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Assessing the Viability of a Sustainable Biomass Electricity Generation in Nigeria: A Feasibility Study

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Electricity generation from biomass is not only affordable and clean but also a crucial alternative to improve per capita electricity generation and consumption in developing countries. Exploiting waste-to-energy (WtE) potential of biomass requires accurate data on daily, weekly, or monthly biomass residual generation across different points within a region or country. This is lacking in most developing countries including Nigeria. To assess the feasibility of a sustainable electricity generation regime from rice husks (RH) in Nigeria, this study employed two important sampling techniques to overcome the lack of comprehensive national data on millers and dearth of data on RH generation, and to increase generalization. A stratified purposive sampling of rice milling centers that included demographic settings (rural, semi-urban, and urban) and size (small, medium, and large scale), and a purposive random sampling of 540 rice millers from 14 states known for heavy rice milling activities were drawn and interviewed using a structured questionnaire. The results show that approximately 68 mills and/or clusters of mills spread across rural, semi-urban and urban areas currently provide sufficient RH for a net power output of between 2 MW and 12 MW of electricity and can effectively solve both in-plant and several surrounding household energy needs. The results also show that such WtE utilization decreases open burning and improper disposal of RH, saving more than 80,000 kgCO2-eq daily with significant environmental benefits. This assessment demonstrates that taking proper stocks of biomass waste generation is not only crucial for energy generation mix but also for potential emission reduction strategies.

1. Introduction

Electricity is a key driver of economic growth. Access to electricity is crucial for education, health care delivery (quality of life), gender equality, and environmental sustainability (Ramamurthi et al., 2016). Despite the many benefits of electricity provision, more than 800 M people worldwide have no access to electricity by 2020 (IEA, 2022). Approximately 590 M of this population, representing more than 75 % of people without access to electricity live in Sub-Saharan Africa (SSA) (IEA, 2022). In Nigeria alone, approximately 80 M people are without access to electricity (Ejiofor et al., 2020). As the largest economy in Africa, Nigeria is in critical need of the electricity required to power its surging population and industrial needs. Nigeria's current electricity supply is grossly inadequate, with an approximately 87.8 % unmet demand (Diemuodeke et al., 2021). Nigeria's per capita electricity generation is among the lowest in sub-Saharan Africa (Ritchie et al., 2023). As of 2020, Nigeria generated an estimated 35, 331 GWh of electricity equivalent to 143 kWh per capita generation (IRENA, 2022). As demonstrated in IRENA (2022), 80 % of Nigeria's meager current generation is powered by fossil fuels, an unsustainable source with significant climate and environmental impact consequences (IEA, 2019). Fortunately, Nigeria’s renewable energy potential is estimated to be 12,000 MW of hydropower, 6.5 kW/m^2/d of solar power, 2,400 MW of wind power, and more than 180 Mt/y of biomass waste (Giwa et al., 2017).
Electricity generation from renewable energy sources (REs) provides at least two important benefits: (1) it is sustainable and a viable alternative to the current use of depleting, finite, and expensive fossil fuels known to cause GHG emissions, global warming, and climate change (Diemuodeke et al., 2021); and (2) it is the basis for green development mechanisms and for achieving the United Nations’ SDG 7 - access to affordable and clean energy. The latter has been identified as pivotal for achieving all other SDGs (Giwa et al., 2017). The

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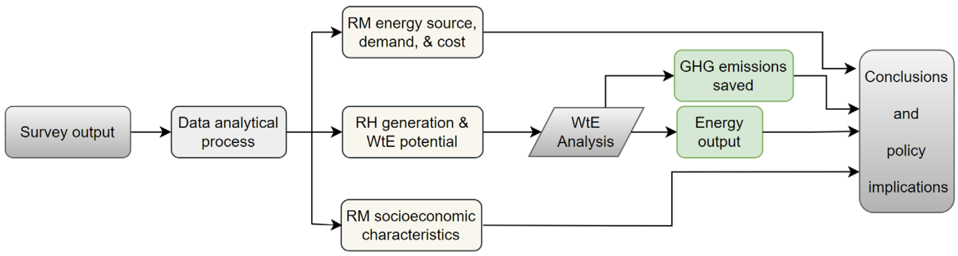
global debate on energy transition is centered on renewable energy, and in developing countries, WtE conversion is one of the most feasible and economically viable alternatives (Mandelli et al., 2016). Finally, Energy generation from biomass is considered affordable and clean because it is renewable, carbon-neutral, and available in agro-residues or waste (Ramamurthi et al., 2016).

