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Optimizing Renewable Energy Selection for Home-Based Microgrid Electric Vehicle Charging: A Case Study of Rumuagholu Metropolis, Rivers State, Nigeria

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Abstract
Integrating Electric Vehicles (EVs) into home-based microgrid systems presents significant opportunities for sustainable energy transition, particularly in sub-Saharan regions where renewable energy resource diversity remains underexplored. This study proposes a home-based microgrid EV charging architecture incorporating an adaptive Renewable Energy (RE) source selection mechanism and evaluates for the Rumuagholu Metropolis in Obio/Akpor Local Government Area, Rivers State, Nigeria. A Simple Logical Analysis (SLA) algorithm is developed to determine the most power-viable RE source - solar photovoltaic (PV) or biogas, on an hourly dispatch basis across the 2019 to 2021 operational period. Simulation results and logical dispatch analyses consistently demonstrate that a grid-connected configuration dominated by solar PV yields the most energy-effective and technically feasible charging solution for the study location. These findings establish a replicable analytical framework for context-specific renewable energy planning and contribute empirical evidence to support the sustainable engineering of decentralised power systems in Nigeria and comparable developing-economy contexts.

Keywords: *Biomass, Logical Analysis, Microgrid, Renewable Energy, Solar-PV*

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I. INTRODUCTION

The global trend in electrical energy consumption has exponentially grown in recent years because of economic development and population increase. This has resulted in the search by Governments of the land for alternative energy sources such as coal, wind, tidal waves, solar irradiation, and biomass. However, due to the specific terrain situations in different regions, the kind of RE resource chosen becomes a core function of the flexibility and availability (Perera et *al*., 2022).

Governments around the world encourage energy users to reduce energy utilisation by increasing their awareness, introducing incentives for users with low energy consumption, and promoting green energy solutions. Other possible solutions may include the reduction of energy usage and utility bills by introducing integrated photovoltaic systems, alerting consumers about their energy usage, using energy-efficient devices (e.g., light-emitting diode (LED) lamps), replacing conventional devices with smart devices (e.g., remotely controllable sockets), and adopting intelligent and automated energy management systems that control smart devices. In this paper, we present an approach that exploits computer models that are simple enough but automated as well to resolve a core problem of RE resource prioritisation, considering the available RE options.

In the last few years, the traditional power grid has been reshaped into an intelligent, highly reliable, and fully automated infrastructure, paving the way to the so-called ‘smart’ grid paradigm. With the aim of sustainable economic development, it is crucial to limit the usage of fossil energy in HEMS. A hybrid renewable energy system is referred to as a combination of solar PV, wind turbine, inverter, battery, and other additional components (Shiau *et al,* 2015). Several models are available in the literature of PV–Wind HRES. Also, the PV–wind hybrid systems are employed to satisfy the load demand (Syafaruddin *et al,* 2014). Once the power resources are sufficient, excess generated power is fed to the battery until it is fully charged. Thus, the battery comes into play when the renewable energy sources (PV–Wind) power is not able to satisfy the load demand until the storage is depleted (Chowdhury, 2016). The operation of the Hybrid PV–Wind system depends on the individual components (Ke *et al,* 2016). In order to evaluate the maximum output from each component, first the single component is modelled, and thereafter the combination can be evaluated to meet the required dependability (Kottas *et al*, 2016).

Mohammadi *et al,* (2016) presented an adaptable and prevailing function in optimizing actual and future operational situations of the Hybrid PV-Wind System, addressing the active and reactive problems of the system. The values of control variables were calculated to reduce to an anticipated power flow problem, in relation to security and/or economy of power generation, as well as putting in view system operating limits (Messai *et al*, 2011). The study revealed that a limit violation can't be evaded (infeasibility), and a "better" alternative solution was generated. Laureri *et al,* (2016) noted that the optimal power flow is one of the critical factors to be considered during the design of Hybrid RES.

