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PROCEEDINGS OF THE 3RD ENERGY AND HUMAN HABITAT CONFERENCE

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EDITOR: PROF MTE KAHN

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3rd Energy and Human Habitat Conference 2022

Editor's Synopsis

This Proceedings includes the papers presented at the 3rd Energy and Human Habitat Conference which took place between 28-29 November, 2022, in Cape Town, South Africa as a face to face event at the Castle of Good Hope.

The Conference was organized by the African and International Use of Energy platform consisting of academics from the Cape Peninsula University of Technology, the University of the Western Cape, University of South Africa, and University of Stellenbosch. The organizing committee, advisory board and review board, as well as the editors are grateful to the delegates who had submitted and presented papers.

The conference papers included experimental as well as overview studies applicable to Energy and the application or enhancement of human habitat. Although the conference was open for inclusion of studies from an energy policy and energy economics perspective, almost all the papers received in this call were of a more technical nature.

The conference received papers via its online submission platform and responded by related email. Reviews were double blind with two reviewers per paper and a third editorial review for decision to include the paper in the proceedings. Several paper abstracts were received but was not of sufficient quality to meet initial review requirements and some were also outside the scope of the conference. The conference received over 48 abstracts and received 38 papers as submissions. Only 21 papers were accepted and graded for inclusion in this Proceedings after peer review and these included only highly positive reviews with minimal corrective work.. The rejection ratio of papers was 44% rejection.The highest single institution papers accepted for publication was 28%, hence meeting the South African DHET requirement.

The authors were required to avail themselves for a face to face presentation with session chairs at the conference venue.

Prof MTE Kahn

Energy Institute, Cape Peninsula University of Technology

28 November 2022

Opening Remarks

Dr Marco Adonis, HOD , DEECE, CPUT

3rd Energy and Human habitat Conference

28 & 29 November 2022, Castle of Good Hope, Cape Town, South Africa

Distinguished Participants, Colleagues, Ladies and Gentlemen,

Good Morning.

I am very honoured to deliver opening remarks on behalf of the Department of Electrical Electronic and Computer Engineering of the Cape Peninsula University of Technology, at this esteemed Conference.

I would like to welcome all participants for their keen interest and enormous efforts to make this meeting possible.

At the outset, I would like to thank co-organizers of this event. My special thanks goes to Professor Mohamed Tariq Kahn, Director of the Energy Institute, and Convenor of this Conference. Prof Kahn have been at the helm of the energy conferences since 2012 and have done a first for us in organising this event at the Castle of Good Hope. A Special Thanks to the Organising Committee, and the Review Committee, the Session Chairs and the many students and staff that were involved in making this event happen here today. For two years the conference continued as a digital event, and this is the fist face to face event since 2019.

I think you, the delegates here, will be more experienced and knowledgeable than myself on the theme of Energy and Human Habitat . So my remarks will be very short. I just would like to highlight the huge potential of Energy Technology in the achievement of SDGs , which are an important international achievement for the 2030 goals and beyond.

More than 700 million people on the African continent still do not have access to modern, productive energy sources, and many of them continue to use antiquated, ineffective traditional energy sources. The difficulty is still in successfully and sustainably getting this solution to the most remote off-grid areas, even though the answers already exist.

Energy poverty is still a problem, and many homes haven't been able to connect to the electricity despite significant attempts to expand the grid to several towns, produce more megawatts, and offer various "low cost" energy products and services for the "poor". Microgrids and effective use of modern technological advances hold the key to bridge the gap with Human Habitat and electrification. Grid extension alone does not provide energy access as long as the end-use energy dilemma is not resolved.

In addition to this, since the Paris Agreement went into force in 2016, reducing greenhouse gas emissions has become another important mission for all. Our nation is embarking on the Just Transition in the Energy sector to address concerns with job losses and re-skilling that could be associated with such a change from fossil fuels to renewables. This is why Conferences like these are important. To create networks of researchers that can share their views and ideas in order to create better understanding and co-operation.