A review by Giwa et al. (2017) showed that Nigeria has the technical potential to pursue a sustainable RE mix, including biomass sources, such as RH. Other similar studies have examined electricity generation from RH at specific milling centers, namely, off-grid electricity generation in Nigeria based on RH gasification (Ejiofor et al., 2020), a techno-economic assessment of co-gasification of RH and plastic waste (Salisu et al., 2021), and a techno-economic and environmental assessment of RH power energy plants in Nigeria (Diemuodeke et al., 2021). These studies do not provide an assessment of RH generation, energy needs, and/or energy deficits of mills or clusters of mills and surrounding communities across Nigeria and in areas known for heavy rice milling activities. Such assessment is not only relevant for energy planning but is also crucial for establishing whether RH electricity generation in several specific rice mills around the country is feasible and sustainable. To fill this gap, a systematic field study of existing rice millers, husk generation capacity, in-plant energy needs, and energy needs of surrounding communities was conducted using two sampling frameworks designed to generalize the results: stratified purposive sampling and purposive random sampling (Patton, 2002). In addition to contributing to the current debate on renewable energy transition in Nigeria, this study is crucial to both scientific and business communities because it quantitatively summarizes the potential feasibility of sustainable RH electricity generation regimes in Nigeria.

2. Research Methods and Data

In keeping with the research objectives, this study implemented a two-stage systematic field survey to collect data on milling activities and RH daily generation in Nigeria using two sampling frameworks. In the first stage, a stratified purposive sampling of 14 states known for heavy rice production activities was selected and the 10 top rice milling centers, considering location or demographic settings (rural, semi-urban, and urban) and size (small, medium, and large scale) were selected. In the second stage, a random sampling of 5-8 millers from each of the top 10 rice milling centers was conducted. The survey was implemented by 10 trained research assistants (RA) using an electronic Mobile app (DataScope®) with live data feed and location GPS capturing features. 700 respondents were targeted but a final sample of 540 millers was interviewed and validated during a one-month period (11th October ~ 9th November 2022). The response rate was 77%. The data captured by the survey are summarized and discussed below. Figure 1 shows the analytical framework for the study.



3. Results and discussion

3.1 Demographic characteristics of millers

Figure 2 illustrates the distribution of some socioeconomic characteristics of respondents, showing (a) millers' age, (b) millers' education, (c) rice mill's years of operation, and (d) ownership status of rice mills. The age of responding millers appears to be normally distributed within the working-age population from 18 years to a little over 63 years. The age distribution histogram also suggests that more than 80 % of responding millers were within 48 y. This indicates that the Nigerian rice milling sector is dominated by millers from almost all active working ages but, most importantly, young populations. Responding millers also appear to be well educated, as shown in Figure 2b. More than 70 % of millers have at least a minimal formal education. Notably, 43 % of millers have secondary education, while 20 % percent have post-secondary education. This implies that rice milling activities in Nigeria are predominantly performed by well-educated and well-informed millers.

Years of operation of rice mills show that the bulk of rice mills (approximately 80 %) have been in operation within the last 20 y, and fewer than 20 % percent have been in operation for more than 20 y (Figure 2c). Most importantly, about 20 % and 30 % of mills began operations within the last four and eight years, respectively, implying that half of all responding mills (about 50 %) have been in operation within the last eight years. This means that there are start-ups and experienced players in Nigeria's rice mill sectors.