Clean energy or renewable energy, such as photovoltaic (PV) power and wind turbines, as well as flexible loads, such as electric vehicles (EVs), have received significant attention from researchers. PV generation forecasts have been combined with HEMS in a dynamic pricing system to reduce expenditures and improve end-user comfort (Iwafune *et al*., 2015). Solar-assisted thermal loads have been incorporated in models by Nguyen (Nguyen *et al.,* 2015). A Qoe approach has been introduced for HEMS with PV (Pilloni *et al.,* 2016), and wind turbines have been considered renewable resources for participation in HEMS (Hemmati, 2017). In addition, time-scale parameters and uncertainties have been modeled in wind power systems (Mehrjerdi and Rakhshani, 2019), and improved utilization of renewable sources has been enhanced by energy-sharing algorithms (Celik *et al*., 2017). The usage of Vehicle-to-Home (V2H) and Vehicle-to-Grid (V2G) capabilities of EVs, along with the two-way energy trading of energy storage system (ESS) has all been considered in a single HEMS (Erdinc *et al., 2015*). A stochastic dynamic programming framework with robust EV management strategies has also been proposed in (Wu *et al*., 2023) to deal with the optimization problem of stochasticity.

With the aforementioned research studies, it is obvious that solar and wind resources are widely adopted. It is also pertinent to note that most existing studies needlessly employ complex methods in the evaluation of the suitable energy options; also, there are limited studies considering the combination of renewable energy, such as solar with biomass options and particularly considering a simpler logical analysis.

In this research paper, we attempt to leverage the method of simple logical analysis for evaluating and assessing the most suitable energy plan considering a solar-biomass RE system.

II. Material and Methods

2.1 Electric Vehicle Charging Load Profile

The daily load profile of a typical autonomous unit basing on a recent study on Electric Vehicles (EV) charging stations simulation in (Li *et al.,* 2022) is considered and employed for microgrid simulations. The hourly readings for a typical period in a day are as shown in Figure 1. From initial simulations, this loading amounts to about 24.17kWh/day on average and a peak power of 54.07kW on the baseline as shown in Figure 1.

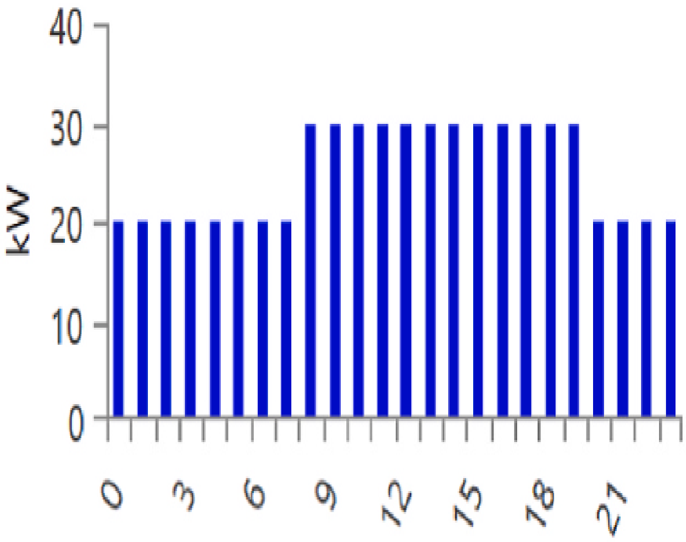

Figure 1. Daily profile used in this study (Source: Li *et al.,* 2022)

2.2 Renewable Energy System Modeling

The renewable energy system considered in this study comprises a biogas generator and a solar photovoltaic (PV) generator. The biogas subsystem includes anaerobic digesters, a gas storage unit, and a biogas-fueled engine–generator set. In contrast, the PV subsystem consists of solar modules arranged in series and parallel configurations, supported by power conditioning and control components. The combined system provides electrical energy by converting biomass-derived gas and solar irradiance.

