle of a PV panel for a certain location using some intelligent methods [77], without solar radiation data.

5. Related policies

The Promotion of RE and Energy Efficiency (EE) Program (PREEEP) is a project championed by the Ministry of Energy and Mines in collaboration with GIZ to promote EE and RE. The government is also encouraging the use of energy saving appliances such as energy saving bulbs.

The National Energy Policy 2002 was mainly put forward to enable the energy sector to contribute to the economic and social welfare of Ugandan population in an environmentally sustainable way. This was followed by various initiatives such as the study of RE potentials and identifying the candidate sites for development. As a result, a number of solar and hydropower projects have been proposed and some are operational such as the Bujagaali 250 MW hydropower station.

The MEMD in 2007 announced the RE Policy 2007 (REP-2007) whose major aim was to increase the use of modern RE, from 4% to 61% of the total energy consumption (excluding hydropower) by the year 2017. Other secondary objectives were to support the provision of sustainable and reliable RE services while at the same time make it accessible to the population, mainly to foster the eradication of poverty. Modern bioenergy systems and technologies were one of the targets. It was in this policy that the Feed-in-Tariffs (FIT) for RE and Standardized Power Purchase Agreement were established. Key targets included increasing solar water heater installations to 30,000 m^2, and applying industrial energy appraising while awarding certificates of performance to outstanding industries and the distribution of efficient equipment to industries.

Table 4
FIT for RE, O&M percentage, capacity limits and the valid period for the tariff [78].

RE resource	Tariff (US$/kW h)	O&M (%)	Cumulative capacity limit (MW)				Valid period of payment (Years)
			2013	2014	2015	2016	
Hydro (H) (9 > H < =20 MW)	0.079	7.16	30	90	135	180	20
Hydro(1 > < =9 MW)	Linear tariff	7.24	30	75	105	135	20
Hydro(500kW > < =1 MW)	0.109	7.08	1	2	2.5	5.5	20
Bagasse	0.081	22.65	30	70	95	120	20
Biomass (MSW)	0.103	16.23	5	15	24	45	20
Biogas	0.115	19.23	5	15	24	45	20
Landfill gas	0.089	19.71	0	10	20	40	20
Geothermal	0.077	4.29	10	30	50	75	20
Wind	0.124	6.34	25	75	100	150	20

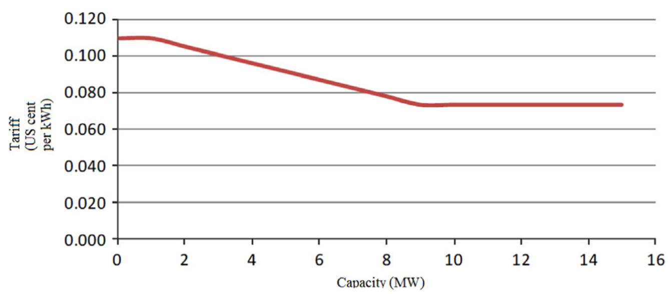

Fig. 6. Linear Tariff rates defined for 1 to 9 MW [78].

5.1. *Feed-in tariff policy*

Uganda took an early lead in East Africa to implement the FIT system. Rwanda has taken tremendous steps in developing the RES but the developments were faced with a number of regulatory challenges because the FIT was not then in place [78]. Uganda adopted the Global Energy Transfer Feed-in-Tariff (GET-FIT) scheme for RE. The Global Energy Transfer Feed-in-Tariff (GET-FIT) program is an arrangement intended to help the advancement of RE in developing countries through the creation of international public-private partnerships. In this set-up, international AAA-rated donors such as national governments, development banks, and international climate-related funds contribute premium payments for RE projects in partnership with developing country governments [79]. In Uganda, the tariffs for each energy resource technology are determined by means of a US$/kW h levelized cost-approach with the consideration of electricity generation costs incurred by RE energy operators [80]. Table 4 gives the details of the phase 2 REFIT tariffs, O&M percentage, capacity limits and payment period introduced in Uganda in 2012. To cope up with the unstable foreign exchange rate of the dollar in the country, the REFITs are accustomed to adjustment to accommodate the inflationary fluctuations by applying Eq. (1).

$$\mathrm{FIT}_y = \left[\mathrm{FIT}_{y-1} * (1-w)\right] + \left[\mathrm{FIT}_{y-1} * \frac{\mathrm{PPI}_y}{\mathrm{PPI}_{y-1}} * w\right] \quad (1)$$

where
FIT_y is the feed-in tariff applied in the current year y;
FIT_{y-1} is the feed-in tariff applied in the foregoing year;
w refers to the share of O&M in the starting FIT in the year 'y'
PPI is Core Producer Price Index defined for US by the Bureau of Labor Statistics [80].

