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Increasing the Production Efficiency of Abakaliki Rice Mill Cluster by Provision of Environmental Friendly and Alternative Hybrid Energy Source

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ABSTRACT
The agricultural sector plays a central role in the economic development of many developing nations, including Nigeria. Among the various agricultural produce, rice holds significant importance as a staple food, contributing substantially to food security and the livelihoods of millions. This study examines energy consumption and the potential for solar energy integration within the Abakaliki Rice Mill Industrial Cluster, a key rice processing hub in Ebonyi State, Nigeria. Established in 1967, the cluster currently relies on both firewood and diesel generators, powering machines used for milling, de-stoning, and bag-sewing. This reliance on diesel fuel creates significant challenges, including high operational costs, unreliable fuel availability, and fluctuating fuel quality. The high cost of diesel contributes to increased rice prices and potential artificial scarcity, impacting food security. Additionally, emissions from diesel combustion and firewood burning contribute to air pollution, greenhouse gas emissions, environmental degradation, and health risks. Frequent breakdowns of diesel-operated machinery further disrupt mill operations. Energy assessments reveal that each cluster, containing up to 14 milling machines, consumes approximately 109,200 liters of diesel annually, costing ₦136.5 million. A comparative cost analysis, using PVsyst software, evaluated the current diesel system against a proposed 200 kWp PV solar system. Results indicate that the PV system could generate 293,495 kWh annually with an 81% performance ratio, offering substantial cost savings and reducing CO2 emissions by 3,294.4 tons per year. The study concludes that a mini hybrid PV power plant is a viable and beneficial alternative, promoting economic viability, sustainability, and environmental responsibility. Mill operators have expressed a strong interest in alternative energy solutions due to the existing diesel-related challenges if built sustainably.

Keywords:
Rice mill,
GHGs emission,
Mini Hybrid,
Milling Machine,
PVsyst.

INTRODUCTION

Rice milling plays a crucial role in global food security, as rice is a staple food for over a third of the world's population, including Nigerians who consume it in diverse ways across all socioeconomic classes (Okoye & Irem., 2019). Globally, about 85% of rice production is for human consumption (Muthayya *et al.,* 2014; Jeong *et al.,* 2017). In Nigeria, where rice is a staple for 90-95% of the population (Danbaba, 2019), the rice milling industry has significant potential to boost employment, the economy, and food security. Beyond its nutritional value, rice also has medicinal uses, treating ailments like stomach upset, heartburn, indigestion, and even some cancers and warts (Zhang, 2021). Long before Ebonyi State was created in 1996, Abakaliki was renowned for its high concentration of rice mills, the largest in West Africa (Okoye & Irem., 2019; Okonkwo *et al.,* 2021). Today, around 500 privately owned mills operate across the state, processing and distributing rice to wholesalers and retailers. Major Rice farming areas include Ikwo, Abakaliki, Izzi, Ebonyi, Afikpo South, and Ivo. The increased production from these areas has led to the development of a robust marketing system to handle the surplus. Abakaliki's suitability for rice cultivation dates back to its fertile, hydromorphic soils, similar to those in Ishielu and Ehugbo. By 1960, Abakaliki rice had achieved national and international recognition, traded and transported extensively throughout Nigeria and even to Ghana (Okonkwo *et al.,* 2021).

The popular Abakaliki Rice Mill cluster established in 1967 is a large privately owned and cooperative-operated milling industry located along the popular Ogoja Road, opposite the Abakaliki Motor Mechanic site in Abakaliki LGA, Ebonyi State. The Cluster plays a vital role in the economy of the State, serving as a key hub for rice production and processing. It boosts agricultural productivity, ensuring a steady supply of high-quality rice to local and national markets while supporting food security. The cluster generates significant employment opportunities across the rice value chain, from farming to processing and marketing, while also supporting related industries such as transportation and equipment manufacturing.

In addition to creating jobs, the cluster contributes substantially to the state's revenue through taxes and export earnings (Okonkwo *et al.,* 2021), improving local incomes of the State and the standard of living of the people of Ebonyi. Its renowned rice quality has attracted investors and fostered market expansion, further promoting rural development (Emeafor & Okpoto, 2018), while simultaneously serving as a center for knowledge and technology transfer, equipping farmers and processors (including rice harvesters and mill operators) with modern techniques to boost efficiency and yields.

