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# Utilisation of rice residues for decentralised electricity generation in Ghana: An economic analysis

Pooja Vijay Ramamurthi [a,*], Maria Cristina Fernandes [a], Per Sieverts Nielsen [b], Clemente Pedro Nunes [a]

[a] CERENA/DEQ, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
[b] DTU Climate Centre, Systems Analysis, Department of Management Engineering, Technical University of Denmark, Denmark

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ABSTRACT

Developing countries, especially in Sub-Saharan Africa, face large challenges to achieve universal electrification. Using the case of Ghana, this study explores the role that rice residues can play to help developing countries meet their electrification needs. In Ghana, Levelised Electricity Costs (LEC) of a grid-connected 5 MWe straw combustion plant ranged between 11.6 and 13.0 UScents/kWh, based on region of implementation. Rice straw combustion is a viable grid-connected option in all regions, as the bioenergy Feed-in-Tariff is 29.5 UScents/kWh in Ghana. Residue supply cost contributes significantly (49–54%) to LEC of rice straw combustion.

LEC of husk gasification mini-grids ranged between 5 and 53 UScents/kWh for rural populations between 3000 and 250 people. Husk gasification mini-grids can be a suitable electrification solution for these un-electrified populations, as its LEC is lower than the average LEC of grid extension diesel mini-grids and off-grid solar systems for remote communities in Ghana. Electricity produced from husk gasification has the potential to cater to 7% of the needs of un-electrified communities in Ghana. The methodology and analysis of this study can support policymakers of similar countries decide the economic feasibility of decentralised bioenergy solutions while forming national electrification plans.



## 1. Introduction

Electricity is a key driver of economic growth, and can lead to improved education, health delivery, environmental sustainability, agricultural development and gender equality [1,2]. Despite this, 25% of the global population lives without electricity [2] where Sub-Saharan African (SSA) accounts for 40% of this population. In SSA, 89% of urban areas have access as opposed to 46% in rural areas [3]. International Energy Agency (IEA) predicts that even in 2030, 49% of rural SSA will still lack electricity access [2].

Ghana, a country in SSA has made relatively remarkable progress in electrification. However, even in Ghana, if electrification continues at the present rate, it will not achieve universal electrification by 2020 as planned in its National Electricity Scheme (1989) [4]. Similar to other developing countries, the major reason for slow electrification (rural electrification is at 50%) in Ghana has been an emphasis on national transmission grid expansion. This leads to 'energy isolation' for the rural poor with regard to grid-based electrification, where complex geography of rural areas, long transmission lines requirements, and low electricity demands of diffused rural communities makes grid extension uneconomical. There is increasing widespread agreement that energy access for the rural poor requires an integrated approach which focuses on grid-based and autonomous decentralised options [5]. Renewable Energy (RE) is modular in nature, making it ideal for decentralised technology. RE also provides independence from national-level grid-based planning, has limited capital requirements, can lower national concerns of energy security and carbon emissions and promote local employment [1]. Ghana's Renewable Energy Act (2011), which targets supplying 10% of the country's electricity through renewables by 2020 also actively promotes RE deployment in the country [7]. While RE options have numerous advantages, a key consideration is their economic viability. Studies show the merit in analysing costs of decentralised electrification systems in SSA, as they are often the least-cost option for scattered rural

* Corresponding author. Center for Study of Science, Technology and Policy, #18, 10th Cross, Mayura Street, Papanna Layout, Nagashettyhalli, RMV II Stage, Bangalore 560094, India.
*E-mail address:* pooja@cstep.in (P.V. Ramamurthi).

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communities (Table 1). It can be noticed in Table 1 that there has been a focus on solar and diesel options in SSA, and lack of information on modern bioenergy solutions.