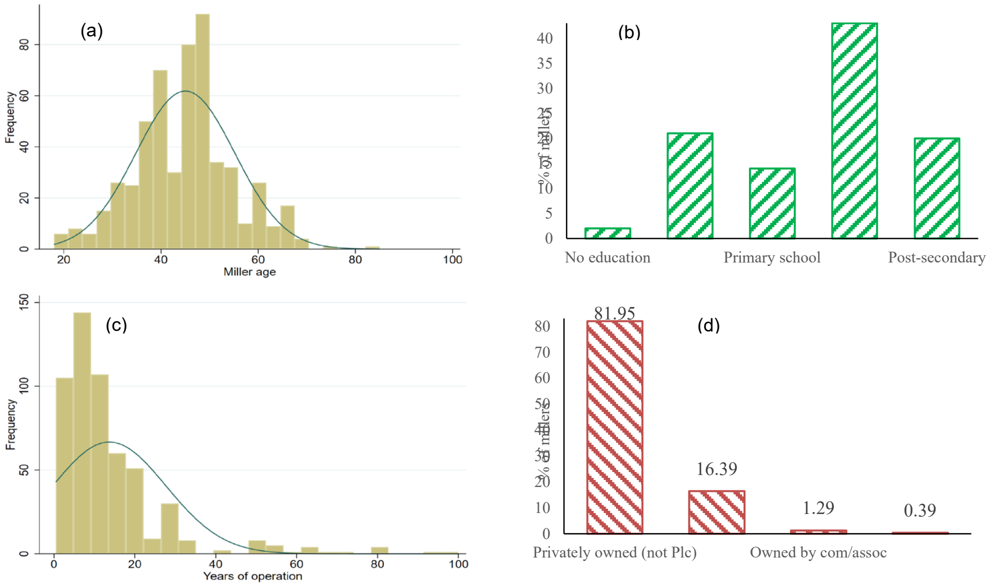


Figure 2: Distribution of (a) Miller's age, (b) education, (c) years of operation, and (d) ownership status. Source: author's illustration from survey data.

This trend is expected because although the rice mill sector in Nigeria has a long history, there have been recent changes in state policies on rice self-sufficiency, such as the agricultural transformation agenda (ATA), rice transformation agenda (RTA) (Okodua, 2018), national rice development strategies I and II (FMARD, 2020), and more recently, the central government's soft loans for rice production, called the Anchor Program (Okonkwo et al., 2021). The surge in rice mills in recent decades was in response to increased rice production, as dictated by these policies and initiatives to boost domestic rice production. The mill ownership distribution illustrated in Figure 2d shows that the rice milling sector in Nigeria is private sector driven. While this is crucial and was encouraged by state policies to ensure a competitive rice value chain processing industry, 82 % of responding mills operate under a shadow economy i.e., unregistered mills (Plc – public limited company – indicates registration status of the mills). These large unregistered and unregulated mills present serious regulatory and planning challenges, as the state can neither incentivize nor generate tax revenue from these mills.

Finally, the distribution of milling type (size) by demographic location illustrated in Figure 3 shows that almost half of the responding mills (45 %) were situated in rural areas, 25 % in semi-urban areas, and 30 % in urban areas. One-fifth of mills (20 %) in rural areas are stand-alone mills, while 11 % and 9 % of stand-alone mills are in semi-urban and urban areas, respectively. Standalone mills are small-to medium-scale mills that operate independently and in isolation.

