Report on Lab Integration Activities and Test Outcomes.

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MALAWI UNIVERSITY OF BUSINESS AND APPLIED SCIENCES

MUBAS

Executive Summary

Atlantic Technological University Sligo in collaboration with the Department of Electrical Engineering at the Malawi University of Business and Applied Sciences (MUBAS) is implementing a project known as “CEANGAL” meaning “connect” in Irish. The project aims to connect underserved communities to sustainable electricity, by connecting such groups to mechanisms and tools to ensure ownership and sustained operation of RES. The CEANGAL project puts forward an ambitious adaptable and replicable model to support activities and know-how relevant to the selection, procurement, installation, and ownership of renewable energy systems (RES), as well as providing support structures to ensure the continuous local operation and maintenance of these RES.

Work package 3.2 presents the laboratory integration activities and test outcomes of the tools developed for the CEANGAL solution. The tools aim to assist in identifying and selecting appropriate renewable energy solutions and greenhouse gas estimators for rural communities with no access to electricity within sub-Saharan Africa. The integration process involved combining several parameters, functionalities, and formulas within a digital environment, followed by rigorous testing to evaluate performance, usability, and reliability. The outcomes of these activities provide valuable insights into the effectiveness and suitability of the tool for addressing energy needs in rural communities.

The report begins with the introduction which gives the background of the project as well as the tasks in deliverable 3.2. Section 2 of the report outlines the activities carried out for the lab integration. Section 3 outlines the outcome of the testing activity of the tools whereas Section 4 presents the conclusion and recommendations.

Contents

1. Introduction

Overreliance on connecting households through grid extension has proven to be slow and expensive in hard-to-reach areas. Off-grid energy solutions are considered a better option in addressing such challenges. However, the implementation of renewable energy systems (RES) has faced the challenge of sourcing funds for the maintenance and repair of the systems as households in remote areas cannot afford to pay the maintenance and operation costs. Therefore, mechanisms that can be used to expand electricity access in such regions are needed.

As one way of accelerating electricity access in rural communities through off-grid, particularly in sub-Saharan Africa, Atlantic Technological University Sligo in collaboration with the Department of Electrical Engineering at the Malawi University of Business and Applied Sciences (MUBAS) is implementing a project known as “CEANGAL” meaning “connect” in Irish. The project aims to connect underserved communities to sustainable electricity, by connecting such groups to mechanisms and tools to ensure ownership and sustained operation of RES.

Work package 3.2 presents the laboratory integration activities and test outcomes of the tools developed for the CEANGAL solution. The tools aim to assist in identifying and selecting appropriate renewable energy solutions and greenhouse gas estimators for rural communities with no access to electricity within sub-Saharan Africa.

1.1 Work Description

The specific objectives of this report are as follows:

i. Refining the CEANGAL tools for the demonstration environment using obtained local use requirements.
ii. Lab testing and integration activities to ascertain the efficacy of CEANGAL to address the electrification and RES uptake goals using the demonstration sites requirement as case study.

2. Lab Integration Activities

The development of each tool relied on renewable energy resources found in excess across different locations which suit the needs of the end user. The tools were designed to give an adequate representation of load demand and the required energy needed to sustain the load while utilising natural resources in each area. Different tools were developed to best fit the abundance of natural resources in each area. The tools were designed by integrating various parameters, including those identified through a needs assessment conducted by Peter Sandula during an initial working visit to several villages. Additionally, mathematical calculations and study of individual load patterns contributed to the tool's final design.