As noted from Table 4, RE technologies are assigned constant rates with the exception of hydro in the range of 1–9 MW whose rates are defined as a function of capacity as shown in Fig. 6. Further details regarding REFIT in Uganda are found in [80].

It can be observed from Table 4 that the FIT rate is based on the cumulative capacity limit (CCL) for each year. Since larger capacity is needed in the subsequent years to maintain the FIT, independent power producers (IPP) for RE will consider the assessment of solar energy generation at large scale in which choices of configurations exist [81]. For instance, in the first configuration, they might have to consider absolute minimization of storage with excessive increase of power production capacity which is relatively cheaper due to minimized storage but with less energy security. Conversely, a configuration with extreme storage corresponding to absolute minimization of generation capacity can be applied which is more expensive, provides less power output but at the expense of increased energy security. The first configuration scheme may be one of the options to enable the IPPs to meet the required capacity limits. [80].

5.2. *Subsidy policy*

The partnership between the Private Sector Foundation of Uganda, the government through the Electricity Regulatory Authority (ERA) and nine donor agencies led to an offer of a 45% subsidy on solar power equipment, up from the earlier 17% value which was set by the government. The purpose was to encourage private suppliers to invest in solar products in rural areas to enable remote areas have access to electricity [82]. Subsidies and incentives for RE were planned and guided by The Rural Electrification Strategy and Plan covering the period 2005–2011. The aims of the strategy were to attain unbiased regional supply of energy, exploit the environmental benefits of rural electrification subsidies and promote grid expansion alongside developing off-grid electrification in remote areas. As a result, electricity has been deeply subsidized and the Ministry of Energy estimated that since 2005 the government has spent about €390 million on power subsidies. Although the subsidies have not been completely scrapped, it is anticipated that subsequent rounds of price hikes will be implemented in the near future. The decision will encourage the increase of private sector investment in the power supply sector and also enable the Uganda government to invest in large hydropower projects.

6. Challenges

There is a very close linkage between energy and development. Energy policy and strategic planning can favorably converge with any form of development provided the two concepts are planned to achieve resource diversification. Among the developing nations of Southeast Asia are countries like India, Malaysia, Singapore and China that are benefiting from a positive economic outlook and significant poverty reduction due in part to increased access to electricity [10].

Further utilization of RE resources to meet the growing energy needs of the Ugandan population can be achieved through addressing the following:

- Development of the required manpower resources

Technically trained human resources are a necessary ingredient in any developmental activity. Francis observes that two of the reasons for low private sector investment in the energy sector in Uganda are technical and financial risks [83]. In Malaysia, the lack of technical expertize from the pertinent agencies is reported to result into poor quality products and give RE utilization a bad image [84]. Therefore, the concerned authorities should prioritize the area of training and development of individuals to support the energy sector.

- Economic empowerment of the masses

Economic empowerment indirectly means reducing the level of poverty within the population. It is not exaggeration to mention that high levels of poverty are still prevalent in Africa, particularly in Uganda. Poverty alleviation can disrupt the application of RE as non-RE is inexpensive in the short term [85]. Improving electricity generation is one of the major channels for reducing economic and social problems. Javadi et al. notes that electricity can improve the human lifestyle by raising the level of health, education, welfare and technology [86]. So, the government should concentrate on advancing energy capacity alongside poverty alleviation efforts.

7. Efficient policies suggested to improve RE exploitation in Uganda

Although Uganda is one of the countries in Africa to introduce FITs, others being Tanzania, Kenya, Mauritius, Algeria, Rwanda, South Africa and Egypt [14], this policy should be well managed in order to attract potential investment companies and at the same time close monitoring of their activities should be done. Well trained personnel in the government or private audit organizations should be assigned the responsibility of handling this process in order to facilitate the smooth operation of the REFIT program. In our previous research, it was presented how the FIT can be utilized to provide electricity to different regions in Uganda by using a net metering plan [87]. However, according to our observation, the major obstacle is a lack of funding. The solution to this is incorporated in the REFIT where IPPs will be responsible for funding the power projects and sell the produced energy to the government through PPAs.