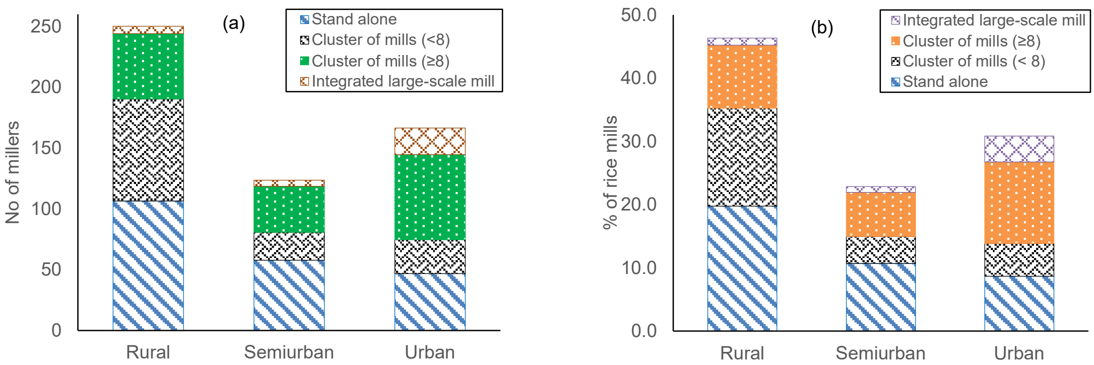


Figure 3: Distribution of milling type (size) by demographic location (a) actual sample (b) in %. Source: author's illustration from survey data

Notably, most rice mills in Nigeria operate as industrial clusters that allow them to form associations and unions with unfettered access to both tangible and intangible assets owned and serviced by their associations and/or cooperation. Figure 3 also shows that a quarter of the mills in rural areas operate in industrial clusters, while 11 % and 18 % of the mills in semi-urban and urban areas, respectively, operate as industrial clusters. Small-scale mills operating in less than eight clusters are jointly considered medium-scale, whereas those operating in clusters of eight and over are jointly considered large-scale. Integrated large-scale mills are mostly situated in urban areas, perhaps because of better access to roads and electricity supply.

3.2 Rice mill energy source, energy demand, and average monthly energy cost

Rice milling involves several processes, including boiling, drying, milling, and post milling activities. Each process or operation requires a steady supply of energy (electricity). Figure 4 describes the current situation of in-plant electricity access and source. Overall, three-quarters of the rural millers depend on personal generators for electricity supply because they have little to no access to electricity (Figure 4a and 4b). Half of the millers in semi-urban and urban areas also depend on personal generators for electricity supply due to limited access (Figure 4a and 4b). These results were confirmed by Figure 4c, where working hours of electricity access were significantly lower for rural millers with access to electricity than for semi-urban and urban millers which had access for almost half of the daily working hours. The Cost per–70-100 kg bag of mill rice depends on the milling location, with rural millers spending less per bag of paddy milled. This may be related to the process and quality of the milled rice. Unlike rural millers, semi-urban and urban millers often follow quality specifications to ensure that milled rice appeals to consumers (Johnson and Masias, 2016).