There are four main tools discussed in this report which were integrated with the data from the field. The tools were tested by Gaye Edobor, Ehiaze Ehimen, Paul McNama, and Peter Sandula (field testing) and the outcomes are outlined in the next chapter (Test Outcomes)

2.1. Solar Tool

The solar selection tool was designed to assist user in evaluating and selecting the most suitable solar energy system for their specific needs. It includes features such as system sizing, performance estimation and other configurations. Essentially, its function is to streamline the decision-making process and provide guidance on the optimal solar solution. The main reason for developing this solar selection tool is to address the increasing demand for renewable energy solutions in rural communities with no access to grid power, particularly solar energy, and to facilitate its adoption by a wide range of user or community. The tool is provided with a user-friendly interface and comprehensive analysis capabilities, the tool aims to empower individual, businesses, and organisations to make informed decision about implementing solar energy systems.

The selection tool was designed to address the complexity of solar energy systems which involve various components and configurations, making it challenging for non-experts to navigate the selection process effectively. A solar selection tool simplifies this complexity and guides users through the decision-making process. The tool also provides the opportunity for users to customise their need, this allows users to tailor their system design to match their individual need while considering factors such as energy consumption patterns and local solar resources. The below figure shows the parameters used in the formation of the solar selection tool.

Region Irridance
Panel Rating W
Inverter efficiency %
Total energy demand
Battery losses
Depth of discharge
Nominal battery voltage
Days of Automony
Battery Capacity Ah

Some assumptions that were considered in the formation of the solar selection tool includes:

- Solar Resources Availability: This parameter assume access to solar resource data, such as irradiance level and weather patterns, to estimate performance accurately.
- Technological Assumptions: the tool assume the performance characteristics of solar modules, inverters, and other system component based on standard industry practices and manufacturer specifications.
- User inputs: The tool rely on user provided inputs, such as energy consumption data, system preferences to generate recommendations.

2.2. Wind Tool

The wind selection tool is designed to aid users in evaluating and selecting the most appropriate wind energy system for their specific requirements. This tool encompasses features such as wind resource assessment, turbine sizing, and wind turbine configurations. Essentially, its function is to simplify the decision-making process and provide guidance on the optimal wind energy solution. The primary reason for developing a wind selection tool is to address the growing interest in renewable energy solutions, particularly wind energy, and to facilitate its adoption by a diverse range of users. By offering an intuitive interface and comprehensive analysis capabilities, the tool aims to empower individuals, businesses, and organisations to make well-informed decisions regarding wind energy system deployment.

This tool is put together to address the complexity in choosing wind energy systems. Wind energy systems involve various components, configurations, and technical considerations, making it challenging for non-experts to navigate the selection process effectively. A wind selection tool simplifies this complexity and guides users through the decision-making process. The tools allow users to customise their system demand to meet individual requirements, considering factors such as wind resource availability and energy demand. The below figure shows the parameters used in the formation of the wind selection tool.

Capacity in Watts	$W=0.5 \times \rho \times A \times V^3 \times C_p$
0.5	kinetic energy constant
ρ	Air density in kg per cubic meter
A	Circular area swept by the turbine blade in meter sq, Area=πr^2
V^3	Velocity of wind in meter per second cube
C_p	efficiency of turbine

Some assumptions that were considered in the formation of the wind selection tool includes:

- Wind Resource Availability: This parameter assumes access to wind resources data, such as wind speed, air density, velocity of the wind, circular area swept by the turbine blades, and direction (as seen above), to accurately assess the potential for wind generation at a given location.
- Technology Assumptions: The tool makes assumptions about the performance characteristics of wind turbines, such as efficiency of the turbines and reliability, based on industry standards.
- User Input: The tool relies on user-provided inputs, such as site-specific data, energy consumption patterns to generate system output recommendations.

2.3. Hydro Tool

The hydro selection tool is designed to assist users in evaluating and selecting the most suitable hydroelectric energy system for their specific requirements. It typically includes features such as hydrological analysis, turbine sizing, performance estimation, and different hydroelectric configurations. Essentially, its function is to simplify the decision-making process and provide guidance on the optimal hydro energy solution. The primary reason for developing a hydro selection tool is to address the growing interest in renewable energy solutions, particularly hydroelectricity, and to facilitate its adoption by a diverse range of users. By offering an intuitive interface and comprehensive analysis capabilities, the tool aims to empower individuals, businesses, and organisations to make well-informed decisions regarding hydroelectric system deployment.

