LEAP-RE

Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

Research & Innovation Action

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Identification of relevant inspiring cases

as a deliverable for WP14

Version Final

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Abbreviations and Acronyms

Acronym	Description
WP	Work Package
RE	Renewable Energy
RES	Renewable Energy Sources
EV	Energy Village
SDG	Sustainable Development Goals
AASTU	Addis Ababa Science and Technology University
BIUST	Botswana International University of Science and Technology
MU	Moi University
MaK	Makerere University
UVA	University of Vaasa

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Summary

This deliverable introduces six relevant inspiring cases of the LEAP-RE WP14 Energy Village project. According to the Energy Village Concept, there usually is enough renewable energy potential in a village to cover its own needs and often also some excessive potential to be used for the needs of a larger area. The villages featured in this report showcase innovative approaches to harnessing renewable energy sources for local communities, promoting sustainability, and reducing reliance on non-renewable energy sources. The renewable energy resources, the energy consumption and the hybrid system solution for six inspiring energy villages in Africa are included in this report. The villages are the AASTU campus and Wonji village in Ethiopia, Regent Hill and Majwanaadipitse in Botswana, Refugee camp (Bidibidi) in Uganda and Cheboiwo in Kenya.

The AASTU campus is endowed with enormous solar, wind, and biomass renewable energy resources due to its location near the equator. Currently, a huge amount of firewood and fuel oil is used at the campus in addition to the electricity from the grid. In the Wongi village, there is a prominent amount of biomass thanks to the local sugar factory. In addition to this, there is also potential to utilize solar and wind power. However, the village is currently not energy self-sufficient, let alone supplying to the national grid. Instead, the factory consumes a substantial amount of electricity from the grid, oil fuel and firewood. Regent Hill Energy Village is formed around the International School in Gaborone and has pre-primary, primary and secondary school classrooms, facility buildings, a sports ground, a garden and a swimming pool. The main potential source for renewable energy is solar energy. In June 2021, the school purchased a small grid-tied 40kWp solar system without storage and there are plans to further develop the system. Majwaanadipiste village is a rural, off-grid community consisting of 500 villagers with a low income and high unemployment rate. Most of the villagers only use firewood for cooking and low-quality solar lamps as light at night. Only a few villagers use gas bottles for cooking. However, there is potential for utilizing solar, wind and biomass-based energy in the village. The energy consumption or load profile for zone two in the Bidibidi refugee settlement was estimated for three primary energy uses cooking (firewood), lightning and water pumping (electricity). The Bidibidi refugee settlement has several potential renewable energy sources ranging from bioenergy sources, solar energy sources and wind energy. Most households in Cheboiwo depend on firewood and a few on charcoal for cooking. The majority of them use electricity for lighting and very few use kerosene and solar. Most residents have not adopted the use of renewable sources of energy, however, there is potential for biomass, solar and wind energy.

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All the potential energy villages presented in this deliverable are unique. However, they all have potential for producing energy based on renewable energy sources and thus shifting from fossil fuels to renewable energy and at the same time raising the quality of life of their residents.

Keywords

Energy village, Cheboiwo, Renewable energy resources, Inspiring cases, Energy consumption, potential

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1. Introduction

Africa is expected to become an increasingly energy-demanding continent now more than ever. As it stands now, with 1/5th of the world's population, Africa accounts for only 6% of global energy demand and little more than 3% of electricity demand. The average energy consumption per capita in most African countries is well below the world average and traditional use of bioenergy is still the largest source of energy in Africa, meeting 45% of primary energy demand and over half of final energy consumption, with serious consequences on health and pressure on the environment (deforestation, biodiversity loss). As is well-known the African Union (AU) is determined and committed to the full implementation of the Paris Agreement. Ever since many initiatives here at home and from international organisations have been underway to investigate renewable energy resources and energy-efficient mechanisms in alignment with Sustainable Development Goals (SDGs). Even so, Africa has a long way to go before this comes true and is awaiting more initiatives to play a key role.

In the meantime, the LEAP-RE (Long-term Europe-Africa Partnership on Renewable Energy) project came into existence with specific objectives: to accelerate the usage of reliable, sustainable and affordable renewable energy to name a few. The project has a constituting consortium of 96 partners; 21 from African countries and 13 from EU countries. Under its work package 14, four organisations in Africa namely AASTU in Ethiopia, MU in Kenya, Mak in Uganda, BUIST in Botswana and one in Europe namely UVA (the WP leader) in Finland are exploring the potential for energy villages. The energy villages and the respective countries in Africa are shown in Table 1. Renewable energy village projects have gained prominence as models for achieving energy security, environmental sustainability, and community empowerment. These projects exemplify the successful integration of renewable energy technologies into the fabric of daily life, resulting in reduced carbon emissions and enhanced quality of life for residents.

Over the last couple of years, over one million refugees have crossed into Uganda from the neighbouring countries of the Democratic Republic of Congo, South Sudan, Somalia, Eritrea and Burundi. This has been due to the instability in the Great Lakes region and the Horn of Africa (UNHCR, 2019). More than 80% of these refugees live in rural refugee settlements with only the remaining 20% as urban refugees (GIZ, 2018). Uganda's open refugee policy (UNHCR, 2018) has favoured the influx of asylum seekers who are settled as both urban refugees and others as rural refugees in the various refugee settlements across the country. It is noteworthy to mention that, unlike other refugee host countries that implement a camp-based model for refugees, Uganda implements a settlement-based model where the refugees are integrated with the host communities and have the freedom

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to move and work within the country. Nevertheless, most of these humanitarian settings are set up in areas or regions where access to natural resources, proper infrastructure and power distribution networks is already limited (Baldi et al., 2022). The notable refugee settlements in Uganda are, Bidibidi, Palorinya, Lobule, Imvepi, Adjumani, Palabek, Rhinocamp, Kiryadongo, Kyangwali, Rwamwanja, and Kyaka II refugee settlements (Response, 2020).

The refugees on integration with the host community, and not any different from the host communities, have several needs that ought to be met. These include the need for protection, education, environment and energy, food security, health and nutrition, livelihood and resilience, shelter, settlement and non-food items, water, sanitation and hygiene (WASH). As far as energy needs are concerned, both the refugees and the hosts are dependent on natural resources to meet their basic energy needs of cooking, lighting and heating (Response, 2020). The sustainable use of the resources to meet these energy needs requires proper planning for policy formulation. Planning also helps in developing guidelines for the implementation of measures to ensure sustainability. Energy planning at the village level needs an integrated ecological, economic and social model to assist sustainable rural development (Putra & Lelawati, 2014). In this case, an energy village concept is seen as a key game changer. In this subject matter, an energy village is defined as a small town or region with a population between 100 to 12000 inhabitants.

In this case, the LEAP-RE project has come in handy to provide an opportunity to accelerate the concept of sustainability of energy supply for rural settings through the Energy Village Model. The concept of Energy Village has gained prominence in several countries as spearheaded by research institutions shown in **Error! Reference source not found.**.