I would like to thank all the presenters, facilitators, and participants, for making the time to be here. Thank you

3rd Energy and Human Habitat Conference 2022

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3rd Energy and Human Habitat Conference 2022

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The conference disseminates original research and new developments which are published in this conference proceedings. The conference covers the following disciplines in the field of energy:
Energy and Society,
Smart Energy
Renewable Energy
Blockchain and smart contracts in energy
Smart Grids, Microgrids and Minigrids
EV and Electric Transportation
Energy Storage and Power Electronics
Energy Efficiency
Energy Economics
Energy Development

Publications produced for the conference

The following publications ensure that the research reports given during the conference are disseminated widely

Conference Proceedings

The conference proceedings contain full papers which are subjected to a blind peer review process.

The proceedings with ISBN number, will be digitally disseminated, and will be published online on our website, as well as co-published on either Elsevier SSRN and its associated e-Journals or Zenodo under the AIUE e-Journal.This is a digital library under OpenAIR and the CERN. OpenAir as the vanguard of the open access and open data movements in Europe was commissioned by the EC to support their nascent Open Data policy by providing a catch-all repository for research and is open to all search engines. This provides a high quality repository of scientific information and dissemination. A DOI number to be associated with the individual research papers.
The target audience for the proceedings are specialists in the field.

Editorial and the Review Process

Our review board consists of international and national experts in specialist fields covered in the conferences. They are from different academic institutions, and from industry. Authors are invited to submit an abstract prior to submission of a paper. The abstracts of proposed conference papers are sent for evaluation, and only accepted abstracts would lead to the invitation to submit a full paper which is then reviewed by no less than two reviewers. A third editorial review is done before the papers are accepted for publication in the proceedings.

The Chairman and/ or Conference Administrator informs each main author of the outcome of the evaluation timeously, inviting the successful author(s) to submit a print-ready manuscript in accordance with possible comments and the instructions and guidelines provided in the conference paper template.
The author submits his paper via the electronic paper submission and review process, indicating the original paper number.

Upon receipt of the manuscript the paper is sent for review to at least two members of the editorial panel who specialise in the disciplines covered in the paper. Reviewer members of the editorial panel, review the paper by answering specific questions, indicating if the paper meets specific set criteria. A separate section allows for comments on the quality of the paper addressed separately to the editors and to the authors. These comments often also indicate what needs to be done to improve the quality of the paper. The reviewer has the option to attach an annotated copy of the manuscript which is returned to the authors with the review reports.

Once sufficient reviews have been received, the Conference Chair and/or Administrator informs the author(s) of the outcome of the evaluation, which is either that the paper is rejected or accepted for publication in the proceedings, or the author may be invited to improve the paper in line with recommendations from the editorial panel and then resubmitted.

The papers are checked and corrected for typographical errors and adherence to the template provided, which satisfies also the requirements of the digital repository styleguide. Only papers which have been accepted by the editor(s) are published in the conference proceedings.

Criteria used by editorial panel members when evaluating papers

Originality - Novel and interesting, warranting publication. The paper contains original research and /or new developments
Contents: Relevant to conference and socio-economic needs.
Title and abstract: Clearly describes the contents is suggested that he article
Language: Paper is clearly written without grammatical or other errors
Introduction: It clearly states the objective and the problem being investigated
Method: The author explains accurately how the data was collected and the information is suitable for answering the questions posed in the research
Result: The analysis and/or model is clearly presented, in a logical sequence and discussed sufficiently.
The paper is technically sound.
Conclusion: Claims are supported by the results and are reasonable, sound and justifiable
Reference: References are complete, adequate and appropriate
Figures and tables: All necessary and acceptable, suitable for a quality publication?
Units formulas and abbreviations conform to accepted standards

AIUE Proceedings of the 3rd Energy and Human Habitat Conference 2022

An energy access assessment report focusing on resource and cost assessment for Rwanda

Adimchinobi Asiegbu
EECE Department
Cape Peninsula University of Technology
Cape Town, South Africa
221599061@mycput.ac.za

Marco Adonis
EECE Department
Cape Peninsula University of Technology
Cape Town, South Africa
adonism@cput.ac.za

Ali Almaktoof
EECE Department
Cape Peninsula University of Technology
Cape Town, South Africa
almaktoofa@cput.ac.za

Abstract:

An energy access assessment report focusing on resource and cost assessment for Rwanda, profiles different energy resources, in various spatial locations with the objective of analysing different sources of energy and their ease of exploitation. The five basic dimensions of providing a complete energy assessment are fully described and used to perform the energy assessment. Rwanda is blessed with various energy sources like biomass (peat, methane gas production, and agricultural residues), hydroelectric power resources from various rivers flowing in numerous uneven valleys, solar photo-voltaic energy resources, wind energy resources, fossil, and fuel wood energy resources. The cost of developing and implementing energy sources after they have been selected and approved for cost analysis is done using the Incremental energy access cost (IEAC) and the incremental cost of access to clean energy for energy resources.