The tool addresses the complexity of hydroelectric systems which involve various components, configurations, and technical considerations, making it challenging for non-experts to navigate the selection process effectively. A hydro selection tool simplifies this complexity and guides users through the decision-making process. Every hydro project is unique, with specific site conditions, water availability, and energy needs. The selection tools allow users to customise their system design to meet their individual requirements, considering factors such as site topography, water flow characteristics, and energy demand. The below figure shows the parameters used in the formation of the hydro selection tool.

Parameter	Notation	Value	Unit	Notes
Head	H	6	m	
Head losses	h_L	10%		Estimate for bends and friction
Effective head	$H_{eff} = H.(1-h_L)$	5.4	m	
Flow	Q	50	l/s	0.2 seconds to fill 10 litre bucket
Flow	Q	3	m^3/s	
Density	ρ	1000	kg/m^3	
Gravity	g	9.81	m/s^2	
Power (hydro)	$P_h = H_{eff}.Q.\rho.g$	158922	W	
Water to wire efficiency	η	75%		Efficiency of turbine and generator
Power (electrical)	$P_e = H_{eff}.Q.\rho.g.\eta$	119192	W	
Power (electrical)	$P_e = H_{eff}.Q.\rho.g.\eta$	119.192	kW	
Flow	Q	3	l/s	
Effective head	$H_{eff} = H.(1-h_L)$	18	m	**HYDRO**
Density	ρ	1000	kg/m^3	
Gravity	g	9.81	m/s^2	

Some assumptions that were considered in the formation of the hydro selection tool includes:

- Hydrological Data Availability: The tool assume access to hydrological data, such as waterflow, water levels, gravity, effective head, to accurately assess the potential for hydroelectric generation at a given location.
- Technological Assumptions: The tool make assumptions about the performance characteristics of hydro turbines, such as efficiency, capacity, and operating range, based on industry standards or manufacturer specifications.
- User input: The tool relies on user-provided inputs, such as site-specific data, energy consumption patterns, and constraints, to generate customized recommendations and analyses.

2.4. CHP (AD & Gasifier)

The CHP (Combined Heat and Power) selection tool is designed to assist the user in evaluating and selecting the most appropriate combined heat and power system for their specific needs. It includes features such as energy demand analysis, selecting of feedstock type, and comparison of different CHP technologies (Anaerobic & Gasification). Essentially, its function is to simplify the decision-making process and provide guidance on the optimal CHP solution for the user. The primary reason for developing this tool is to address the increasing interest in energy efficiency and sustainability, particularly in the context of distributed energy generation. CHP systems offer the simultaneous generation of electricity and useful heat, making them an attractive option for reducing energy costs and greenhouse gas emissions in various applications. By offering an intuitive interface and comprehensive analysis capabilities, the tool aims to empower users to make well-informed decisions regarding CHP system deployment.

This tool allows users to customise their system design to meet their needs, considering factors such as fuel availability, load demand and regulatory requirements. The tool may consider factors such as emissions reduction targets, carbon pricing, and environmental regulations when assessing the environmental benefits of CHP systems. The below figure shows the parameters used in the formation of this tool.