Table 1: List of explored potential energy villages in Africa

S/N	Energy village	Partner
1	AASTU campus	AASTU, Ethiopia
2	Langano	
3	Wonji	
4	Tulefa	
5	Regent Hill	BIUST, Botswana
6	Matsaudi	
7	Jamataka	
8	Majwanaadipitse	
9	Kayanzi	Mak, Uganda
10	Refugee camp	
11	Nakasengere	

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12	Maiba Murole	
13	Wanale	
14	Cheboiwo	MU, Kenya
15	Lelan	
16	Langas	
17	Kerio valley	
18	Nandi hills	

In each of the potential energy villages, for the establishment of the energy village community, meetings with stakeholders and data collection have been made. As a result, the type and amount of energy consumption of each village were identified and quantified. Better yet, the potential of the individual villages endowed with renewable energy resources was pinpointed. It was observed that the community in the energy villages use firewood in large proportion. Yet, renewable energy resources such as solar, wind and other biomass are untapped resources that have the potential to radically change the energy usage of the energy villages. With no procrastination, the utilisation of these renewable energy resources in the energy villages seems the way forward.

For this deliverable, the project partners of WP14 chose six inspiring cases in terms of their potential and way of energy utilisation. These villages are AASTU and Wonji energy villages in Ethiopia, Regent Hill and Majwanaadipitse in Botswana, Refugee camp in Uganda and Cheboiwo in Kenya. However, there are also many more villages with great potential for renewable energy production, these six are just examples.

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2. Two inspiring cases in Ethiopia

2.1 AASTU Energy Village

AASTU Energy Village is located on the outskirts of Addis Ababa. It has 250 hectares of land within which 7000 students reside, 1000 staff work and contains a seed of its own that gives rise to the hub of science and technology, better yet, envisions to be home of researchers and innovators. This energy village is endowed with enormous solar, wind, and biomass renewable energy resources due to its location near the equator (8°53′02″ N, 38°48′35″ E). On the other hand, the village consumes a considerable amount of firewood and charcoal for the two cafes, electricity from the national grid for different utilities, and oil fuel for vehicles and diesel oil generators for the time being.

Figure 1. View of AASTU Energy Village.

2.1.1 Renewable energy resources

2.1.1.1 Solar

Owing to its location near the equator, AASTU receives more than 12 hours of solar energy per day. As measured by the meteorological station installed in the energy village, the solar intensity is about 5.76 kWh/m2/day under clear sky conditions and the solar sun hours are more than 7 hours. The solar irradiance, as a result, is above 800 W/m2 that can be tapped using concentrators, flat plate collectors (FPC) and/or photovoltaic (PV)

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panels. AASTU Energy Village also owns a suitable slot of land for FPC and PV panel installation. In addition to the slot of land, some of the buildings have appropriate top roofs for easy solar panel installation.

2.1.1.2 Wind

AASTU Energy Village is a windy area where wind energy is a 24/7 phenomenon. The statistical analysis of data gathered from the meteorological station installed in the village showed that the annual average and the most frequent wind speed is 7.2 m/sec at 50 m height as is depicted in Figure 2. Besides, the wind power density can reach up to 300 W/m^2.

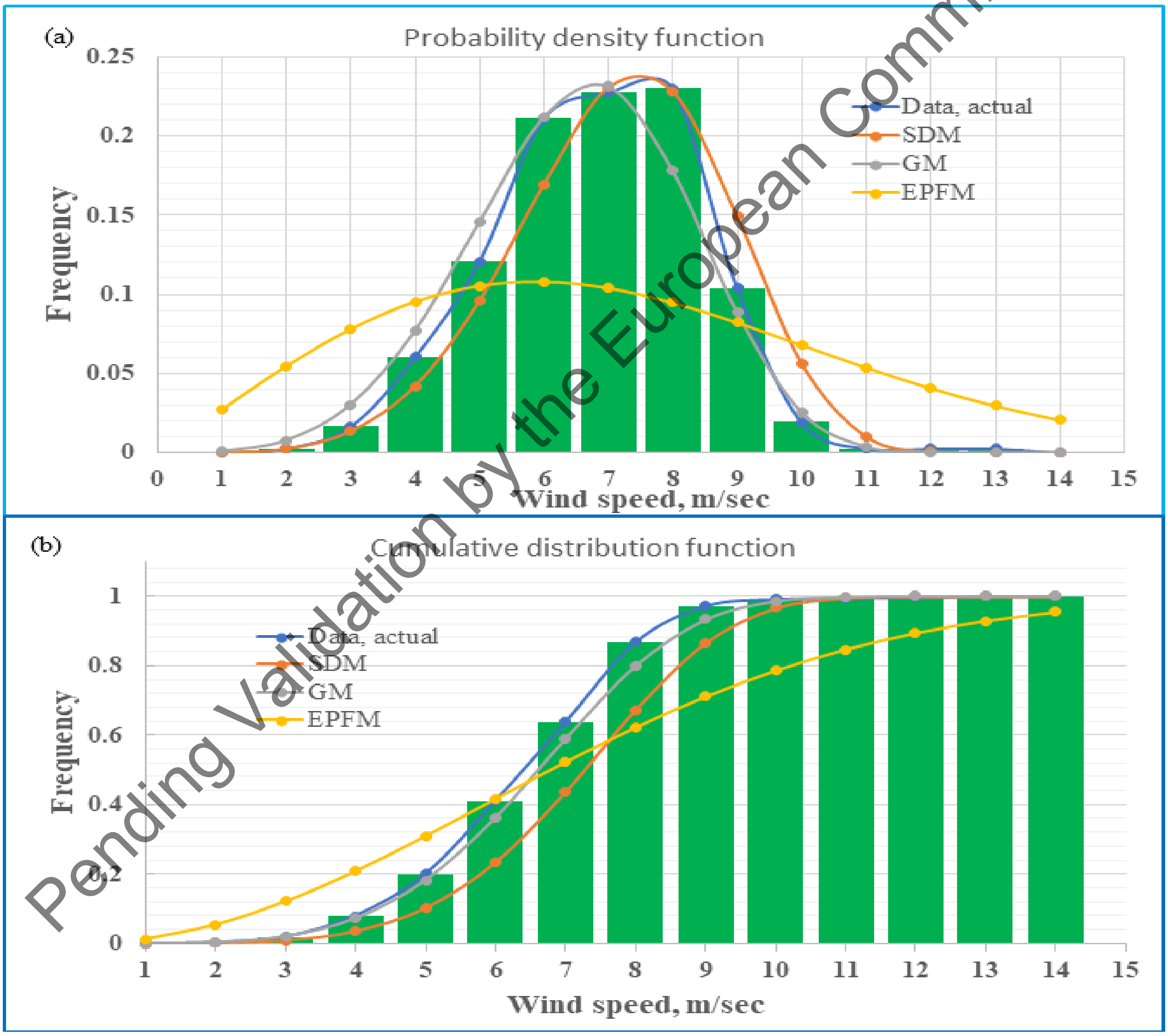

Figure 2. Weibull distribution model fitted to meteorological data; a) probably density function and b) cumulative distribution function.

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2.1.1.3 Biomass

In addition to solar and wind renewable energy resources, AASTU is also endowed with biomass resources. Food waste from the cafés and human waste account for a large proportion. The food waste is quantified to be more than 500 tons per annum and the human waste is estimated to be 300 tons per annum. These resources have the main potential to produce a considerable amount of methane and substitute the non-renewable energy consumption.

Figure 3. AASTU café leftover weighing

2.1.2 Energy consumption

Despite AASTU having several renewable energy resources, the firewood and fuel oil consumptions are high and incur millions of Birr. AASTU uses about 500 m^3 of firewood

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and more than 200,000 litres of fuel oil year in and year out in some of the appliances. Even though electricity appears to be intermittent, the consumption goes as high as 1.5 GWh.

Figure 4. Firewood consumption at AASTU EV.