Besides the grid-connected PV systems, regional based micro-grid DG systems should be adopted especially in remote areas far away from the national grid. These have the advantages of reduced blackouts in the main grid, high efficiency performance, environmental suitability and are becoming the preferred option for new and remote applications where the cost of grid extension is unaffordable and not the best option [88].

It is suggested that the adoption of renewable energy by the individual households be further promoted to increase the exploitation of RE in Uganda. Eder et al. in their research identified three critical dimensions that are crucial for the adoption of RE as being technical, economic and social [89]. They suggest an emphasis on the relative advantages of the new technology. In addition, there are economic requirements regarding a viable financial system for adopters, especially in such a low-income market. The social dimension is critical, particularly the importance of foreign firms collaborating with local actors.

Although the government has continuously subsidized electricity, the subsidies schemes have failed to improve the electricity supply situation in the country. This may be attributed to the channels and ways of subsidization used by the authorities. The country has suffered the increasing burden of subsidizing power amidst a depreciating shilling, especially diesel generating companies, which contributed power to the grid [90]. However, this type of financing is short lived and not cost-effective as it leads to more pollution. The long term solution would be the provision of incentives to individual households or communities to install small scale RE systems in their proximity. This will definitely reduce the burden on the scarce available grid power. As an example, in Spain the government established more than 50 autonomous communities (ACs) with the powers to pass bylaws regarding the use of RE energy. There are two categories of local incentives granted to the local communities: subsidies and tax incentives [91]. The councils can authorize a non-refundable subsidization for the implementation of solar energy in which 50% of the activity cost can be funded. However, the granting process is competitive dependent on well established procedures; first based on priority and the application submitted by the community or based on nomination of the local community budget.

Pertaining to the future development of RE through the "vision 2040 report" [33], it is estimated that Uganda will require 41,738 MW by year 2040 thus increasing its electricity consumption per capita to 3668 kW h. These energy requirements are expected to be achieved through the use of the country's RE and non-RE energy resources as well as the importation of electricity from neighboring countries. In addition, national grid accessibility is also projected to be 80% and new transmission lines will be constructed to transport power especially to the economic zones as well as supporting rural electrification programs. This can easily be achieved by adopting decentralized grid access through the application of hybrid DG systems.

Given the relative importance of the development of RE resources, the government may set up a special body responsible for overseeing all the activities related to RE projects. This will help in streamlining the priority needs in this RE sector. For instance in Malaysia, the Sustainable Energy Development Authority (SEDA) was proposed to be set up with responsibilities such as advising the government on matters related to RE, promote and implement the state policies concerning RES and foster their development in the country [92].

Standardization of renewable energy production processes is necessary to support those small scale RE industries such as briquette making industries. Ngusale et al. reported the energy situation in Kenya, briquette making process as well as the challenges and opportunities in briquette making [93]. It was realized that despite the challenges faced in the briquette making process such as lack of standard ratio and specific mixture for optimum briquette production, most briquette producers are well along in the briquette business and consumers are satisfied with the use the briquette fuel as an alternative fuel. However, with standard production procedures, the quality and quantity of output would increase. In Uganda, the biomass energy strategy 2013 is a step in a right direction though more effort is needed fully empower the renewable energy industries [53].

8. Conclusion

In the beginning of the second half of the 20th century, Owen Falls dam hydropower was the first power station in the country to provide electricity for Uganda and some neighboring countries. Although other hydro power stations have been constructed supplemented by thermal diesel generation, bagasse from Kakira and other small quantities from other RE, the Ugandan population is still suffering from a lack of electricity with reported access by only about 12% of the population and per capita consumption of less than 10% of the world median consumption. Located in East Africa, Uganda is one of the countries with abundant RE resources ranging from solar, wind, hydro, geothermal and bioenergy resources. However, not even a quarter of the available RE potential is utilized at the time of writing. In this paper, we have presented the review of the potential of RE resources with regard to different regions in the country. The current status of RE application has been reviewed, and the present energy related policies and subsidy schemes have also been analyzed. Challenges facing the exploitation of RE have been discussed and efficient policies to overcome the sighted challenges and improve RE exploitation in Uganda were suggested. Future development strategies for RE in Uganda have been articulated. Although feed-in tariffs have been introduced in the country, their success will depend on how they are administered by the concerned authorities and power producers. The status of energy, in particular electricity in rural areas, has been discussed and ways to make the rural electrification scheme benefit the rural community have been suggested.

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