Figure 1: Abakaliki rice mill cluster, showing the central entrance road in a wing & a cluster frontage

The Abakaliki mill complex is organized into three wings labeled Line A, B, and C with 24 clusters, each consisting of a central road flanked by milling buildings on both sides. In each of the lines, buildings on the right are numbered with odd numbers, while those on the left are even-numbered. Each building is considered a cluster, housing four large milling halls. Each hall typically contains a minimum of three milling machines, one de-stoning machine, and two bag-sewing machines. The current energy source in the cluster is firewood and Diesel generators. This has made the operators to use diesel to run the machines and firewood in parboiling rice. The use of/and high cost of diesel in Nigeria increases the price of rice per Kg milled from the cluster and also creates its artificial scarcity thereby adding to the food insecurity. Equally the emission from the combustion of the diesel and burning of firewood has significantly added a lot of pollutants to the atmosphere including greenhouse gases, contributing to environmental degradation and posing health risks to the local population (Nwachukwu *et al.,* 2021). The diesel operated machines easily breaks down and keeps the mill operators out of operation. Some of the damaged diesel machines assembled outside the cluster is displayed in figure 2.

The Abakaliki Rice Cluster, despite its significant contribution to Ebonyi State's economy, faces production efficiency challenges primarily driven by reliance on fossil fuels (diesel). This project is therefore aimed at proposing a green energy source that is cheaper and environmentally friendly. Our objective is to determine the most suitable combination of renewable energy sources (e.g., solar, wind, biomass) and conventional energy sources to create a hybrid energy system that maximizes rice production efficiency, minimizes operational costs, and reduces environmental impact within the Abakaliki Rice Cluster.

Figure 2: Diesel generators used in the cluster; images taken at the site

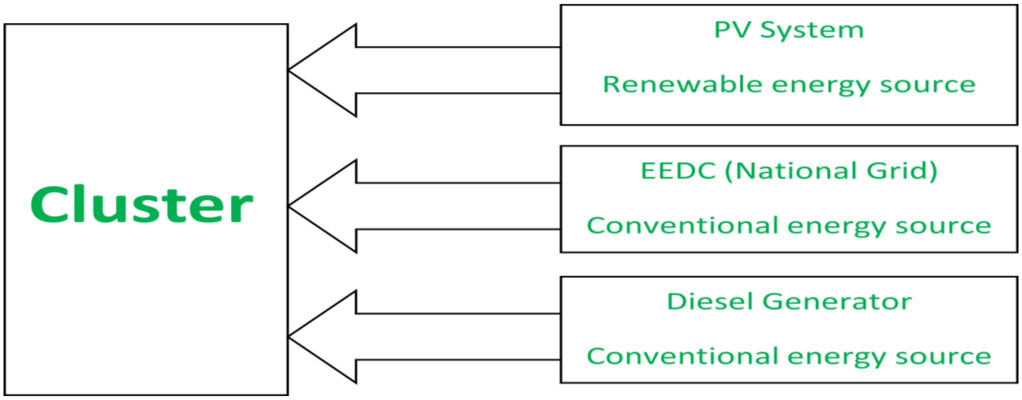


Figure 3: The Proposed Hybrid Energy System

The proposed hybrid energy system promises a wealth of benefits for stakeholders within the Abakaliki Rice Cluster. Farmers will see reduced production expenses thanks to a decreased reliance on expensive diesel, leading to increased profitability and improved livelihoods. Rice processors will gain access to more efficient and sustainable energy solutions, lowering their energy costs and improving product quality, thus boosting their competitiveness. Consumers can look forward to lower rice prices due to these reduced production costs, making rice more affordable and accessible. The government can utilize the study's findings to develop policies that encourage sustainable energy development and support agricultural programs in Ebonyi State. Finally, the transition to renewable energy will contribute to environmental conservation by minimizing greenhouse gas emissions and combating the effects of climate change in Nigeria.

Numerous tools are available for analyzing both grid-connected and stand-alone photovoltaic (PV) systems. PV modules offer a safe, reliable, low-maintenance, and environmentally friendly power source with a long lifespan (Christian *et al.,* 2023). Successful PV system implementation requires understanding their operational performance under varying climatic conditions (Picault *et al.,* 2009). Financial analysis is also a key component of project planning. For system design, simpler tools are often used for initial sizing, while more complex simulation tools are employed for detailed design and optimization before installation. These software tools can be broadly categorized into those used for pre-feasibility analysis, sizing, and simulation (Dalton *et al.,* 2009).

PVsyst, a dedicated PC software package developed by the University of Geneva (Christian *et al.,* 2023), integrates all three of these functionalities: pre-feasibility design, sizing, and simulation. The design process within PVsyst typically involves specifying the location and load requirements of the PV system, selecting components from a product database, and then allowing the software to automatically calculate the appropriate system size (Turcotte *et al.,* 2001). Ramadhan and Naseeb (2011) conducted a cost-benefit analysis of implementing photovoltaic (PV) solar systems in Kuwait, motivated by the rising financial costs of energy resources and the environmental impact of fossil fuels. The analysis revealed that accounting for the value of saved fossil energy resources and the cost of reducing CO_2 emissions significantly lowers the effective economic LCOE. The study concludes with a recommendation to implement PV solar technology in Kuwait, citing its economic and environmental benefits.