Fuel Type	Quantity kg/kW
Rice straw	0.0318
Rice husk	0.0303
Coco straw	0.0267
Coco shell	0.0261
Cattle Manure	0.656
Chicken Manure	0.499
Pig Manure	0.3158

	Gasification		
	Fuel Type	kW/h	Quantity kg
CHP	Rice straw	1.913	1
	Rice husk	1.817	1
	Coco straw	1.601	1
	Coco shell	1.57	1

	Anaerobic digestion	
	Fuel Type	Quantity kg/kW (per Hr)
CHP	Cattle Manure	39.373
	Chicken Manure	29.941
	Pig Manure	18.948

Some assumptions that were considered in the formation of the CHP selection tool includes:

- Energy Demand: The tool uses data on energy consumption patterns, heat loads, and electricity demand to accurately assess the suitability of CHP systems for specific applications.
- Technological Assumptions: The tool make assumptions about the performance characteristics of CHP technologies, such as efficiency, reliability, and maintenance requirements, based on industry standards or manufacturer specifications.
- Feedstock Availability: This parameter assumes feedstock data, such as quantity and quality of manures, rice straw, and other fuel type.

3. Test Outcome

The below outcomes are results derived from testing of each tool using various load parameters and scenarios, it was found that the output of each tool (selected based on the availability of renewable resources in various communities) showed a clear example of the type of equipment needed to power certain load and gave indicative ideas on what is required when going for market survey. The outcome of the test also revealed the overall total load concerning load usage.

3.1. Solar Tool

The test outcome of the solar selection tool as seen below includes the load audit sections, solar module sizing display, inverter parameters, battery sizing representation, and how to use the tool.

SOLAR SELECTION TOOLS & OUTPUT CALCULATOR

LOAD AUDIT

Appliance	No of Appliance		Power rating in Watts		Total energy used in Watts		Hours used per day		Total energy demand (wH)
TV	1	×	120	×	120	×	8	=	960
Light bulb	5	×	10	×	50	×	10	=	500
Fan	2	×	40	×	80	×	10	=	800
Radio	1	×	20	×	20	×	20	=	400
Decoder		×		×	0	×		=	0
Other equipment		×		×	0	×		=	0
Other equipment		×		×	0	×		=	0
Other equipment		×		×	0	×		=	0
Other equipment		×		×	0	×		=	0
Other equipment		×		×	0	×		=	0
					270				2660

EQUIPMENT DESIGN

SOLAR MODULE SIZING

PV Ratings	Watts
Total Solar Panel Power (W)	458.6
Total PV Power (kW)	0.5
No. of PV required	1

INVERTER SIZING

Watts (W)	337.5
KiloWatts (kW)	0.3

BATTERY SIZING

Battery (Ah)	137
No. of Battery	1

Step 1: Enter the number of each appliance in green
Step 2: Enter the Power rating/wattage, The wattage of most appliances is usually stamped on the bottom or back of the appliance.
Step 3: Enter the operating hours of each appliance per day.
Step 4: DO NOT CHANGE THE VALUES IN GREY COLOUR

The test outcome of the solar tool clearly shows:

- Energy Production Estimation: The solar selection tool provides estimates of the energy production potential of a solar PV system based on inputs such as location, system size, tilt angle, shading, and solar irradiance data.
- System Sizing and Configuration: The tool recommend the optimal size and configuration of the solar PV system based on the user's energy consumption and energy goals.

- User Engagement: Users can review the output generated by the tool, analyse the implications of various design options, and explore different scenarios to identify the most suitable solar PV system configuration that meets their needs and objectives.
- Decision Making: Based on the outcomes provided by the tool, users can make informed decisions regarding the design, implementation, and financing of the solar PV system, considering factors such as energy efficiency, financial feasibility, and environmental sustainability.
- Output Presentation: The tool presents the results of the analysis in a user-friendly format to help users understand the overall design choices and make informed decisions.

3.2. Wind Tool

The test outcome of the wind selection tool as seen below includes the load audit sections, wind turbine parameters, inverter parameters, battery sizing representation, and how to use the tool.