2.2 Wonji Energy Village

Wonji sugar factory is located due East-North at 08° 22′ 32.34″ N and 39° 18′ 41.14″ E some 100 km from the capital Addis Ababa. The energy village potential was explored with the sugar factory at the centre and some 1400 villagers residing in its environment. The factory has 6250 tons of cane crushing capacity, and 6250 quintals of white plantation

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sugar production per day. It owns about 10,000 hectares of cane cultivation land with 160-ton cane productivity per hectare. Besides, the boilers produce 130 tons of steam at 500 °C and 65 bar and send it to a steam turbine that in turn generates 31 MW (installed capacity). It was assumed that 9–10 MW would be consumed within the factory and the surplus could be sent to the national grid. On top of sugar production, the by-products are bagasse, final molasse, and filter cake. Besides cane top, solar and wind are other renewable resources in the energy village. Be that as it may, the energy village is currently not energy self-sufficient, let alone supplying to the national grid. Instead, it consumes a substantial amount of electricity from the grid, oil fuel for the 1.2 MW generator and transportation, and firewood for calcium oxide preparation.

2.2.1 Renewable energy resources

2.2.1.1 Biomass

During its operation seasons, the energy village produces bagasse, filter cake, final molasse and cane top as a by-product. Some of these renewable resources are untapped and are waste. The cane top accounts for more than 8% of the cane being harvested and is estimated to be 800 tons per day provided that a green harvesting mechanism is practised, other than burning. The cane top can be used to make briquettes of high calorific value and it in turn can be used in modern stoves to cook food. The bagasse production is 28% of the cane crushed and based on the designed capacity, the performance of the factory is 6250 TCD (tons of cane per day). As a result, the amount of bagasse produced would be 1750 tons per day. Even though the factory does not use all, if not most, of the bagasse owing to turbine malfunction and disposes of it in the bagasse yard currently, a large proportion of bagasse produced would be consumed during normal operating conditions. In the best-case scenario, 2% of the bagasse would be surplus and could be used for different applications. Based on this assumption, the bagasse in excess would be 35 tons per day. The bagasse in excess would be used as a renewable energy resource in different forms for the villagers in the energy village. Moreover, molasses and filter cake can also be some sort of energy resource.

2.2.1.2 Wind and solar

The most frequent wind speed in Wonji energy village is 8 m/sec as was estimated using 10 years of annual average wind data from the Ethiopian Meteorological Agency (EMA). The wind power density is estimated to be more than 300 W/m^2.

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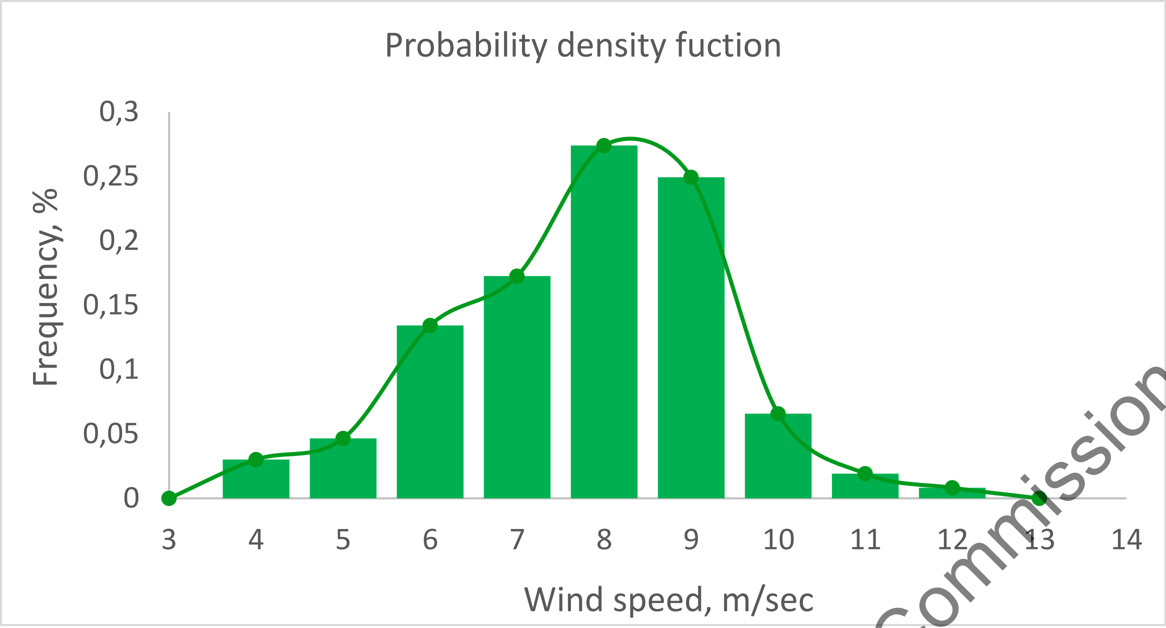

Figure 5. Probability density of wind speed distribution.

Similarly, the solar intensity of the village was determined and the annual average was found to be 5.98 kWh/m2/day. The solar sun hour is more than 7 hours and as a result, the irradiance is above 800 W/m^2.

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3. Two inspiring cases in Botswana

Botswana belongs to Sub-Saharan Africa (SSA) and has a very small population of 2,359,609 (Statistics Botswana, 2022), which is spread over 581,730 km^2. Thus, the population density in Botswana is about 4 people per square kilometre. About 730,000 inhabitants live in rural areas (MacroTrends, 2023) with limited access to electricity. Botswana receives a good amount of solar irradiation, about 300 clear sky days. The country Botswana has an average total solar radiation of 21MJ/m2/day, which is approximately 2,100kWh/m2/yr and among the highest worldwide. The average direct Normal Irradiation (DNI) ranges from 2118 to 2848KWh/m^2, and the average Global Horizontal Irradiation (GHI) ranges from 2045 to 2337KWh/m^2 per annum. Figure 6 shows the Botswana GHI and DNI solar maps.