Uhwo *et al.* (2022) designed and simulated a proposed 500 kW grid connected PV system using PVsyst for Rivers State University to care for its annual load of

995,161 MWh and sold the excess energy to PHCN. Christian *et al*. (2023) evaluated a 3000 kWp grid-connected solar PV plant in Nigeria, finding it generated 4,222,327 kWh annually, displacing 405,600 liters of diesel and saving ₦223,080,000 annually, highlighting the economic and environmental benefits of solar energy in industrial applications. Some other researchers have used similar software tools such as Sanni and Mohammed, who in 2018 analyzed a residential PV system in the climate of Ado Ekiti, Nigeria by RETScreen software.

This study focuses on designing a kilowatt-scale, mini-hybrid, grid-connected solar PV power plant for a rice mill cluster in Abakaliki. Using PVsyst 7.4.8 Energy analyzing software, the research simulated the system's performance, including energy production, performance ratio, efficiency, and all associated losses.

MATERIALS AND METHODS

Data Collection

Initial data collection involved a physical assessment and cluster inspection. This was conducted using questionnaires and oral interviews. The resulting data informed the subsequent onsite assessment and observation, which then served as the basis for the PV system design and simulation.

System Design and Simulation:

i. Load Demand Calculation: The energy requirement (load demand) for each cluster was determined by summing the power ratings of the milling, de-stoning, and bag-sewing machines within that cluster. The cluster's energy consumption was then calculated using the power, energy, and time relationship,

ii. $$power = \frac{Energy}{Time\ in\ operation\ on\ daily\ basis} \quad (1)$$

iii. The total wattage of each cluster was determined to be 200 kWp.

iv. PV System Definition: Using PVsyst V7.4.8 software, the PV system was designed and simulated. System variants were created by inputting parameters such as field type, plane tilt, azimuth angle, planned power (kWp), PV module type and quantity, and inverter type and quantity.

v. Simulation Process: Simulations were run for each system variant. After each simulation, the results were displayed and saved.

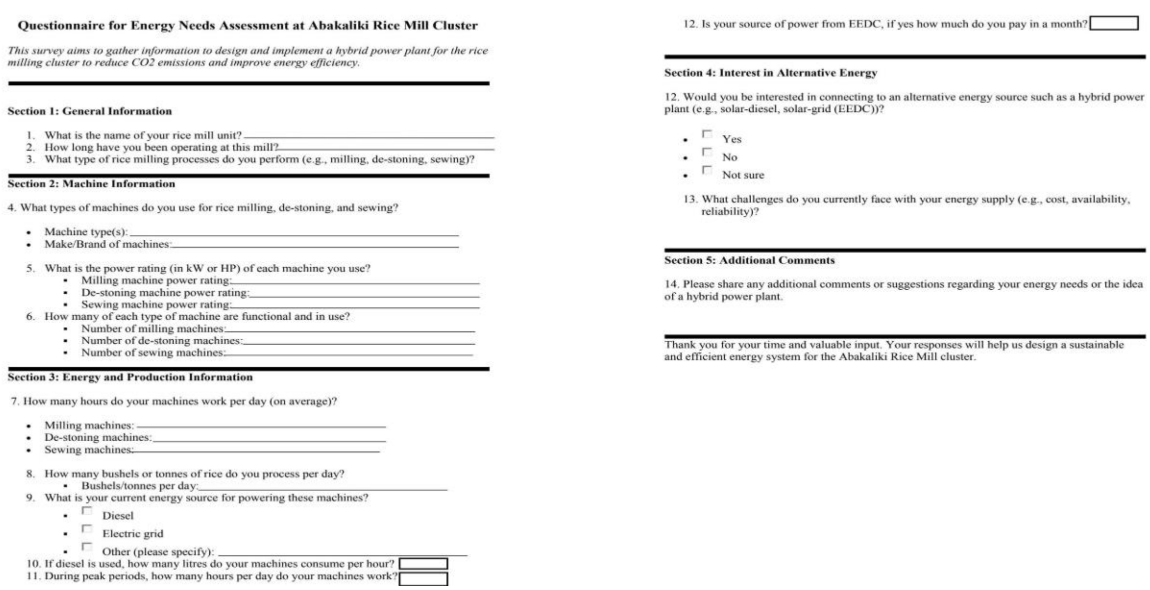
vi. Energy and Cost Analysis: Detailed simulation results were used to conduct an energy analysis. A cost analysis was then performed, comparing the cost of operating a cluster using diesel generators versus the proposed PV system.

System Specifications

The simulated system consisted of 286 CIS Mono Twin Half-cell bifacial PV modules, each rated at 700 Wp. The modules were arranged in 22 strings of 13 modules in series. A tilt angle of 30° and an azimuth angle of 180° were used. Six (6) 180 kWac solar inverters were used for grid interconnection.