The total cost of 100% electricity access is $2,525,402,880, The incremental cost of access to clean energy is 077, biomass = $2,982,810,650 and from clean cooking = $2,285,000,000. Modern device use is encouraged for better energy resource utilization and improved efficiency of the associated devices, and importantly, lower energy poverty. The research data in this paper is used to solve complex energy resources and energy modern devices efficiency problems creatively.

Keywords:

distribution systems; microgrid; mini grid; inverter; power quality; smart grid; photo voltaic array; natural gas; biomass

***Corresponding Author** Email: 221599061@mycput.ac.za

I. Introduction

An energy access assessment report focusing on resource and cost assessment for Rwanda is research paper that assess the availability, adequacy, and sustainability of various renewable energy sources, which will assist policy makers, academic researchers, investors, and the Rwanda government in energy access planning and developing modern energy for economic and social development of the Rwandan economy and her population with considerations to the cost assessment of the energy resources. This energy resources assessment will produce useful information for decision making and planning in the context of modern lifestyle and modern energy development. This will result in the reduction of dependence of biomass for cooking needs, encouraging domestic alternative and sustainable energy sources, promoting improved biomass cookstoves programs and the development of database for periodic regional energy levels [1]. Hence, the Energy assessment dimensions will be used to detect, extrapolate, analyze, and compile an energy access assessment. These parameters that give the direction or path to follow in other to perform the various energy resource assessment carefully and meticulously are known as energy resource dimensions and they are:

1. Energy resources availability and potential economic prospects

2. Energy resources adequacy
3. Energy resources sustainability
4. Ease of access of the Energy resources
5. Cost of use of the Energy resources [2]

The primary energy resources abundant and analysed in Rwanda include:

1. Biomass energy resources
2. Fossil fuel energy resources
3. Hydropower energy resources
4. Wind energy resources
5. Solar energy resources [3]

The data produced at the end of the different levels of assessment include potential and economically exploitable available energy resources, the spatial distribution of energy resources, and temporal availability patterns spread out in different durations per year based on the United Nations (UN) 2030 agenda for Sustainable Development Goals (SDG) Number 7 [4].

The cost assessment is the assessment done on the energy resources with the objective and task of providing cost effective options for providing modern and clean energy access, total clean energy access cost for the supply (producer) side and the demand (consumer) side cost, respectively. It provides meaningful investments opportunity, the present cost, and other associated costs that are tied to the energy access program (EAP) and its implementation in Rwanda.

In addition, the cost assessments provide per unit cost of producing and utilizing modern clean energy and even the total cost of energy provision to poor households, which is a good indication of energy burden and affordability of energy access in Rwanda.

II. METHODOLOGY

1. The Resource Assessment in Rwanda

Resource assessment needs to be done to ascertain to what extent is the nation of Rwanda blessed with economic viable and exploitable energy resources, their temporal availability, sustainability, and spatial distribution spread out over a duration of time in hours, days, weeks, months, and years as the case maybe (and depending on the type of the energy resources).