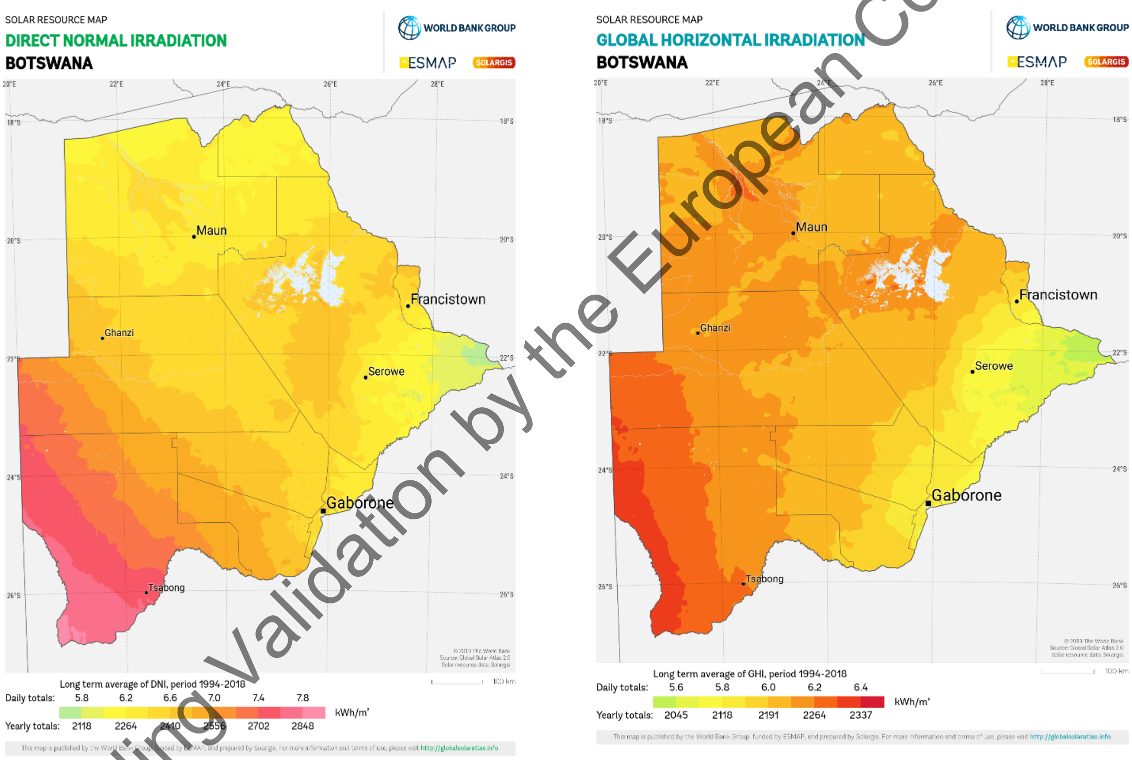

Figure 6. GHI and DNI solar maps of Botswana (Solargis,2020).

Wind speed and wind directions that are measured by weather stations in Botswana are moderate and vary strongly from region to region and depend on the year (Statistics Botswana, 2021). Botswana has a lot of bush and slowly growing wood as well as cattle dunk as biomass sources.

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3.1 Regent Hill International School in Gaborone – Energy Village

Regent Hill International School in Gaborone has pre-primary, primary and secondary school classrooms, facility buildings, a sports ground, a garden and a swimming pool. The energy village has a population of about 2,560 people and is located in Gaborone (24°39'31.9"S 25°51'47.8" E). The school is a day school and is open from 7:30 to 16:30 during the week. The school campus is closed during the weekend.

Figure 7: Regent Hill School Energy Village

Regent Hill Village is connected to the national grid. Oil fuel is used for the school vehicles, such as the school bus. Solar energy is the main renewable energy source. The amount of biomass renewable energy resources is negligible. Wind as a renewable energy source is available, however, to low on the yearly average.

3.1.1 Renewable energy resources

Climate and local conditions play a vital role in the selection of renewable energy sources. At the school campus biomass production through waste, cutting of trees etc. is very low. Also, wind as renewable energy is not a proper renewable energy source due to an average wind speed of <5m/s over a year. Thus, a self-sustainable hybrid renewable energy approach will fail to create an innovative business model at the Regent Hill school EV. Thus, solar will be the renewable energy source with an enormous potential for Regent Hill School

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EV to achieve energy security, environmental sustainability, and resilient self-sustaining smart renewable energy solution. Looking at Figure 8, the photovoltaic potential at Regent Hill school village is between 1830 and 1860 kWh/kWp per year or on average 5.0 to 5.1 kWh/kWp per day.

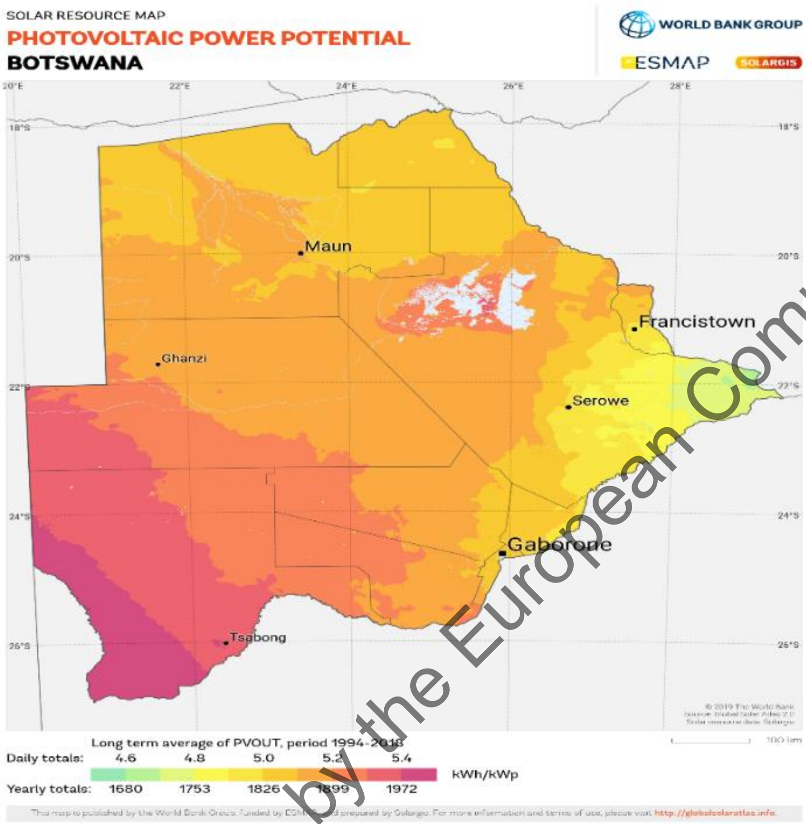

Figure 8. Solar potential map of Botswana (Solargis,2020).

In June 2021, the school purchased a small grid-tied 40kWp solar system without storage. The panels are mounted on the roof of the school building (see Figure 7). The energy data are monitored and available through the SUNNY portal from SMA. The roof of the school buildings allows to addition of additional PV panels for a system size up to 150kWp.

3.1.2 Energy consumption

Regent Hill School EV school has been accepted in the Pilot Botswana Power Corporation/Power Africa Roof Top Solar program which will enable them to export overproduction of clean energy into the Grid. The EV is Botswana’s first grid-tied solar photovoltaic (PV) school. Figure 9 shows the energy consumption monitored through the energy management system from SMA. Botswana experiences often power cuts that stop production at school. In January and February, the data collection was interrupted due to

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internet problems (Wi-Fi) at the school. The SMA energy management system shows three values: (i) power supplied through the grid (red colour), (ii) energy consumption from the PV system (green colour), and (iii) the energy feed in the grid (yellow colour). Interestingly, during the winter time, there is an enormous increase in the monthly consumption of energy (about 25MWh) compared to the monthly use during the summertime (about 10MWh).

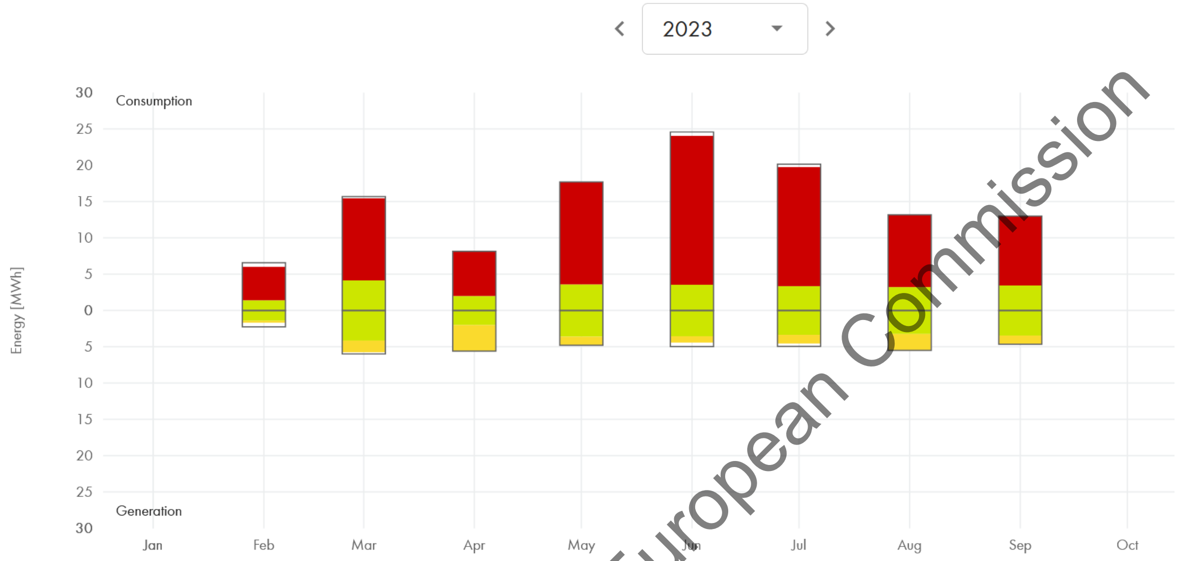

Figure 9. Monthly energy consumption of Regent Hill school EV in 2023.