Statistical Analysis

Originlab software, OriginPro 8.1 was used for additional calculations.



Questionnaire for Energy Needs Assessment at Abakaliki Rice Mill Cluster

This survey aims to gather information to design and implement a hybrid power plant for the rice milling cluster to reduce CO2 emissions and improve energy efficiency.

Section 1: General Information

1. What is the name of your rice mill unit? ____
2. How long have you been operating at this mill? ____
3. What type of rice milling processes do you perform (e.g., milling, de-stoning, sewing)?

Section 2: Machine Information

4. What types of machines do you use for rice milling, de-stoning, and sewing?

- Machine type(s): ____
- Make/Brand of machines: ____

5. What is the power rating (in kW or HP) of each machine you use?
   - Milling machine power rating: ____
   - De-stoning machine power rating: ____
   - Sewing machine power rating: ____
6. How many of each type of machine are functional and in use?
   - Number of milling machines: ____
   - Number of de-stoning machines: ____
   - Number of sewing machines: ____

Section 3: Energy and Production Information

7. How many hours do your machines work per day (on average)?

- Milling machines: ____
- De-stoning machines: ____
- Sewing machines: ____

8. How many bushels or tonnes of rice do you process per day?
   - Bushels/tonnes per day: ____
9. What is your current energy source for powering these machines?
   - ☐ Diesel
   - ☐ Electric grid
   - ☐ Other (please specify): ____
10. If diesel is used, how many litres do your machines consume per hour? ☐
11. During peak periods, how many hours per day do your machines work? ☐
12. Is your source of power from EEDC, if yes how much do you pay in a month? ☐

Section 4: Interest in Alternative Energy

12. Would you be interested in connecting to an alternative energy source such as a hybrid power plant (e.g., solar-diesel, solar-grid (EEDC))?

- ☐ Yes
- ☐ No
- ☐ Not sure

13. What challenges do you currently face with your energy supply (e.g., cost, availability, reliability)?

Section 5: Additional Comments

14. Please share any additional comments or suggestions regarding your energy needs or the idea of a hybrid power plant.

Thank you for your time and valuable input. Your responses will help us design a sustainable and efficient energy system for the Abakaliki Rice Mill cluster.

Figure 4: Questionnaire for Energy Needs Assessment of Abakaliki Rice Mill Cluster

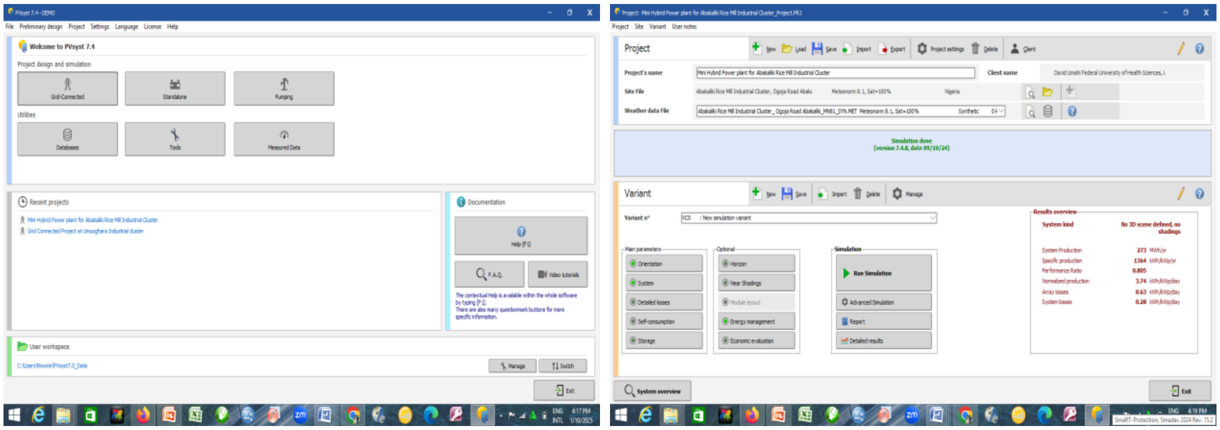


Figure 5: The user interface of Pvsyst V7.4.8

RESULTS AND DISCUSSION

Physical assessment results

The result of the investigation through questionnaire, oral interview and direct observation indicates that a milling cluster operates with a maximum capacity of 14 milling machines (16Hp each), 4 de-stoning machines (2Hp each), and 8 sewing machines (1Hp each). All machines operate a maximum of 5 hours daily. The cluster's total energy consumption is estimated at 3,222,720,000 joules (900.76 kWh) with wattage of 179,040 watts (179.04 kW or 0.17904 MW). All operators have at least two years of experience, and most machine owners have over 25 years of experience in the business. The cluster performs milling, de-stoning, and bag-sewing processes.