2.2.1 Biogas Generator Model

The biogas generator converts the chemical energy of biogas into electrical energy. For simplified analysis, the energy output is estimated as a function of the biogas volume and its energy content:

$$E_{bg} = BV \times BEE \quad (1)$$

Where:
E_{bg}= Electrical energy output from biogas (kWh)
BV = Biogas Volume (m^3)
BEE = Biogas Energy Equivalent (kWh/m^3)

To reflect operational conditions, system efficiency may be considered:

$$E_{bg} = BV \times BEE \times \eta_{sys} \quad (2)$$

Where:
η_{sys} =Overall system efficiency

2.2.2 Solar Photovoltaic (PV) Generator Model

The solar PV generator converts solar irradiance into electrical power through semiconductor-based PV modules. Solar power at Standard Test Conditions (STC) is computed as (Ayodele *et al.*, 2017, Olatomiwa, 2016):

$$P_{pv} = N_s \times N_p \times V_{oc} \times I_{sc} \times FF \quad (3)$$

where,
N_s= number of PV modules connected in series
N_p= number of PV modules connected in parallel
V_{oc}= open circuit voltage of the PV module at STC
I_{sc}= short-circuit current of the PV module at STC
FF= PV module fill factor

2.3 Simple Logical Analysis Modeling

In order to achieve the desired alternative renewable energy switching policy, a model for Simple Logical Analysis (SLA) needs to be developed. In this study, a data-driven logic (pseudo-code) is implemented as follows in Listing 1:

Listing 1: The SLA computational program

Step 1: Compute the Solar and Biogas Power densities, *Psolar* and *PBiogas* for site using Eq.(1) and Eq.(3)
Step 2: Initialize SLA signalling variables: *modePBiogas*, *modePV*, *modeSelect* and *modeContribution*, *i*
Step 3: Run the SLA module logic:

```
for i = 1:n

if(Pbiogas(i)  >Psolar(i))

modeBiogas(i) = 1;
modePV(i) = 0;

   else
modeBiogas(i) = 0;
modePV(i) = 1;


   end
```

```
end

modeSelect = [modeBiogasmodePV];

modeContribution = (Pbiogas  +Psolar) >11.26; %> 11.26kW/hr - EV-hourly
```

Step 4: Print Results to screen

The essence of SLA as demonstrated in Listing 1, is to identify firstly the winning renewable scheme based on the state representations of Biogas Turbines (modeBiogas) and Solar PV module system (modePV).

III. Results

3.1 Simulations Using the MATLAB Dynamic Environment

To evaluate the effectiveness of the proposed hybrid system, a simulation program has been developed. This program is specifically enabled to demonstrate the alternate energy selection based on solar energy and bio-gas regimes for Rumuagholu metropolis using a simple logical method. The simulation results capture firstly the computation of the monthly-daily generation of both RE power schemes (Solar-PV and Bio-gas), then the logical simulator part for prioritizing an RE scheme one at a time.

3.2 Daily-Hourly Computations

This was done to estimate the monthly-daily energy generating capacities for a given month, i.e., for the month of January (id 1) through to December (id 12), and for the years 2018 to 2021, considering the Solar-PV and bio-gas power model.

The monthly-daily power generation for both schemes (Solar-PV and Biogas) for the considered years is shown in Figures 2 through 5.