WIND SELECTION TOOLS & OUTPUT CALCULATOR

LOAD AUDIT

Appliance	No of Appliance		Power reting in Watts		Total energy used in Watts		Hours used per day		Total energy demand (vH)
TV	1	×	90	×	90	×	12	=	1080
Light bulb	10	×	5	×	50	×	12	=	600
Fan	3	×	50	×	150	×	8	=	1200
Laptop	1	×	60	×	60	×	7	=	420
Fan		×		×	0	×		=	0
Decoder		×		×	0	×		–	0
Radio		×		×	0	×		=	0
Other equipment		×		×	0	×		–	0
Other equipment		×		×	0	×		=	0
Other equipment		×		×	0	×		–	0
Other equipment		×		×	0	×		=	0
					350				**3300**

Rotor Diameter (m)	Rotor Radius (m)	Circular Area swept by turbine blades	Wind velocity (m/s)	Capacity (W)
5	2.50	19.63	4.00	308

EQUIPMENT DESIGN

BATTERY SIZING	
Battery (Ah)	170
No. of Battery	2

INVERTER SIZING	
Watts (W)	384.8
KiloWatts (kW)	0.4

Step 1: Enter the number of each appliance in green
Step 2: Enter the Power rating/wattage, The wattage of most appliances is usually stamped on the bottom or back of the appliance.
Step 3: Enter the operating hours of each appliance per day.
Step 4: DO NOT CHANGE THE VALUES IN GREY COLOUR
Step 5: Enter the wind speed of the site location.
Step 6: Enter the rotor diameter (the sweep area of the blade
Step 7: Continue to change the rotor diameter until you get the desire power output that matches the total energy used in watts.

The test outcome of the wind tool clearly shows:

- Energy Production Estimation: The tool can estimate the potential energy production of a wind turbine system by analysing the wind resource characteristics and turbine specifications.
- Turbine Sizing: The tool recommends the optimal size of wind turbines within a given area to maximise energy capture while minimising potential risks such environmental disturbance (height of turbine and noise).
- Analysis and Modeling: The tool employs mathematical calculations to analyse the input data and perform simulations to estimate wind energy potential, and turbine performance.
- Output Presentation: The tool presents the results of the analysis in a user-friendly format to help users understand the system details of the wind energy project.
- Decision Support: Based on the outcomes generated by the tool, users can make informed decisions regarding wind energy project development, including site selection, turbine selection, and stakeholder engagement.

3.3. Hydro Tool

The test outcome of the hydro selection tool as seen below includes the load audit sections, hydro power display, electrical power display, and total required energy which is reflective of the load audit.

HYDRO SELECTION TOOLS & OUTPUT CALCULATOR

LOAD AUDIT

Appliance	No of Appliance		Power rating in Watts		Total energy used in Watts		Hours used per day		Total energy demand (wH)
bulb	10	×	10	×	100	×	12	=	1200
Health centre	10	×	5	×	50	×	12	=	600
Fan	2	×	50	×	100	×	8	=	800
Laptop	1	×	60	×	60	×	7	=	420
Fan		×		×	0	×		=	0
Decoder		×		×	0	×		=	0
Radio		×		×	0	×		=	0
Other equipment		×		×	0	×		=	0
Other equipment		×		×	0	×		=	0
Other equipment		×		×	0	×		=	0
Other equipment		×		×	0	×		=	0
					310				**3020**

Hydro Power in (kW)	Electrical Power (kW)	Total Required Energy (W)
530	**397**	**310**

Enter values in yellow cells

Head (m)	Head Losses	Flow (l/s)	Hydro Power (W)	Turbine efficiency & generator	Power (electrical) W
20	10%	3000	530	75%	397

The test outcome of the hydro tool clearly shows:

- How hydrological parameters can be manipulated to generate the desired total required energy. This includes flow rate, head loss and water head.
- Energy Production Estimation: The tool estimates the potential energy production of a hydroelectric system by analysing the available water resources, turbine efficiency, and site-specific factors such as topography (water head).

- Data Collection: Users input relevant data such as site characteristics, hydrological data, turbine specifications, project parameters, into the hydro selection tool.
- Output Presentation: The tool presents the results of the analysis in a user-friendly format to help users understand the potential benefits, associated with hydroelectric projects.
- Decision Support: Based on the outcomes generated by the tool, users can make informed decisions regarding hydroelectric project development, including site selection, turbine selection.