Figure 10 reveals a closer look at the daily energy consumption in June 2023. In June we have winter in Botswana. The night temperatures are often around 5°C in the morning. During the week the daily energy consumption is above 1 MWh. Beyond that, it is even worth having a look at the load profile during the day and the peak demand during the winter. We will see in the next subsection, that this leads to an inspiring challenge for RES at Regent Hill School EV.

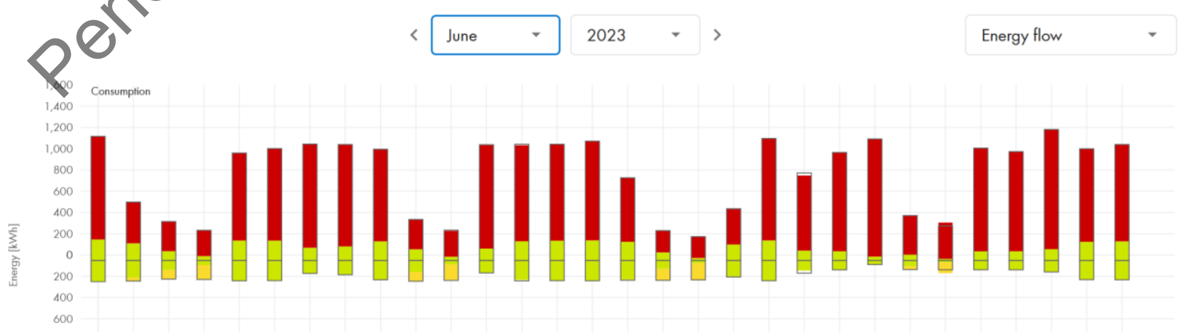

Figure 10. Daily energy consumption in June 2023 at Regent Hill School.

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3.1.3 Inspiring challenges

Exemplarily for the summer period we display the load profiles for seven consecutive days at the end of November 2022 (Figure 11). From Monday to Friday, the load profile shows a peak demand of about 50 kW, while the base load is about 10 kW. At the weekend the energy consumption is just the base load. Thus, at the weekend the school feed the produced renewable energy in the grid. the starting on 21/11/2022. The lower panel in Figure 11 shows that the total consumption is about 2.8 MWh. The 40kWp solar system produces 1310.89kWh energy. During the week 1128.76 kWh are self-consumed (86 per cent of the produced electrical energy), while at the weekend 182.13 kWh are exported to the grid. The self-sufficiency rate is 40% from 21/11/2022 to 27/11/2022. We also observe that the load profile is broad. The peak demand is 4-5 times the base load.

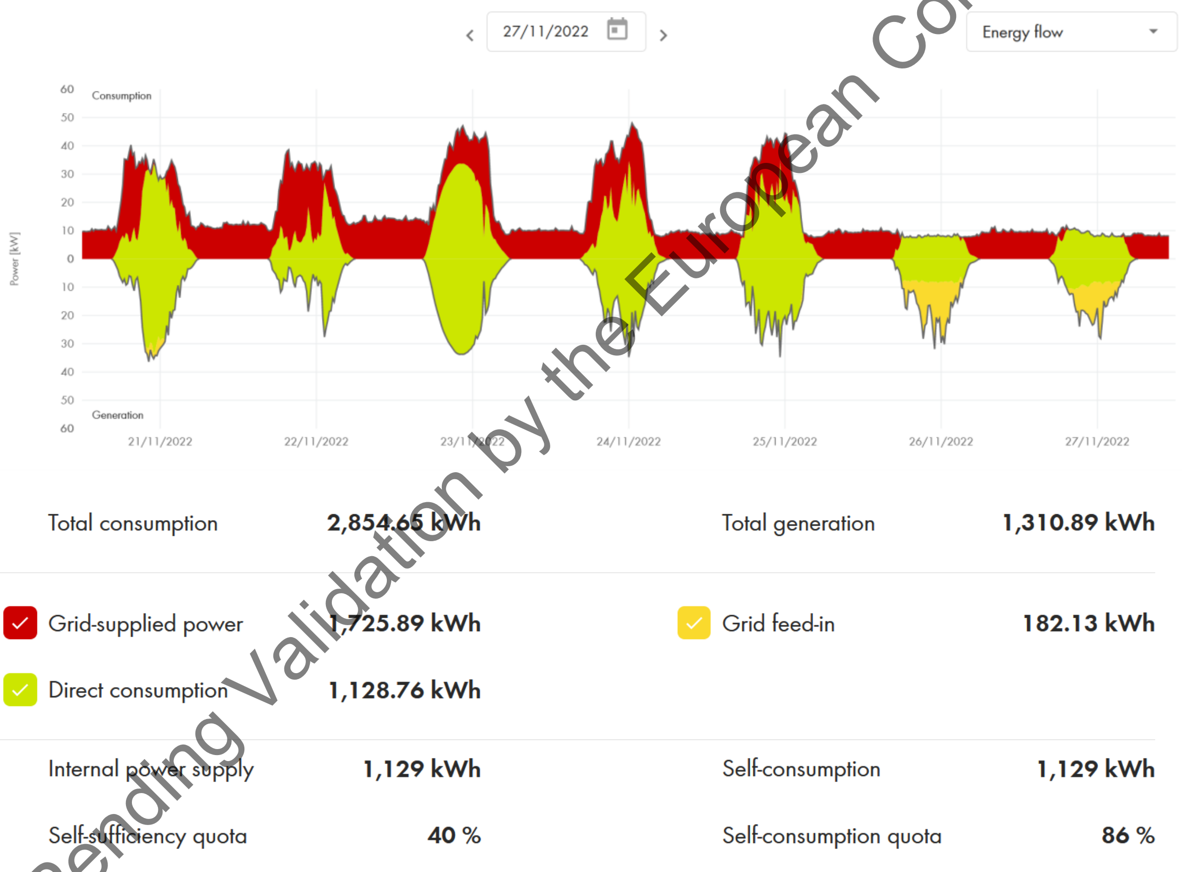

Figure 11. Summer season: load profiles from 21/11/2022 to 27/11/2022 at Regent Hill School.