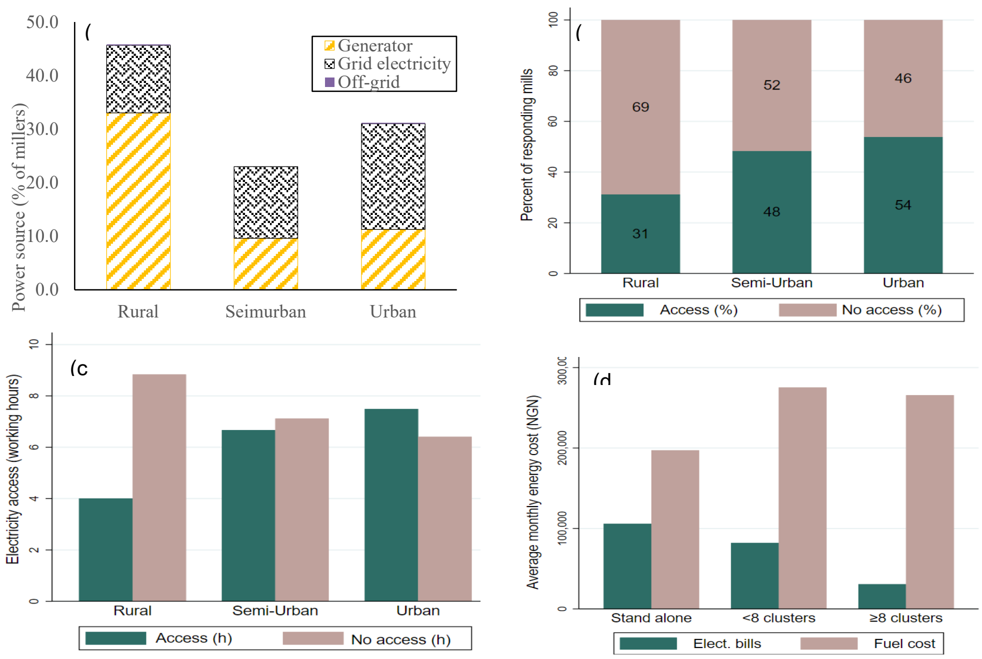


Figure 4: Distribution of (a) power source, (b) Electricity access, (c) Electricity access-working hours, (d) Monthly energy cost. Source: author's illustration from survey data.

3.3 RH potential and implications for power generation

Figure 5 provides a summary of the daily average husk generation by (a) mill location and (b) location versus mill size or type. Overall, rural millers generated approximately 6 t/d of RH on average, while semi-urban and urban millers generated between 12 and 14 t/d on average (Figure 5a). When adjusted for mill size (type) in each location, the results show substantial variation in the daily amount of RH generation among millers, indicating that several clusters of millers across rural, semi-urban, and urban locations currently generate substantial amounts of husks that can be utilized for biomass energy generation.

Table 1 provides a further analysis of potential WtE utilization based on specific milling centers. The results in Table 1 reveal interesting findings. Approximately 17 rice mills located in rural areas individually generated sufficient daily RH to yield a total net output of 13 MW, which could supply the in-plant electricity needs of 6.3 MW and approximately 8,500 household assuming 0.8 kW per household (Mitsubishi Research Institute, 2015).

This WtE utilization will save approximately 19,695 $kgCO_2$-eq of emissions from uncontrolled dumping and burning (UNFCCC, 2021).

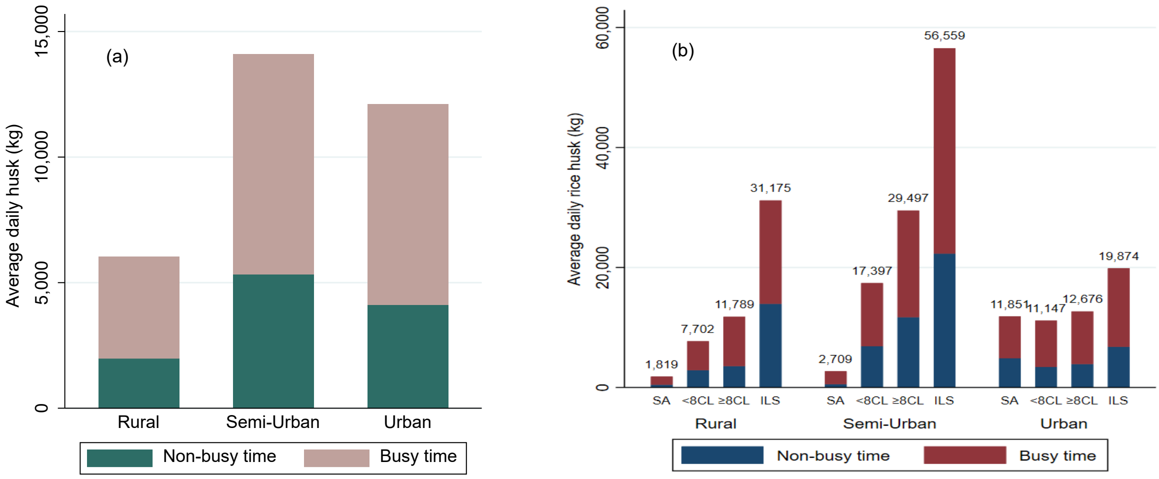


Figure 5: Distribution of (a) RH generation by mill type and season (b) RH generation by mill type, season, and location. Note: SA ~ stand-alone mills, CL ~ clusters of mills, and ILS ~ integrated large scale mills.
Source: author's illustration from survey data