The quantity and quality of the primary energy resources needs to be known. The primary energy resources include the following:

1. Biomass energy resources (400MW of peat energy resource potential and another 100 tons per day 1MW with up 350 tons of waste to energy resource centrally managed)
2. Fossil fuel energy resources (investment potential of 50-100MW of power from methane).
3. Hydropower energy resources (137MW Ruzizi III and 287MW Ruzizi IV investment potential)
4. Wind energy resources (still at the infancy level)
5. Solar energy resources (4.5kWh/m2 per day and 5 peak sun hours, solar energy is an abundant energy resource in Rwanda) [5]

1.1 Energy resources **availability** and **potential economic prospects**

This refers to potential energy resources that are economically viable, economically exploitable, spatial, and temporal location and distribution of these energy resources. In Rwanda the available energy resources are biomass energy sources (biogas, wood, peat, methane gas, biological residues and organic wastes) with 85% national energy consumption in Rwanda and 5% contribution to GDP [6]. Rwanda has 155,000,000 tons of dry peat reserves, around 77% of this energy resources is found around Rivers of Nyabarongo and Akanyaru with 2.1×10^{18} J energy potential economic prospect that has a calorific value of 13,360 kJ/kg [7]. Methane gas extractable in Kivu Lake and KivuWatt project can produce 700 MW of electricity from methane for a duration of 55 years [8]. However, Rwanda has no significant exploitable petroleum oil reserves. The population of Rwanda is projected to grow at a peak rate of 181,818 persons per year, as shown in figure 1. The population growth needs to match the modern energy need, to avoid energy access problems in future.

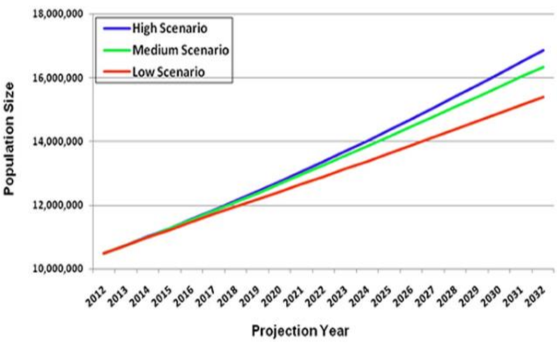

Figure 1: Rwanda population growth Projection [9].

Solar power irradiation is in the interval of 4 kWh/m² to 5.4 kWh/m² or from 2000 to 2500 J/cm2/day from Ruhengeri north to Kigali south, and from the Eastern provinces to Southern provinces [10]. The hydro energy resources untapped potential is more than 300 MW located in 333 possible sites for small hydro-power electrical generation [11]. Based on the hydropower Atlas of Rwanda, produced by the nation's ministry of Infrastructure in 2009, majorities of the identified locations or sites are within the interval of 50 kW and 1 MW in renewable energy resource potential capacity, which are found along major rivers flowing southern direction from Mount Karisimbi, country northern part, through the Ruzizi River to Lake Kivu in the west [12]. Rwanda has an installed electricity generation capacity of 226.7 MW from 45 power generation plants serving 13 million people in 2022, which is an equivalent of 54.5% national rate of electrification [13]. However, only 46.6% have access to electricity in Rwanda in 2020, and it is likely to remain the same until 2022 due to Covid-19 global pandemic.

1.2 Energy resources adequacy

This is the dimension that measures the resourcefulness of the quantity of the energy resources, clearly showing whether it meet the energy need of the population or the Rwandan economy over a short-, medium- and long-term periods, respectively. For example, Rwanda is running a fuel wood deficit of about 4,500,000 cubic meters per year because in 2018, about 99.6% of households used biomass to cook and 53% cooked with a three-stone fire [14]. Rwanda with dry peat reserve of 2.1×10^{18} J energy potential, methane gas extractable energy source value of 700 MW of electricity from methane for a duration of 55 years, Solar power irradiation in the interval of 4 kWh/m² to 5.5 kWh/m², and the hydro energy resources untapped potential of more than 300 MW located in 333 possible sites for small hydro-power electrical generation, has adequate biomass, fuel wood, fossil fuel, hydropower, solar power energy sources which is extractable and easily accessible. The wind energy resources are still in infancy stage, and it is being studied as at the time of this technical report.

1.3 Energy resources sustainability

This is the principle of sustaining human development goals while simultaneously sustaining the natural system and the ecosystems where the society and system depends on. The effects of energy resource exploitation and use on the health, energy security, environment, and economic perspectives must be considered in assessing the sustainability of the primary energy source to be accepted and developed. For example, some Rwandan household may be relocated to new environment, so that energy resource could be harnessed and exploited. Also, there could be an ecological effect due to the use of biomass and other Green House Gas (GHG) emissions activities which possess a health threat if not well considered in the initial plan. In the context of this careful research, biomass especially fuelwood as energy source is not sustainable in Rwanda or only sustainable in the short terms, fossil fuel is sustainable in the medium terms, hydropower and solar power is sustainable in the long terms, but wind energy sustainability is not yet verified and compiled due to poor wind resources in most of the regions of Rwanda.