When looking at Figure 12, during the winter season a completely different load profile compared to the summer season (see Figure 11). In the morning (7 am) the energy demand increases drastically from about 15 kW to about 150 kW. The peak demand is 10 times higher than the base load. The self-sufficiency rate drops to 16% compared to 40%

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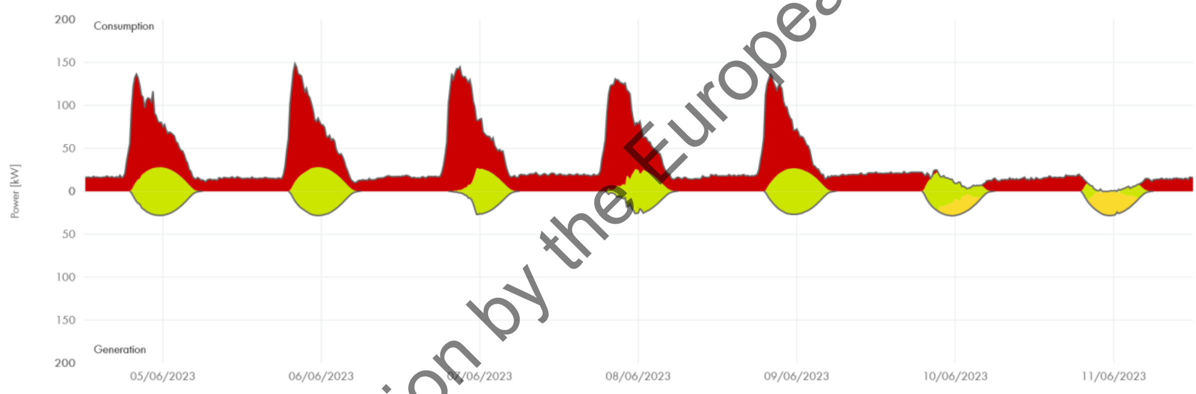
in Figure 11. The total energy consumption for 7 days in the winter is twice the total energy consumption in the summer. This is an inspiring challenge to cope with for RES in Botswana. The reason for the drastic increase in the peak demand in June (during wintertime) is the electrical heating through the aircon in each classroom. At night and during the weekend, the energy consumption is the base load. The school has bought a gas heater to reduce the load in the wintertime to avoid load peaks leading to enormous costs and associated penalties from Botswana Power Cooperation (BPC), the energy supplier. The inspiring challenge is to find a solution for the school to reduce the peak load together with smart and effective control of energy-intensive equipment which fulfils a business model having a return of investment between 5 to 10 years. One solution for this is adding a second-life EV battery energy storage system besides the existing solar system. Based on these findings in WP14 we applied for funding through the ARECA project proposal sent to the HORIZON-CL5-2023-D3-02-16: Accelerating the green transition and energy access in Africa call.



Total consumption	5,783.24 kWh	Total generation	1,157.56 kWh
Grid-supplied power	4,852.62 kWh	Grid feed-in	226.94 kWh
Direct consumption	923.56 kWh		
Internal power supply	924 kWh	Self-consumption	924 kWh
Self-sufficiency quota	16 %	Self-consumption quota	80 %

Figure 12. Winter season: load profiles from 05/06/2023 to 11/06/2023 at Regent Hill School.

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3.2 Majwanaadipitse Energy Village

Majwanaadipitse village is located near Serowe, Central district (22°06’30’’S, 26°52’59” E). It is located approximately 70 kilometres north of Palapye. Majwaanadipiste EV is a rural, off-grid community consisting of 500 villagers with a low income and high unemployment rate. The village has tuck shops, a clinic and a primary school.

Figure 13. Majwanaadipitse Energy Village

Majwanaadipitse village has no access to the national grid. Most of the villagers only use firewood for cooking and low-quality solar lamps as light at night. Only a few villagers use gas bottles for cooking. The main income for the villagers comes from cattle and growing crops. Once a year, before ploughing, the villagers remove invasive thornbush from the agricultural areas.

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3.2.1 Renewable energy resources

Solar energy resource is the preferable renewable energy source for that region, which is available the whole year. The measured annual solar data for Majwanaadipitse village are 2267.4 kWh/m2 (direct normal irradiation), 2092.5 kWh/m2 (global horizontal irradiation), 626.kWh/m2 (diffuse horizontal irradiation). The optimum tilt for a PV module is 25° and the global irradiation at the optimum tilt is 2279.1 kWh/m2. A second renewable energy source is wind energy. The annual average wind speed is 6.55 m/s at 100 m elevation. The thick bush surrounds the village and can provide a good source of biomass together with the agricultural residues and the dunk from the cattle. When looking at Figure 8, the photovoltaic potential at Majwanaadipitse village is the same as in Gaborone, i.e., between 1830 and 1860 kWh/kWp per year or on average 5.0 to 5.1 kWh/kWp per day.

3.2.2 Energy consumption

In terms of energy use, the majority of Majwanaadipitse households use firewood (we estimated roughly 2kg mopane wood per person per day) and candles for lighting. In addition, a few households use small solar systems for lighting and charging purposes (Figure 14). The solar lighting systems comprise a small-sized solar panel with a torch and radio. During our interviews, we found that the village shop is using (LPG) Liquid Petroleum Gas (LPG) for running refrigerators and diesel generators. The annual consumption of diesel petrol is 960 litres (about 24000 BWP) and 228kg LP gas (about 4400 BWP). In addition, there are farms equipped with a borehole, where diesel generators are used to pump water.

Figure 14. Solar systems used in households in Majwanaadipidse Energy Village

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Figure 15. 50kWp Minigrid renewable energy system at the school in Majwanaadipitse Energy Village

Figure 16. Transmission lines to the school and staff houses.

In 2020, the Government of Botswana commissioned and installed a 50kWp microgrid at the primary school in Majwanaadipitse (Figure 15). This off-grid solar power system is comprised of 150x300 Watt solar ground-mounted panels on a mounting structure 2m above ground and a 4x40 kWh Lithium Iron Phosphate battery system (1 master, 3 slaves),

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inverters and solar charge controllers. The mini-grid renewable energy system is a 60kVA three-phase off-grid system that powers the school and the teachers' houses. The school building and the teachers' houses are connected through transmission lines (Figure 16).

3.2.3 Inspiring challenges

Through our meetings with the school staff, we found that the 50kWp microgrid is underutilized. During a normal sunny day, already at 11 a.m., the batteries are fully charged. The school and staff house consume during a sunny day less electrical energy than produced by the microgrid. An interesting and inspiring question refers to the optimized use of the microgrid. A central question is how we can use the excess energy produced by the microgrid during the day. One possibility is to extend the battery storage. Based on our communication with the Council in Serowe, the Council already is discussing that option in connection with an extension of the transmission lines to the Kgotla to provide electricity for the administrative houses. Another option is to provide electrical energy to Water utilities in Botswana. Majwanaadipitse is not connected to the North-South water carrier pipeline. Water utilities use a borehole to provide drinking water for the villagers in Majwanaadipitse. A diesel generator is used to pump the water. This borehole is very close to the microgrid. The excess energy can be used to replace the diesel generator. Moreover, there are also further research questions that include: (i) The solar panel is covered with dust that reduces the power generation efficiency and has potential short-circuiting effects. The initial investigation is to note the improvement in energy generation and establish the frequency of cleaning the panels. External temperature affects solar efficiency, by checking the temperature coefficient on the manufacturer's data sheet of your solar panels, establish the production efficiency of the village as a function of outside temperature.

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4. An inspiring case in Uganda

4.1 Refugee Camp Energy Village

The humanitarian crisis is on an upward trajectory across the globe. This is witnessed both in Africa and the Middle East. This unending increase in refugee influx comes in handy with plans to meet the crisis that accrues. Energy security and development of these refugee settlements are hampered by a lack of accurate data on the existing energy ecosystem (Elena, 2021). Accurate and up-to-date data on the energy situation in Uganda's refugee settlements can be a breakthrough for accurate policies, and resource allocation by both government and humanitarian agencies hence inclusive growth and development.