Power is supplied in the cluster by diesel generators, specifically Japanese-made HR 2 Cylinder (22 horsepower) and Blackstone (16 horsepower) models, along with smaller 3-horsepower Blackstone machines. Milling operations run from 9 a.m. to 1 p.m. daily, extending to 2 p.m. during peak seasons like festive periods (e.g. Christmas and New Year celebrations). Large-capacity machines consume 25 liters of diesel per day and produce up to 100 bushels (50 bags), while smaller machines consume 15 liters of diesel daily and produce 55-80 bushels. The cluster is not connected to the national electricity grid and relies entirely on diesel generators.

The simulation result is presented in Table 1 and Figures 7-11;

Table 1: Balances and Main Simulation Result

Year	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
Janunary	161.8	88.3	27.17	114.0	107.9	19445	18052	**0.791**
February	139.7	92.0	27.99	111.1	107.3	19135	17776	**0.799**
March	167.8	103.6	27.71	146.0	142.2	25188	23457	**0.803**
April	173.9	93.5	26.60	165.2	162.1	28607	26689	**0.807**
May	173.2	87.6	26.36	178.5	175.6	30955	28868	**0.808**
June	156.5	76.5	25.02	167.1	164.6	29165	27169	**0.812**
July	158.0	83.4	25.02	165.1	162.3	28921	26960	**0.816**
August	151.8	81.6	24.66	147.7	144.8	25878	24086	**0.814**
September	158.4	84.3	24.50	141.2	137.2	24680	22987	**0.813**
October	167.9	84.8	25.58	133.6	128.4	23110	21486	**0.803**
November	166.0	76.0	26.15	116.0	109.7	19811	18386	**0.791**
December	162.4	83.4	26.90	109.6	102.9	18599	17252	**0.786**
Average	**1937.4**	**1034.8**	**26.13**	**1695.3**	**1644.9**	**293495**	**273167**	**0.805**

The main simulation results (Table I) show array energy (EArray) of 293,495 kWh and a grid energy (E_Grid) of 273,167 kWh. The 200 kWp solar plant achieved a performance ratio of 81% for the cluster.

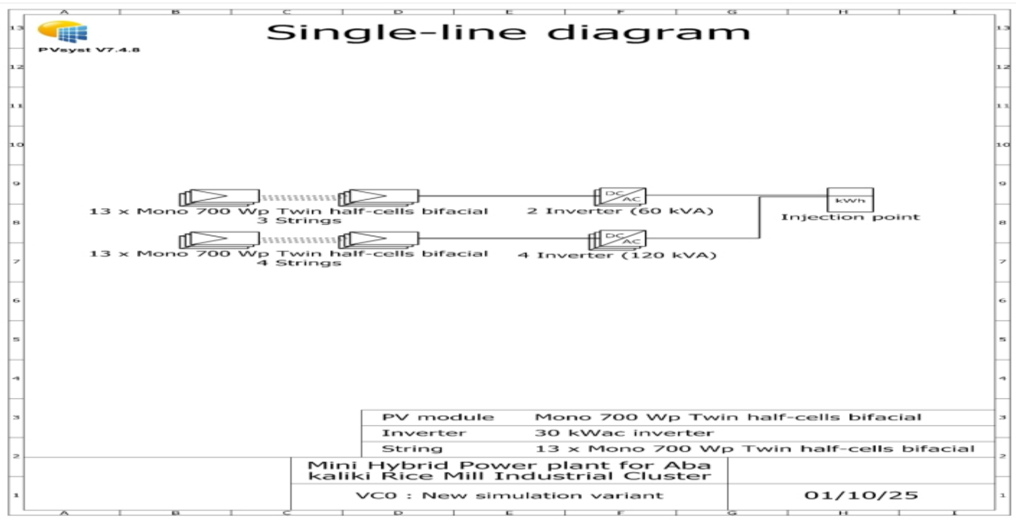


Figure 6: Single-line diagram of the Simulated PV system

Figure 7 illustrates the monthly reference incident energy (kWh/m²) on the collector plane. The graph shows a trend of increasing energy from January to May, peaking in May, followed by a continuous decrease until December. This pattern is directly related to the amount of solar radiation received on the collector plane each month, which is influenced by the changing seasons. The reference incident energy is approximately 4.645 kWh/m²/day. System losses (Ls) are calculated by subtracting the final yield (Yr) from the array yield (Ya).

In this study, system losses (Ls) are 0.28 kWh/kWp/day, array collection losses (Lc) are 0.63 kWh/kWp/day, and the produced useful energy (inverter output, Yf) is 3.74 kWh/kWp/day (Figure 8). Despite these losses, the system still produces a useful energy output (at the inverter) of 3.74 kWh/kWp/day. In other words, for every kilowatt peak (kWp) of installed solar panel capacity, the system generates 3.74 kilowatt-hours (kWh) of usable electricity daily.