1.4 Ease of access of the Energy resources

Relative ease of access to an energy resource is important for its economic use and exploitation. It is very useful to know the manpower duration (in minutes or preferably hours), that is needed to access the resource. Thus, the easier it is to access the energy resource, the preferable and practicable it is for selection and development. In Rwanda time spent in collecting fuelwood has low economic value and health hazards like injuries from collecting firewood, and GHG effects makes biomass less attractive as an energy resource. Fossil fuel like methane gas is accessible but must be processed to have a high-octane value, which ensure high efficiency in the complete combustion (incomplete combustion results in the production of carbon monoxide, a very dangerous gas) of the gas and low GHG emission. Although hydropower, solar power and wind power is accessible, they are spatially located in Rwanda. The development of a solid-state transformer that allows bidirectional flow in alternating current or direct current forms respectively and vice versa, is needed for the distributed generation, integrated by a smart grid energy system.

1.5 Cost of use of the Energy resources

The cost of using energy sources in the provision of basic energy services is important and it varies with the amount utilized. The cost calculated is very important in finding the most cost-effective energy resource. Solar energy cost of generating electrical energy is the lowest, followed by hydropower with high source utilization. Wind energy have low cost of energy but not reliable in Rwanda due to uneven hills. Biomass and fuel wood (cheap but has health issues that will cost money, time, and negative impact on the quality of life) is not cost effective.

i. *Stage 1 Findings*

2. Cost Assessment

The cost assessment is done to determine the most cost-effective ways of energy sources provision and the overall total energy source cost of cleaner energy for all households in Rwanda. This analysis is done on the demand side and the supply side sustainable energy access program (SEAP). It reveals the cost of investment and other associated cost for providing the infrastructure for energy source, optimum utilization, energy access program (EAP) development, and implementation. The per unit cost of cleaner energy and the total cost of energy provision to poor household is retrieved and used to calculate the energy burden of the households and the affordability of energy in Rwanda. Table 1 shows the Power Africa database for Rwanda, an affiliation of 12 United States (US) Government Agencies, more than 145 private firms, 18 bilateral and multilateral development partners, support sub-Saharan Africa to increase access to clean energy.

Table 1: power Africa database 2021 for Rwanda [15].

Population = **12.5 million**	GDP Growth (2017): **6.1%**	% Energy targets met. GDP/Capital (PPP) = **$743**	Ease of Doing Business = **41**	current Capacity: **218MW**
Reached Financial Close: **127MW**	2030 Pipeline: **176MW**	Current Access Rate: **30%**	Households without Power: **1.7 million**	Target: Universal access by 2024 **(52% on-grid, 48% off grid)**
Electricity consumption per household is **425kWh**	Primary energy consumption is **5TWh**	per capital electricity consumption is **62kWh**	Rwanda's national estimated electrification rate is **30% (12% in rural areas, 72% in urban areas)**	Solar: 12MW Thermal: 103MW Hydroelectric: **98MW**

The Rwanda government is targeting to reach 70% electricity access by 2021 (100% by 2030) and a new connection of 300800 households. From the Table 1, additional installed generation capacity of 176MW (by 2030) is needed on top of the current 119MW (present day but reached 127MW financial close). This means the country needs $3 billion investment (2030) to fill this gap, it is estimated that one third of this investment will be provided by private sector.

According to International Renewable Energy Agency (IRENA) (2020), Global Renewables Outlook of Energy transformation 2050 solar photo voltaic (PV) yields the best decrease in cost during the period of 2010 to 2019 at 82%, then Concentrated Solar Power (CSP) at 47%, offshore wind at 29% and onshore wind at 40%. utility-scale solar PV cost decreased from 13% year after year, reaching seven cents (USD 0.068) per kilowatt-hour (kWh) in 2019. Onshore and offshore wind decreased by 9% year after year, reaching USD 0.053/kWh and USD 0.115/kWh. Costs for CSP decreased by 1% to USD 0.182/kWh. Thus, replacing coal with this renewable energy sources will yield 1% of global GDP increase and decarbonization by reducing carbon dioxide (CO_2) GHG by 1.8 Giga tonnes, or 5% of previous year's global total amount [16].