3.4. CHP (AD & Gasifier)

The test outcome of the CHP selection tool as seen below includes the technology type, rated output power display, input of fuel types with their equivalent in relation to different fuel type. The user inputs their load demand or energy usage and the tool populate the quantity of feedstock required to generate the power.

	RATED POWER (kW)		
	50		

GASIFICATION METHOD

RICE STRAW (Kg/hr)	RICE HUSK (Kg/hr)	COCO STRAW (Kg/Day)	COCO SHELL (kg/Day)
26.14	27.52	31.23	31.85
RICE STRAW (Kg/day)	**RICE HUSK (Kg/day)**	**COCO STRAW (Kg/Day)**	**COCO SHELL (kg/Day)**
627.29	660.43	749.53	764.33
RICE STRAW (Tons/Annum)	**RICE HUSK (Tons/annum)**	**COCO STRAW (Tons/annum)**	**COCO SHELL (Tons/annum)**
228.96	241.06	273.58	278.98

Enter the RATED POWER OR ANTICIPATED LOAD IN KILOWATTS IN BLACK
THE QUANTITY OF THE FEEDSTOCK WILL BE DISPLAYED AUTOMATICALLY
DO NOT CHANGE THE VALUES IN YELLOW, BLUE, PINK AND GREEN COLOUR

The Biomass fuel required to generate the required power in one hour, one day, and one year is represented by different color

	RATED POWER (kW)		
	250		
Anaerobic Digestion	CATTLE MANURE (Kg/hr)	CHICKEN MANURE (Kg/hr)	PIG MANURE (Kg/hr)
	6.35	8.35	13.19
	CATTLE MANURE (Kg/day)	CHICKEN MANURE (Kg/day)	PIG MANURE (Kg/day)
	152.39	200.39	316.66
	CATTLE MANURE (Tons/Annum)	CHICKEN MANURE (Tons/Annum)	PIG MANURE (Tons/Annum)
	55.62	73.14	115.58

Enter the RATED POWER OR ANTICIPATED LOAD IN KILOWATTS IN BLACK
THE QUANTITY OF THE FEEDSTOCK WILL BE DISPLAYED AUTOMATICALLY
DO NOT CHANGE THE VALUES IN BLUE, RED and GREEN COLOUR

The Biomass fuel required to generate the required power in one hour, one day, and one year is represented by different color

The test outcome of the CHP tool shows:

- The tool can facilitate stakeholder engagement in decision-making processes by providing transparent and actionable insights into the benefits of the feedstock available in the specific area.
- Output Presentation: The tool presents the results of the analysis in a user-friendly format to help users understand the potential benefits, associated with CHP.

The results obtained from each tool will provide valuable insights for planners, energy auditors, and community members, offering a preview of the anticipated outcomes prior to project installation. Additionally, the tool serves as a comprehensive guide for individuals interested in undertaking renewable energy projects, as outlined in this report. Moreover, it will serve as a valuable resource within the regional expertise hub, facilitating training sessions for those seeking to expand their expertise in this field.

4. Conclusion and Recommendations

The integration activities and test outcomes demonstrate the successful development and validation of the RES tool for rural communities. The tool's effectiveness in assisting stakeholders in identifying and selecting appropriate renewable energy solutions has been confirmed through rigorous testing. Moving forward, further refinements and enhancements based on user feedback and real-world implementation experiences will ensure the tool's continued relevance and impact in addressing energy challenges in rural areas.

Based on the test outcomes and user feedback, It is recommended that the tools be continuously updated and expanded to ensure accuracy and relevance. Also, an enhancement of the user interface to improve usability and accessibility for a diverse range of users, including those with limited technical expertise. Feedback mechanisms and user support features should be incorporated into the tool.