Bidibidi refugee settlement is one of the largest refugee settlements in Uganda (Figure 17). It is located in the North Western part of Uganda in the Yumbe district at the coordinates 3° 31′ 48″ N, 31° 21′ 0″ E. It is a home to over 220, 000 refugees and asylum seekers.

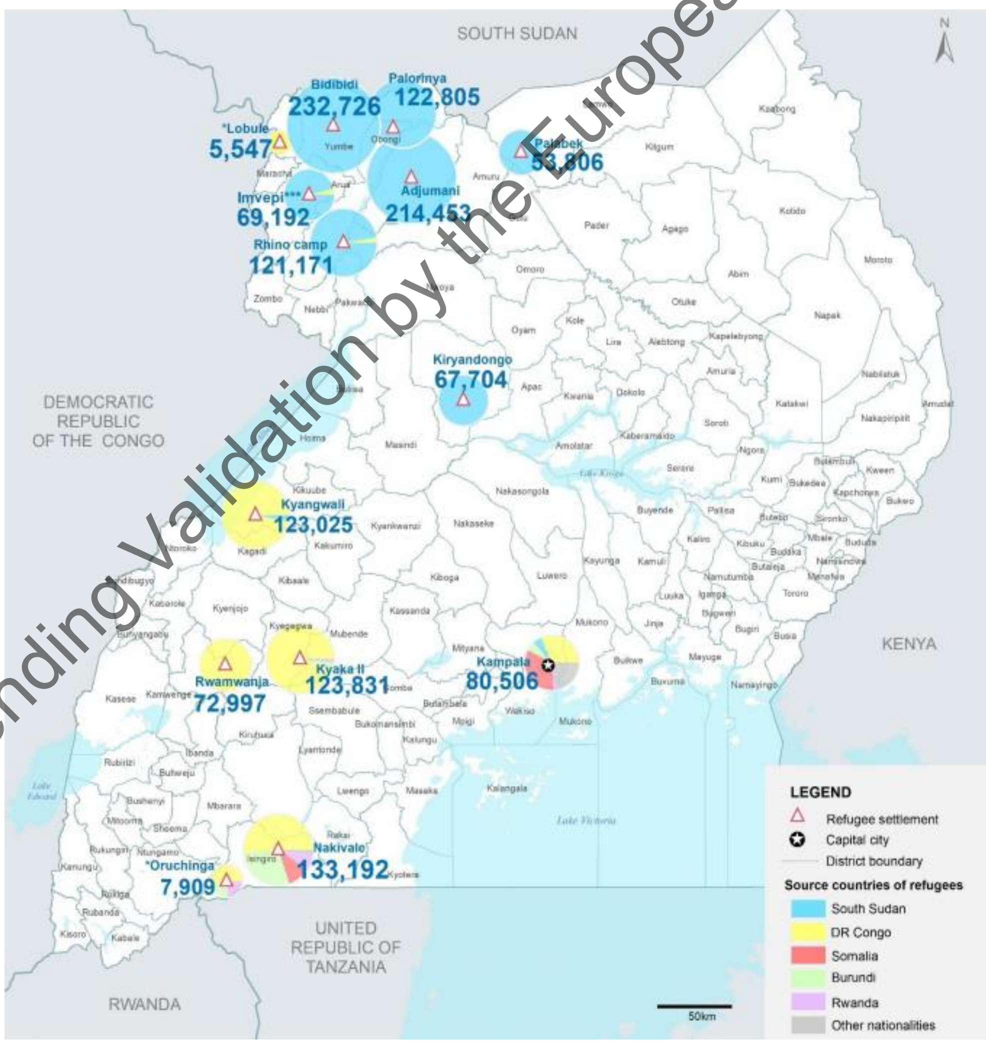

Figure 177. Map of Uganda and location of refugee settlements (Response, 2020).

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Figure 18. Aerial view of some parts of Bidibidi Refugee Settlement.

4.1.1 Renewable Energy Resources

The refugee settlement has several renewable energy sources ranging from bioenergy sources, solar energy sources and wind energy.

4.1.1.1 Solar

It was observed that the average sunshine hour was 8 hours per day with the longest sunshine duration experienced in the months 9 hours per day in December and January an average daily solar irradiation at a tilt angle of 15° is 5.35 kWh/m^2 as shown in Table *2*. Therefore, as a result, the total solar irradiance that can be harnessed is above 500 W/m^2 per day.

Table 2*.* Average daily tilt solar irradiation for the zone.

Month	**Global tilt irradiation (Tilt angle 15 degrees) GK (kWh/m²)**	**Number of days**	**Avg. Daily Irradiation (Tilt 15 degrees) (kWh/m²)**
Jan	184	31	5.94
Feb	164	28	5.86
Mar	171	31	5.52

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Apr	151	30	5.03
May	152	31	4.90
Jun	138	30	4.60
July	130	31	4.19
Aug	144	31	4.65
Sept	165	30	5.50
Oct	181	31	5.84
Nov	183	30	6.10
Dec	187	31	6.03

4.1.1.2 Wind

Not any different from other parts of Uganda except the Karamoja region (Wabukala et al., 2021), the average monthly wind speed for the Yumbe district is 2.6 m/s with a peak speed of 3.5 m/s observed between November and March as shown in Figure 19.

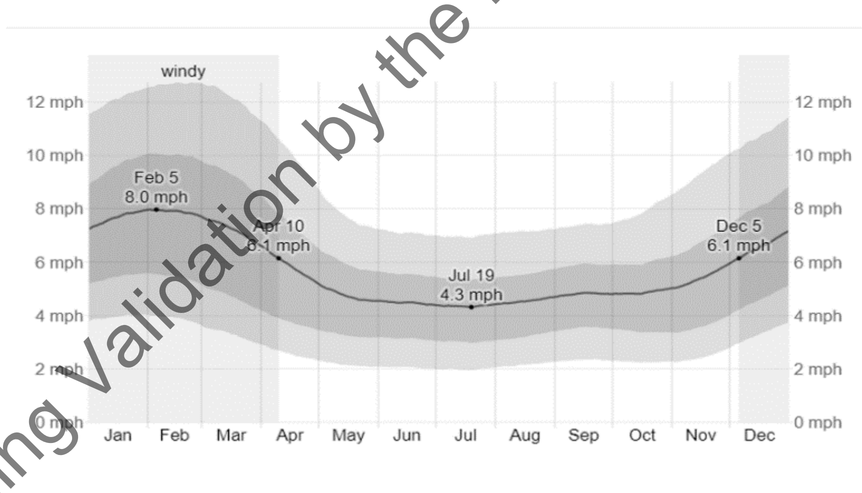

Figure 19. Average monthly wind speed for Yumbe district.

4.1.1.3 Biomass

The main bioenergy sources for the zone are the waste biomass. The refugees and the host population are involved in small-scale animal keeping and poultry rearing through different income-generation initiatives by the agencies within the settlement. The faecal waste, cow dung, chicken dropping and goats' manure give the largest part of the waste bioenergy source for the zone. The potential of waste bioenergy sources that can be used for biogas production from the above-categorized sources is shown in Table 3.

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Table 3. Waste potential for biogas production for the zone.

Waste type	Amount (tonne/year)
Faecal waste	6,614
Cow dung	2,322
Chicken dropping	660
Goats manure	4,760

This waste potential was estimated from the average number that can be obtained from the community within the settlement.