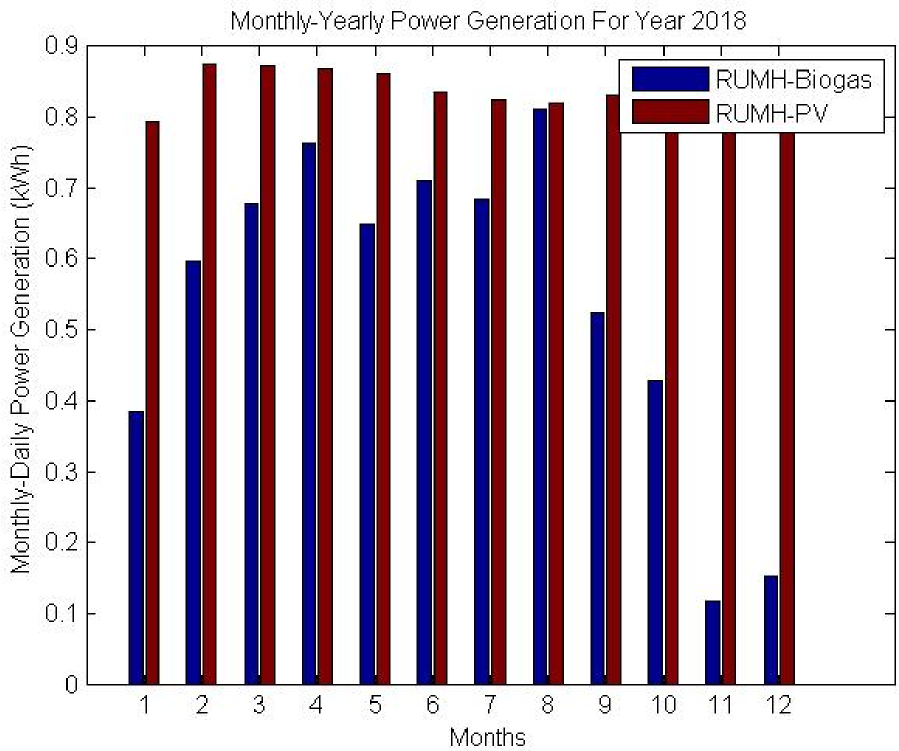

Figure 2. Monthly-Daily Generation for 2018

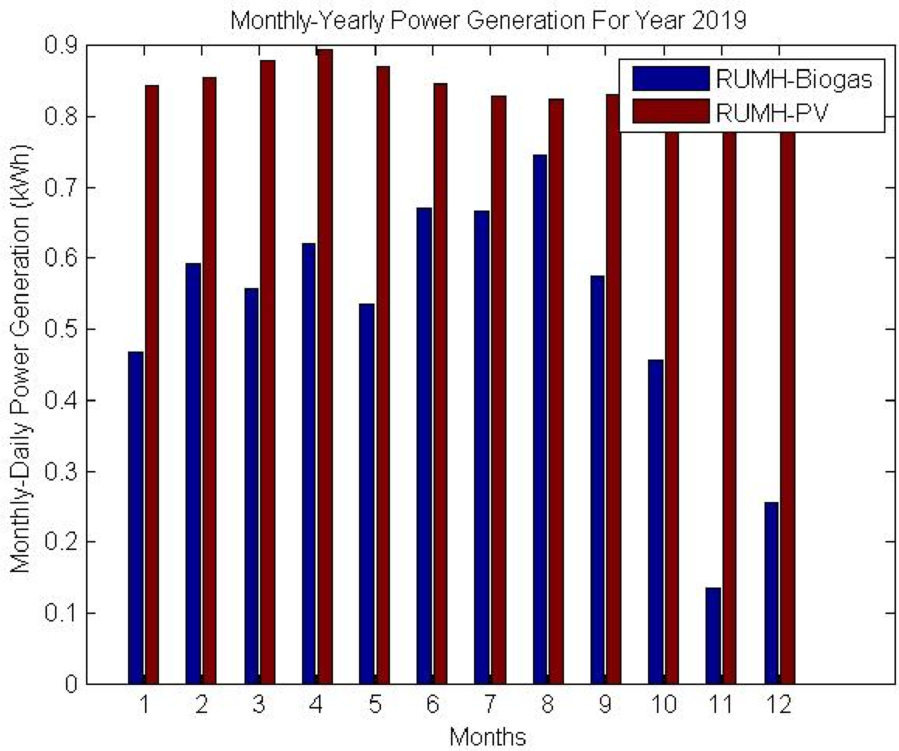

Figure 3. Monthly-Daily Generation for 2019

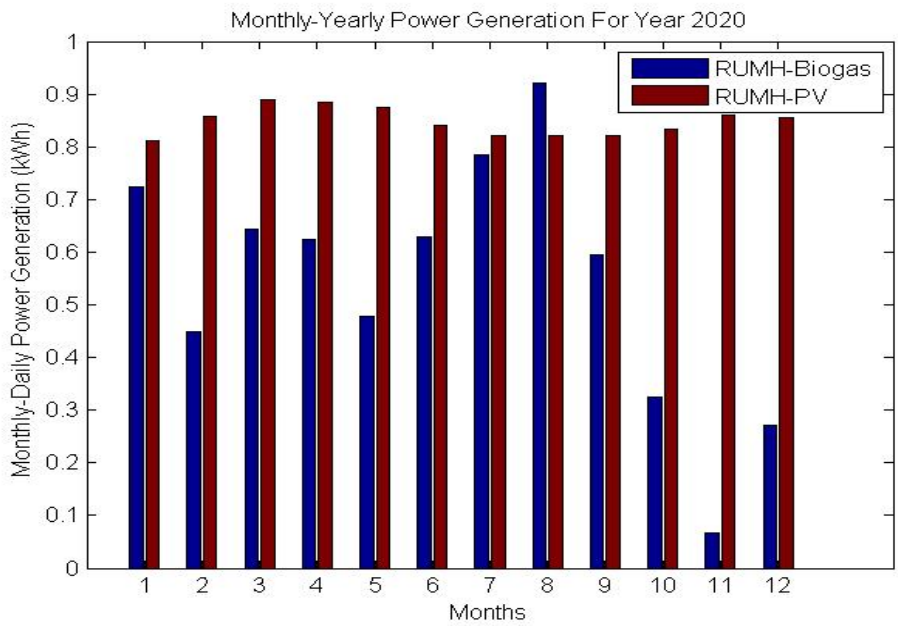

Figure 4. Monthly-Daily Generation for 2020

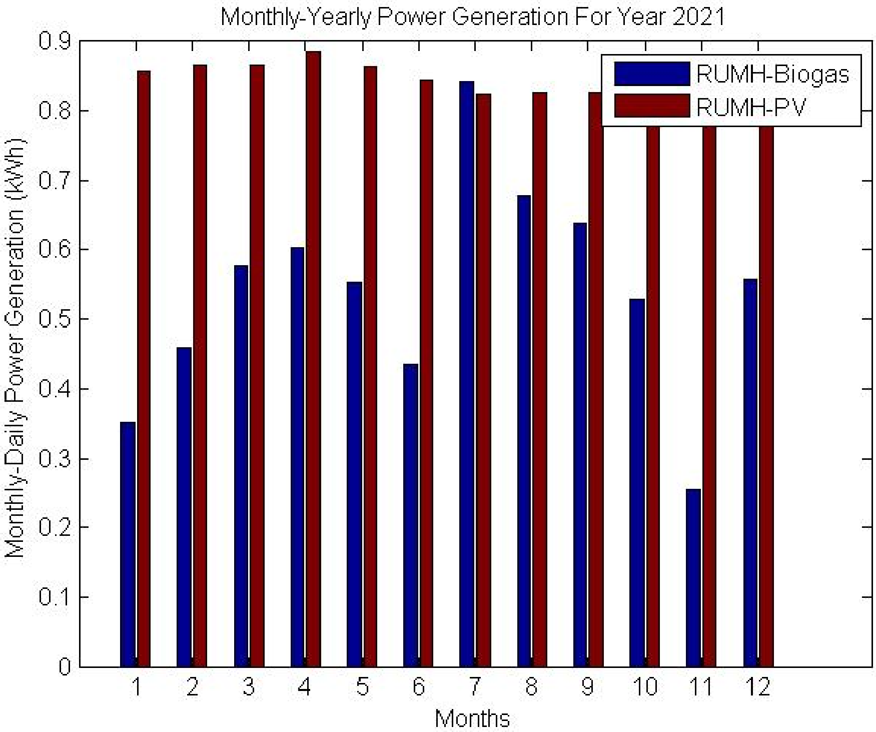

Figure 5. Monthly-Daily Generation for 2021

As can be clearly seen in the simulated plots (Figures 2 through 5), for most of the months, the Solar-PV (RUMH-PV) clearly outperformed the biomass option and hence should be the ideal choice as a viable energy option for the Rumuagholu metropolis.

IV. Conclusions

Renewable Energy (RE) systems are beginning to gain traction as a viable solution to the perennial power issues, and as a result, this research study has been embarked upon, considering two alternatives RE systems, the Solar-PV and the Biomass generation. From a simulation study and on the basis of an SLA routine for a location in Rivers State (Rumuagholu metropolis), the research has shown that the Solar-PV is a viable solution to the power crisis. Hence, it is recommended that this RE option be given more priority. The areas of possible use are primarily centred on the energy sector, particularly in remote locations where access to the power grid is almost non-existent and in urban areas where the cost of supply is exorbitant and unaffordable. The research study will also be specifically useful in grid-connected RE planning and optimization operations for EV charging stations in the research labs and field. Also, it will be desirable to exploit the benefits of some sort of dynamic optimization program in the SLA routine to further enhance the robustness of the SLA solution.

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