Cost of energy sources (PV) = USD 0.182/kWh X 5.5 kWh/m² = $1.001/m² (on the demand side and supply side but other additional cost applies, like installation, material, manpower and technical cost respectively.

Cost of energy resources (biomass) = 5% contribution to GDP X $743 energy/GDP met = $37.15 on the demand side (energy met).

Total cooking cost = fuel cost + annualizes stove cost + inconvenience cost. The cost of cooking gas and its inherent short falls is more expensive in Rwanda than the cost of solar PV, wind, and hydropower. Hence total cooking cost = $37.15 X 47.23% for biomass X 1.7 million = **$2,982,810,650** for household without electricity access and $37.15 X 47.23% for biomass X 12.5 million people = **$22 Billion** for electricity access to all the population from a fraction of biomass energy resource.

As an example of a rural community, the population of rural Ruzizi community is 80% of the Ruzizi District (400859 persons) [17], which is equivalent to 320688 people, translating to 64138 households of five persons. Using the minimum threshold electricity consumption level of 250 kWh/annum for a rural household, the Ruzizi rural community energy need is 16034360kWh/annum or 43930kWh/day. The minimum cost = 250kWh/year/household X 64138 households X $0.182/kWh = $2918253.52/year (**3005801125.60 Rwanda franc**) = ($26,264,281.68 for 9years). The average cost = **425kWh**/year /household X 64138 households X $0.182/kWh = $4,961,074.30 (**5,109,906,529 Rwanda franc**) =$44,649,668.7 (for 9years). The maximum cost = 1000kWh/year/household X 64138 households X $0.182/kWh = $11673116 (**12023309480 Rwanda franc**) = ($105,058,044 for 9 years) Modern minimum threshold electricity consumption level is 250, 425 or 1000 kWh/year/household depending on the level of energy consumption, which is an indication of Gross Domestic Product (GDP) of a nation. Thus, for the poorest population and bottom energy poor that cannot afford to install its own alternative supply in the remotest part of Ruzizi community and not connected to the national grid, they will need at least 43930kWh/day at a cost of $2918253.52/year (**3,005,801,125.60) Rwanda franc**).

HOMER Pro simulation for Ruzizi rural community in Rwanda.

The Homer Pro configuration components used are solar PV, hydrokinetics, hydro-energy, battery, and inverter, excluding wind energy, at Net Present Cost (NPC) = **689,334,059.70 (equal to 6,204,006,537 Rwanda franc in 9years)** Rwandan franc, and COE = 2729.73 Rwandan franc. The system components, parameters, and configuration are shown in table 2 and figure 1. This represents 3% more than the calculated cost of electricity in Rwanda.

Table 2: The system architecture component details

Component	Name	Size	Unit
PV	Generic flat plate PV	25.8	kW
Storage	Generic 1kWh Lead Acid	90	strings
System converter	System Converter	5.23	kW
Hydroelectric	Generic Hydro 100kW	98.1	kW
Hydrokinetic	SMART Free Stream 5kW	1.00	quantity
Dispatch strategy	HOMER Cycle Charging		

Electricity supply options involves the technical characteristics and the associated costs. This is modelled using Generation Technology Options and Costs, Power Generation Capacity Requirements, and Cost of Providing Electricity Access.

The ideal Generation Technology Options and Costs based on this research is PV, Wind, Hydropower, which is the best path to follow in other to achieve the best quality of life and affordable energy. The difference in demand side cost and supply side cost will be low, translating to low energy burden per capital income. PV technology option emerged as the best among the best energy resources in Rwanda.