4.2 Energy Consumption

The energy consumption or load profile for zone two in the Bidibidi refugee settlement was estimated for three primary energy uses cooking, lightning and water pumping. Other sources of energy include charcoal, briquettes, LPG, agricultural residues and solar cookers.

Cooking Energy Consumption

With firewood as a primary source of energy for cooking, the zone uses a mix of energy sources to meet their day-to-day cooking. The most common cooking practice involves the use of three stones which is fuel inefficient as shown in Figure 20.

Figure 20. Showing the most cooking practice in Bidibidi refugee settlement.

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Electricity Energy Consumption

Not any different from other rural areas of the country, the electrical gadgets in the rural settings are the most basic ones as compared to the urban and peri-urban settings. The most notable electrical devices in the zone are radios, phones, bulbs and lighting systems, among others.

Water Pumping Energy Need

The water demand activity for the zone is characterized by the long-distance search for clean water from solar-powered wells and boreholes. This activity is mostly done by the ladies. These water sources are characterized by long queues (Figure 21) due to a huge number of households depending on a single water source.

Figure 21. The most common water sources in the zone.

Water in the zone is mostly used for domestic use, small-scale irrigations, livestock and other small businesses such as washing bays, among others. As shown in Table 4 the total yearly water demand for the zone is 1,019,457.3 cubic meters per year**.**

Table 4. Water demand for the zone.

Demand area	Volume for Zone(L/day)	Total Volume for the zone (cubic meter/yr)
Household use	861,235.2	314,350.8
Livestock	299,040.0	109,149.6
Irrigation	796,941.6	290,883.7
Others	835,816.8	305,073.1

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Total	**2,793,034**	**1,019,457.3**

The overall Energy Demand

Considering the scope of cooking, water pumping and electricity, the total energy demand for the zone is 17.5 TWh/year.

Table 5. The total energy demand for the zone

Energy use	**kWh/year**
Cooking	16,699,467.00
Electricity	584,204.00
Water pumping	222,232.44
Total	**17,505,903.44**

NGOs and Community Engagement:

Through this project, NGOs and the community within the settlement played a key role in the data collection phase. This was through the infield questionnaires administered, focused interviews and other face-to-face engagements. The energy systems implementing factors in the settlement like CARE were all willing to provide data and possibly collaborate during the project implementation phase. This was a key factor to see the willingness to work together arising from others.

Uganda is one of the most hospital countries in the region with an open refugee policy, more refugees and asylum seekers are seen crossing the country's border every day. Therefore, this model can be replicated in refugee settlements like Kiryadongo, and Palorinya, to mention but a few.

Through the sustainable energy policy for rural settings, this project will play a key role in guiding the policymakers and government. Several interventions are already in place to ensure sustainability in energy use in these settlements in Uganda. However, most of them are designed as a quick fix measure without critical analysis of the long-term big picture of energy use in these settings, therefore, this EV will be a great game changer.

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5. An inspiring case in Kenya

5.1 Cheboiwo Energy Village

Cheboiwo village is in Tulwet ward, Kesses sub-county, Uasin Gishu County. The population density of Tulwet ward is 241 persons/sq.km. Most households in Cheboiwo depend on firewood and a few on charcoal for cooking. The majority of them use electricity for lighting and very few use kerosene and solar. Most residents have not adopted the use of renewable sources of energy. However, results from a survey conducted showed that most residents have strong interests in solar PV technologies and biogas. The main impediment to their investment in renewable energy is the high cost of equipment and the intermittent nature of renewable energy sources. The residents are mainly farmers and therefore have agricultural residues for biogas production. About 48% of households get their power supply from the national grid.

5.1.1 Renewable energy resources

5.1.1.1 Biomass

Cheboiwo village is endowed with biomass resources such as agricultural residues (maize stalks), cow dung, market waste and kitchen waste. These substrates are quantified to be about 180 tonnes per annum. This can be used for biogas production for cooking to replace the use of firewood and other non-renewable energy sources.

5.1.1.2 Solar

Cheboiwo village is strategically located and receives approximately 12 hours of solar energy per day. The estimated solar intensity is 5.6 kWh/m^2/day. Solar panels can be installed on rooftops and a plot of land available in the community subject to government approval.

5.1.1.3 Wind

Cheboiwo village is in an area with an average wind speed of 5.29 m/s. The mean wind power density is 182 W/m^2.

In Cheboiwo village, 100% of the respondents showed a strong interest in renewable sources such as biogas and solar PV technologies. The community is ready and willing to embrace the use of renewable energy sources. Similarly, the adoption and success of the energy village concept at Cheboiwo village are expected to inspire similar ventures in other areas in Uasin Gishu County and across the country.

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6. Conclusion

Many of the potential energy villages that we explored in Africa are inspiring and could have been included in this deliverable. We chose the AASTU campus, Wonji sugar factory, Regent Hill School and Majwannadipitse village based on their renewable resources on the one hand and energy usage on the flip page. The latent potential that the inspiring villages are endowed with is way more than the demands. There is a promising lead that the energy villages can be self-energy-sufficient and a replica for others. The inspiring case energy villages are ready for full implementation and there is a conducive environment for investment.

The cases introduced in this report are a very unique, and different from each other. What they do have in common is that they have untapped renewable energy potential for themselves and nearby residents and consumers. They also have features that make us believe there are thousands of similar cases across Africa that could and should be taken along into the energy transition and raising the quality of life for the residents. The energy village concept and the proposed solution can be customized to fit the energy demand of a given village.

The establishment of an energy village at AASTU can be a model for different universities across the country. In quite a similar fashion, all, if not, most universities in Ethiopia use firewood as an energy source to cook food items. The renewable energy resources in the universities are more or less similar to AASTU. As a result, the proposed hybrid energy supply system was presented to 45 universities' top management and other stakeholders. The energy village concept, consequently, can be replicated at the universities and scaled up to large firms based on the availability of renewable energy resources at the sites. The energy village concept and the proposed solution can be customized to fit the energy demand of a given village. Wonji Energy Village on the other hand is an example of an energy village built around a factory. As is the case with AASTU, is a suitable place to scale up to a pilot level and further spread out to other similar places.

The development of a self-sufficient renewable energy concept for Regent Hill School Energy Village can be used for different schools across the country. As a result, a RES solution based on PV roof-mounted PV panels together with battery storage can be used for all schools in Botswana. The audience will be the Ministry of Education and Skills Development and other stakeholders (private companies or private schools) in Botswana. The energy village concept, consequently, can be replicated at other schools and scaled up based on the availability of renewable energy resources at the sites.

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Majwannadipitse Energy Village is a living lab to analyse a micro-grid in an off-grid rural area in Botswana focusing on the optimized use of the micro-grid system. Moreover, the Majwannadipitse community will serve as a living laboratory for implementing and evaluating sustainable solutions within the water-electricity-food nexus. The 50kWp micro-grid system is a suitable pilot project that can be scaled up to larger sizes.

The Bidibidi refugee settlement provides an example of yet another kind of situation. It provides us with vital information on how to work with and engage this type of community. Uganda is one of the most hospital countries in the region with an open refugee policy, and more refugees and asylum seekers are seen crossing the country's border every day. Therefore, this model can be replicated in refugee settlements like Kiryadongo, and Palorinya.

Cheboiwo is an example of a typical village in which nearly half of the population is getting electricity from the national grid. Firewood is used for cooking. At the moment most of the residents have not applied any renewable energy sources, but the interest in this issue is huge, which gives us confidence that Energy Village Concept has great potential.

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