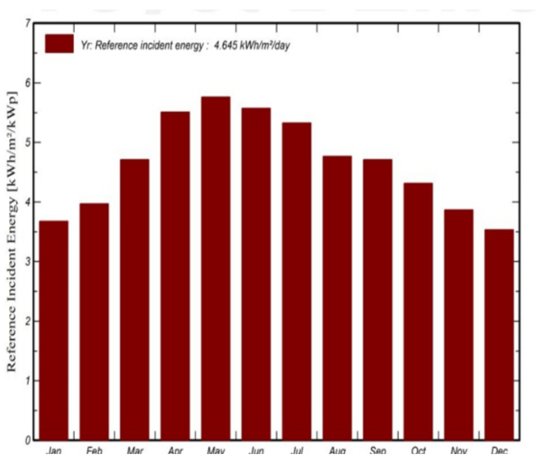


Figure 7: Monthly Reference incidents Energy in collector plane in KWh/m^2

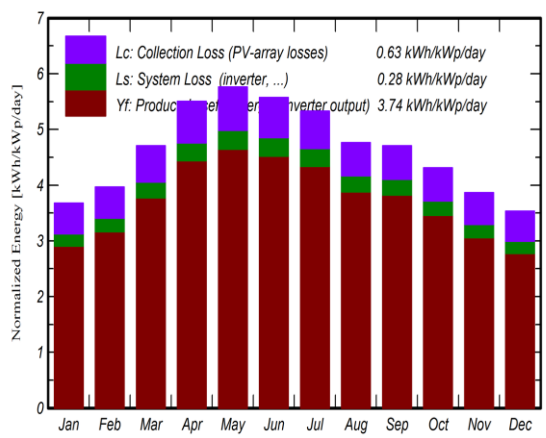


Figure 8: Normalized Energy production per installed KWp

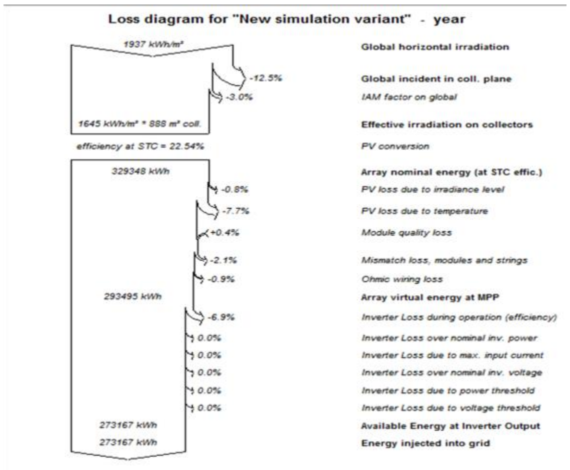


Figure 9: loss diagram over the entire year in Abakaliki rice mill cluster

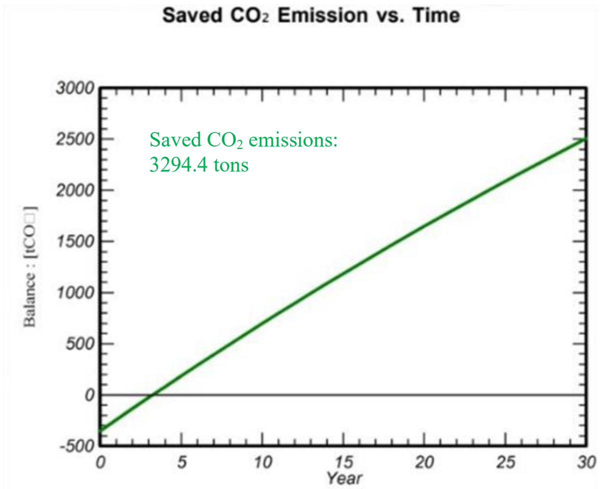


Figure 10: CO_2 emission reduction vs time

Several factors, including environmental conditions, technical limitations, and aging, contribute to energy loss during solar panel electricity generation. A loss diagram, derived from simulations, helps analyze these losses and informs PV plant installation considerations. For the Abakaliki rice mill cluster (Figure 9), the annual global horizontal irradiance (GlobHor) is 1937 kWh/m², while the effective irradiance on the collector (GlobEff) is 1645.0 kWh/m². This effective irradiance, when converted by the PV array, yields a nominal energy at Standard Test Conditions (STC) of 329,348 kWh and an annual virtual energy at the Maximum Power Point (MPP) of 293,495 kWh. This indicates the system's viability and its potential for grid integration. The inverter operates with a 6.91% loss, corresponding to 93.09% efficiency, demonstrating high performance consistent with existing research (Bernadette et al., 2021).