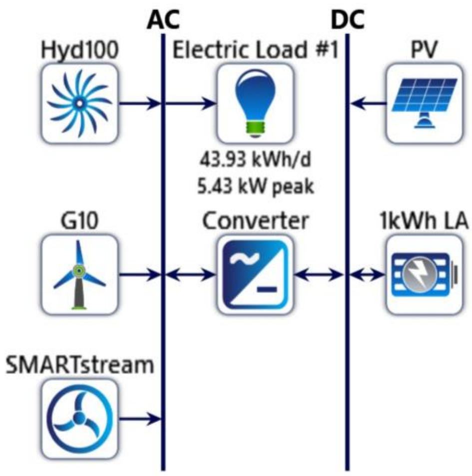

Figure 1: The system configuration

III. Results and Discussion

The Power Generation Capacity Requirements in Rwanda based on the data retrieved is 218 MW, but available power capacity is 127MW with an extra 176MW targeted by 2030 according to Table 1.

The Electricity Supply Capacity Requirement and Technology Mix = USD 0.182/kWh X 5.5 kWh/m² + 5% contribution to GDP X $743 energy/GDP + 425kWh X USD 0.182/kWh + 0.053/kWh and USD 0.115/kWh = %Solar PV technology investment + %biomass technology investment + %CSPV technology investment + %wind energy technology investment = 100% technology mix.

Currently, the Electricity Generation Mix (Energy derivatives) include Solar = 12MW, Thermal = 103MW, Hydroelectric = 98MW and total = 218MW. In terms of percentage as shown in Figure 2, %solar = 5.51, %thermal (biomass, agricultural residue and methane gas from peat used in thermal power plant) = 47.23, %hydroelectric power plant = 44.95.

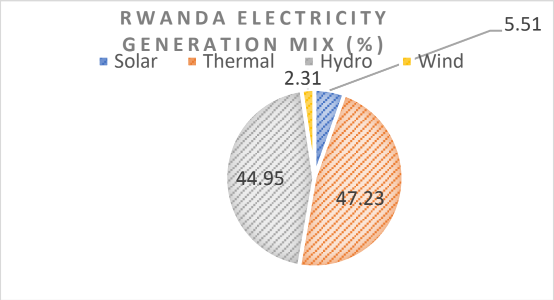

Figure 2: Rwanda Electricity Generation Mix

According to Figure 3, Hydro and PV energy sources, respectively, along with a robust battery storage, presents the best energy opportunity for Ruzizi rural community.

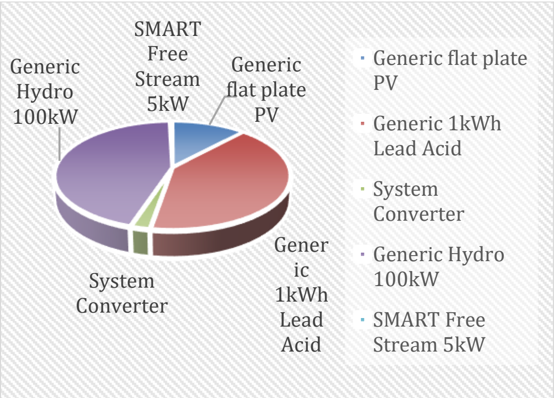

Figure 3: HOMER Pro Erectricity Mix for Ruzizi rural community in Rwanda.

The electrical energy generated from solar PV should be increased to attain self-sufficiency and sustainability in both access to modern clean energy and ecological or biome stability with additional health benefits and GHG reduction in Rwanda. The biomass energy resources should be optimized and utilized in the production of other value-added services like production of Poly Vinyl Chloride (PVC), fertilizers, plastics and polymers, pharmaceutical products, and overall industrialization of the republic of Rwanda.

Cost of Providing Electricity Access to provide 100% access to electricity, an extra 176 MW must be provided = 176000 kW X $0.182/kWh = $32,032/h = 32032/h X 365days X 24h X 9 years (up to year 2030) = **$2,525,402,880 (2601164966400) (2.6 billion) Rwanda franc)**. 53.4% of 12.95 million Rwandans (= 6,915,300 Rwandans (1,383,060 households)) don't have access to electricity. Thus, the cost of providing electricity access in Ruzizi = (320688/6,915,300) X **$2,525,402,880 = $117,112,258. This will guarantee minimum modern energy per household of at least 1000kWh for this off-grid community.**