Table 1: Summary of Daily RH by specific mills, power generation and emission saving potential

	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)
Demography	RH/d (t)	No. Sites	Plant size (MW)	Output (MW)	Total output(MW)	In-plant Need(MW)	Total In-plant (MW)	No hholds	Emission saved ($kgCO_2$-eq)
Rural	10~20	13	0.8	≈0.6	7.8	0.3	3.9	4,875	12,802
	21~30	3	1.3	≈1.1	3.3	0.6	1.5	2,250	4,431
	31~40	0	1.8	≈1.6	-	0.9	-	-	-
	>40	1	>2	≈2.0	2	1.1	0.9	1,375	2,462
Subtotal		17			13		6.3	8,500	19,695
Semi-urban	10~20	13	0.8	≈0.6	7.8	0.3	3.9	4,875	12,802
	21~30	3	1.3	≈1.1	3.3	0.6	1.5	2,250	4,431
	31~40	2	1.8	≈1.6	3.2	0.9	1.4	2,250	3,939
	>40	6	>2	≈2.0	12	1.1	5.4	8,250	14,771
Subtotal		24			26		12.2	17,625	35,943
Urban	10~20	18	0.8	≈0.6	10.8	0.3	5.4	6,750	17,725
	21~30	5	1.3	≈1.1	5.5	0.6	2.5	3,750	7,385
	31~40	3	1.8	≈1.6	4.8	0.9	2.1	3,375	5,908
	>40	1	>2	≈2.0	2	1.1	0.9	15,250	82,462
Subtotal		27			23		10.9	15,250	33,481
Total		68			53		29.4	41,375	89,119

Column Note: Column B, F - Calculated from survey data based on individual milling capacity, columns C–D- calculated based on (Le Tan et al., 2022; Mitsubishi Research Institute, 2015; Ramamurthi et al., 2016), column E = B × D, column G = B × F, column H = (E – G) 1,000 x 0.8 kW per household (where 1,000 is MW-kW conversion factor); column I is calculated using the emission calculator based on (UNFCCC, 2021) guidelines.

Similarly, the daily RH from 24 rice mills situated in semi-urbans could potentially generate a total net electricity output of 26 MW, of which only 12.2 is required for in-plant use. Again, the excess generated electricity could serve 17,625 households. The resulting emission-saving potential is equivalent to 35,943 $kgCO_2$-eq. Finally, 27 rice mills in urban areas individually provide sufficient daily RH that could potentially generate a total net electricity output of 23 MW, where approximately 11 MW is required for in-plant energy needs, and excess electricity (22 MW) can supply 15,250 and save 33,481 $kgCO_2$-eq of emissions.

4. Conclusions

Biomass WtE conversion in emerging and developing countries is not only feasible but sustainable and economically viable. For agrarian economies such as Nigeria, electricity generation from biomass offers a crucial alternative to meet the electricity demands of its teaming populations and expanding industrial sector. Recent national policies on self-sufficiency in rice production have dramatically increased the size and scope of the rice milling sectors in Nigeria and given the very limited electricity generation capacity in the country, the rice milling sectors face serious energy crises. Interestingly, the expanding rice-milling sector provides important opportunities for RH power generation via WtE. Quantifying the flow of RH generation across the vast rice mills in Nigeria is a crucial research agenda that has not been addressed previously. Using a large sample of millers drawn from 14 rice producing states and covering five of the six geopolitical zones (regions) in Nigeria, this study demonstrates that several rice mills and/or clusters of rice mills spread across rural, semi-urban and urban areas generate sufficient RH that when effectively utilize via WtE can potentially provide electricity for rice mills and thousands of households. These findings have important policy implications. First, the rice self-sufficiency policy agenda cannot be achieved without a vibrant rice milling sector with access to a reliable and steady power supply. Second, as the findings show, RH WtE generation is a viable alternative for increasing per capita electricity generation, especially in rural and semi-urban areas of Nigeria, where off-grid and centralized systems can be easily set up. RH WtE generation also provides a viable means for sustainable energy mix in Nigeria.

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