Burning fossil fuels for electricity, heat, and transportation is the largest global source of greenhouse gas emissions particularly CO_2, which contributes to global warming. In addition to this environmental concern, humans are daily exposed to both internal and external radiation from a variety of natural and man-made sources (Olabimtan *et al.,* 2024). The amount of greenhouse gases emitted from electricity use depends on the fuel source and consumption levels. For sustainable development, reducing CO_2 emissions is crucial. A significant environmental cost of fossil fuel-based electricity generation is CO_2 emission, a major greenhouse gas. Studies indicate that conventional power plants produce approximately 0.64 kg of CO_2 per kWh. Replacing fossil fuels with solar power significantly reduces these emissions (Gharibshahian *et al.,* 2017). Simulation results over a 30-year period as presented in Figure 10 demonstrate a reduction of 3294.4 tons of CO_2. This translates to an annual reduction of 109.81 tons of CO_2 if the proposed solar power design is implemented.

Cost analysis of a cluster using diesel and the PV power Plant

Cost-effectiveness analysis is a valuable tool for evaluating and comparing different options by examining their costs and outcomes. It helps identify opportunities to optimize resource allocation. This method has been applied to a unit of the Abakaliki Rice Mill industrial cluster, comparing the costs of diesel and PV power systems. The analysis focused on the 14 functional milling machines within the cluster, each operating a maximum of five hours per day, six days a week, and 52 weeks per year. Each machine consumes 25 liters of diesel per 5-hour workday.

Annual diesel consumption per machine is calculated as 7,800 liters (6 days/week × 52 weeks/year × 25 liters/day). With diesel priced at N1250 per liter, the annual fuel cost per machine is N9, 750, 000 (7800 liters × N1250/liter). Therefore, the 14 machines in a cluster consume a total of 109,200 liters of diesel annually (7800 liters/machine × 14 machines), costing the cluster N136,500,000 (109,200 liters × N1250/liter). This represents the potential annual savings if a PV power system were implemented.

CONCLUSION

This research successfully assessed the energy needs of the Abakaliki rice mill cluster and conducted a comprehensive cost analysis comparing the existing diesel-powered system with a proposed 200 kWp photovoltaic (PV) solar power system. The current diesel-based model incurs substantial annual costs of ₦136.5 million due to the consumption of approximately 109,200 liters of diesel. Simulation results using PVsyst

V7.4.8 demonstrate the significant potential of a PV system, projecting an annual energy production of 293,495 kWh with an 81% performance ratio. Furthermore, the proposed solar plant offers considerable environmental benefits by reducing CO2 emissions by 3,294.4 tons per year. These findings strongly suggest that a mini hybrid PV power plant is a viable and advantageous alternative energy solution for the rice mill cluster. Transitioning to solar power offers not only significant economic savings and operational sustainability but also crucial environmental benefits and the potential for lower product pricing. The expressed interest of mill operators in adopting alternative energy sources, coupled with their challenges regarding diesel costs, availability, and reliability, emphasizes the urgent need for such a transition. This project's focus on identifying the optimal mix of renewable and conventional energy sources for a hybrid system directly addresses these needs, aiming to maximize rice production efficiency, minimize operational costs, and reduce environmental impact within the Abakaliki Rice Cluster. Future research could explore the integration of other renewable energy sources like wind or biomass to further optimize the hybrid system and enhance its resilience.

ACKNOWLEDGMENTS
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STATEMENT OF INFORMED CONSENT
All participants gave their informed consent.

REFERENCES

Bernadette, D., Twizerimana, M., Bakundukize, A., Pierre, B. J., & Theoneste, N. (2021). Analysis of shading effects in solar PV system. *Int. J. Sustain. Green Energy*, *10*(2), 47-62. https://www.sciencepublishinggroup.com/article/10.11648/j.ijrse.20211002.13

Christian, N. I., Ekuma, A. P., Kingsley, O., & Ugah, J. O. (2023). ENERGY AND ECONOMIC EVALUATION OF THE 3000KWP GRID CONNECTED PHOTOVOLTAIC POWER PLANT IN UMUOGHARA QUARRY INDUSTRIAL CLUSTER, NIGERIA. *The Journals of the Nigerian Association of Mathematical Physics*, *65*, 21-26. https://nampjournals.org.ng/index.php/home/article/view/4

Dalton, G. J., Lockington, D. A., & Baldock, T. E. (2009). Feasibility analysis of renewable energy supply options for a grid-connected large hotel. *Renewable energy*, *34*(4), 955-964. https://doi.org/10.1016/j.renene.2008.08.012

Danbaba, N. (2019). Rice postharvest technology in Nigeria: An overview of current status, constraints and potentials for sustainable development. *Open Access Library Journal*, *6*(08), 1. https://www.scirp.org/html/94313_94313.htm