Total Cost of Electricity Supply incremental energy access cost is used to measure access to energy cost when a higher tier of energy access is considered and to meet the energy demand of a higher level of energy services per household under energy access program. **218000kW X USD 0.182/kWh X 9years X 365 X 24h = $3,093,681,600 (3,186,492,048,000 Rwanda franc) for 2030 and 9 years from 2021.**

The breakdown of Total Cost into Demand and Supply Side Costs:

On the supply side, total cost = **$3,093,681,600 and on the demand side, the total cost = (6915300/320688) X 44649668.7 = $962,823,223.7 per household of five persons from 2021 to 2030.**

The investment requirements of $2,525,402,880 (2601164966400 Rwanda franc) is needed in Rwanda for 100% energy access. Approximately 45% increase of this amount is required, if the primary energy source is from hydroelectric sources and if it is from biomass, 47% increase in this cost is required.

Incremental Cost of Electricity Access Cost (IEAC) = **($3,475,617,600 + ($6775860 X 12.5 million/5 persons))/ ($6775860 X 12.5 million/5 persons) = 1.000021 for time difference of 10 years.**

Cleaner Cooking Access Cost is shown in Table 2.

Table 2: Household cooking fuel analysis [18]

	Cookstove efficiencies or type (%)	Cookstove cost/region ($)
Basic fuel wood	21	10
Basic charcoal	24	7
Improved wood	31	29
Improved charcoal	34	26
Advanced biomass	34	44
Modern stove	48	48
Biogas digesters	55	750

For the Cost and Technical Parameters of Cooking Devices, the total cost of cleaner cooking cost = $914 per household of 5 persons X 12,5 million/5 = $2,285,000,000. Using a biogas digester with efficiency of 55% is preferable to mitigate effects of inefficient stove and combustion of fossil fuel and biomass.

The incremental cost of access to clean energy **(ICACE) = $2,285,000,000/$2,982,810,650 = 0.77**, Energy Mix in Cooking under Energy resources from biomass = **$2,982,810,650 and from clean cooking = $2,285,000,000**

IV. CONCLUSIONS

Based on the analysis of Ruzizi community and Rwanda national energy access assessment focusing on resource and cost assessment, the minimum energy required by the people of rural Ruzizi tourist community is 43930kWh/day and 947304.32 kWh/day for Rwanda as a nation with overall investment power plant capacity investment at a cost of (at least) $2918253.52/year (3,005,801,125.60 Rwanda franc). The cost per household depends on the energy usage, energy mix (the percentage of energy consumption from various energy sources), and energy availability. The energy consumption of Rwanda is an indication of the GDP, standard of living, and quality of life Rwandans. For modern living and from this paper's research findings, the government and energy policy makers in Rwanda should use 1000kWh instead of 125kWh as the minimum energy threshold, representing energy poverty line. Above this line translates to energy sufficient households, and below the line represents energy poor households.

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Authors Biographical Statements

	Asiegbu AD was born in 1982 in Nigeria. He received his ND (2016) and BTech (2020) in Electrical Engineering, Specializing in Power Engineering from the University of South Africa, and currently an MEng (Energy) student of Electrical Engineering, DEECE, CPDES, Cape Peninsula University of Technology. He is a member of South African Institute of Electrical Engineering (SAIEE) and Engineering Council of South Africa (ECSA). His research interest includes digital control of power converters, model predictive control, multilevel converters, real-time simulators, and renewable energy technologies, systems, and applications.
	Ali M. Almaktoof was born in Libya in 1978. He received the B. Eng. from AlTahady University, Libya in 2001 and M.Sc. from University of Tripoli, Libya in 2008, and DTech from CPUT in 2015, all in electrical engineering. He is currently a Lecturer and Researcher in Electrical Engineering, DEECE, CPDES, Cape Peninsula University of Technology. He is a member of Institution of Engineering and Technology (MIET) and World Society of Sustainable Energy Technology (WSSET). Dr. Almaktoof research interests include control of power converters, model predictive control, multilevel converters, real-time simulators, and renewable energy systems applications.
	Marco Adonis has a Doctorate Degree from Electrical Engineering, Cape Peninsula University of Technology, Cape Town. Currently, he is the Programme coordinator of Master's in Engineering degree in Energy, and a Senior Lecturer/Researcher, Cape Peninsula University of Technology.