Emeafor, O. F., & Okpoko, P. U. (2018). Tourism and Agro-Processing Industries: A Qualitative Study of Abakaliki Rice Mill. *International journal of Horticulture, Agriculture and Food Science*, *2*, 7-14. https://dx.doi.org/10.22161/ijhaf.2.2.2

Gharibshahian, I., Sharbati, S., & Orouji, A. A. (2017). The Design and Evaluation of a 100 kW Grid Connected Solar Photovoltaic Power Plant in Semnan City. *Journal of Solar Energy Research*, *2*(4), 287-293. https://jser.ut.ac.ir/article_64913.html

Benjamin, N. (2024, September 9), Ebonyi, Home of Rice. Thisdaylive. https://www.thisdaylive.com/index.php/2016/08/17/ebonyi-home-of-rice/

Jeong, J. M., Kim, E. C., Venkatanagappa, S., & Lee, J. S. (2017). Review of rice: production, trade, consumption, and future demand in Korea and worldwide. *Korean Journal of Crop Science*, *62*(3), 157-165. https://koreascience.kr/article/JAKO201732060820256.pdf

Muthayya, S., Sugimoto, J. D., Montgomery, S., & Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. *Annals of the new york Academy of Sciences*, *1324*(1), 7-14. https://nyaspubs.onlinelibrary.wiley.com/doi/abs/10.1111/nyas.12540

Nwachukwu, A., Ikeagwuani, F. C., & Adeboje, A. O. (2021). Investigation on the Background Radiation of Abakaliki Rice Mill in Ebonyi State, Nigeria. *Atom Indonesia*, *47*(1), 25-30. https://atomindonesia.brin.go.id/index.php/aij/article/view/1040

Nweke, F. I. (1981). Smallholder cropping system of southeastern Nigeria: A ‘diagnostic’study. *Agricultural Systems*, *7*(4), 267-288. https://doi.org/10.1016/0308-521X(81)90039-1

Okonkwo, U. U., Ukaogo, V., Kenechukwu, D., Nwanshindu, V., & Okeagu, G. (2021). The politics of rice production in Nigeria: The Abakaliki example, 1942-2020. *Cogent Arts & Humanities*, *8*(1), 1880680. https://www.tandfonline.com/doi/full/10.1080/23311983.2021.1880680

Okoye, C. O., & Irem, C. O. (2019). Rice milling in Amagu community of Ebonyi State: health and economic implications. *Tropical Built Enviro nment Journal*, *6*(2). http://tbejournal.com/index.php/tbej/article/view/50

Olabimtan, . S. O., Chifu, E. N., Nasir, M., & Hafeez, Y. H. (2024). Assessment of Activity Concentrations and Soil-to-Plant Transfer Factors of Natural Radioactivity in Rice Plant Components grown in Kano State, Nigeria. *Nigerian Journal of Physics*, *32*(4), 1-12. https://doi.org/10.62292/njp.v32i4.2023.166

Picault, D., Raison, B., & Bacha, S. (2009, February). Guidelines for evaluating grid connected PV system topologies. In *2009 IEEE International Conference on Industrial Technology* (pp. 1-5). IEEE. https://ieeexplore.ieee.org/abstract/document/4939505/

PVsyst software. CUEPE, University of Geneva. www.pvsyst.com

Ramadhan, M., & Naseeb, A. (2011). The cost benefit analysis of implementing photovoltaic solar system in the state of Kuwait. *Renewable energy*, *36*(4), 1272-1276. https://doi.org/10.1016/j.renene.2010.10.004

Sanni, S. H., & Mohammed, K. (2018). Residential Solar Photovoltaic System Vs Grid Supply: An Economic Analysis Using RETScreen™. *Journal of Solar Energy Research*, *3*(2), 107-114. https://jser.ut.ac.ir/article_67428.html

Turcotte, D., Ross, M., & Sheriff, F. (2001, September). Photovoltaic hybrid system sizing and simulation tools: status and needs. In *PV Horizon: Workshop on Photovoltaic hybrid systems* (Vol. 10, pp. 1-10). https://www.osti.gov/etdeweb/biblio/20228328

Uwho, K. O., Idoniboyeobu, D. C., & Amadi, H. N. (2022). Design And Simulation Of 500kw Grid Connected PV System for Faculty of Engineering, Rivers State University Using Pvsyst Software. *Iconic Research and Engineering Journals*, *5*(8), 2456-8880. https://www.irejournals.com/paper-details/1703211

Zhang, Y. (2021). Diet according to traditional chinese medicine for health and longevity. *Nutrition, Food and Diet in Ageing and Longevity*, 331-356. https://link.springer.com/chapter/10.1007/978-3-030-83017-5_17