Modern techniques of converting biomass into energy services are promising to address today's growing energy challenges. Decentralised bioenergy has been used as a successful commercial technology for electricity generation in the developing regions of India, South-East Asia and China [10–14]. However, there has been little implementation in SSA. Mohammed et al. mention that only one biogas plant project for electricity generation has been established in Ghana [5] and Buccholz et al. studied the performance of two woody gasifier plants that were implemented for industrial purposes in Uganda [15]. Previously, modern bioenergy techniques used cereals, grains and sugar crops which could result in competition with food production, leading to rising food prices, food shortages and unsustainable changes in land use patterns [11]. Today, using lignocellulosic matter such as agricultural, forestry and municipal wastes for the generation of energy is known as Second Generation production of Bioenergy (SGB), and therefore preferred to avoid any threats to food prices, supply of grains to the national food basket and land use change in developing countries. Only SGB technologies have been considered in our study.

Rice is an important commercial crop in Ghana, with an annual production of almost 400 million tonnes of paddy, covering a cultivation area of 162,000 ha in 2009 [16]. Agricultural rice residues (husk and straw) offer considerable potential for energy production (5.65 TJ/year) in the country [17]. In 2012, up to 70–90% of rice residues in major rice growing regions of Ghana were openly burned or dumped in landfills and water-bodies, making rice residue abundantly available for bioenergy production [18].

The availability of rice residue in Ghana and the need to prevent unsafe disposal practises, make it attractive to investigate the role of bioenergy from rice residue to meet the country's electrification demands. As mentioned previously, economic considerations are vital to the success of a technology. This is especially true for bioenergy projects because local conditions determine factors such as residue availability, transport conditions, electricity needs of the local population and available infrastructure for developing the power plant, therefore affecting electricity production costs [10].

Economic viability of rice straw and husk power plants have been analysed in-depth in countries such as India, China, Thailand and Vietnam which conclude that rice residue can be an economically attractive option to produce electricity [10,12,14,19]. In SSA, Fock et al. conducted a pre-feasibility analysis for setting up a 5 MW rice straw combustion plant in Mali [20]. No previous study has compared electrification costs of a decentralised grid-connected and stand-alone mini-grid bioenergy system using agricultural wastes. This is also the first time that the economics of an agro-residue based off-grid system has been developed based on meeting the specific needs of rural communities with varying populations.

After choosing the most suitable rice residue SGB technologies, various factors that influenced the Levelised Electricity Cost (LEC) were identified, and recommendations to minimise the LEC were made. The off-grid plant is intended to serve the specific needs of remote communities, and variation of plant scale was based on community size. LECs of chosen SGB technologies were compared with the cost of electricity production from the national grid, and other mini-grid and off-grid technologies to determine if rice residue based electricity production is cost competitive for these communities. This study is intended to assist policy-makers and other interested stakeholders understand the suitability of agro-residue based electrification options in Ghana. Based on this paper, similar analysis can be carried out in other developing countries as well.

## 2. Materials and methods

### 2.1. Technology options and sizing

Many factors such as type and availability of biomass, socio-economic conditions and end-user applications help determine the most suitable bioenergy conversion process for a certain region [10]. For potential implementation in Ghana, four technology pathways were initially investigated; bio-chemical processes included fermentation of rice residues for bioethanol production and Anaerobic Digestion (AD) for biogas production. These processes were found to be unsuitable for Ghana. AD is ideal for feedstock which has Moisture Content (MC) greater than 50%. However rice residues have a typical MC of only 10–30%. Additionally, AD requires water and animal dung for inoculum. Water is scarce in Northern Ghana and animal dung is scarce in the Central regions due to lack of cattle. Hence, no region is well suited for AD. Globally, the technology for production of ethanol from lignocellulosic feedstock is still in its initial phases of research and development, with production costs being quite high and bioethanol form rice residues in Ghana maybe an option only in the future [18]. As bio-chemical routes were ruled out, thermo-chemical options were further investigated for specific application to rice straw and husk.

#### 2.1.1. Rice straw

Combustion of straw has been widely used for heat and power generation in Europe and North America. Denmark has been a pioneer in straw combustion plants. The feedstock used in European plants has primarily been wheat straw [20]. The amount of ash

**Table 1**
Studies on decentralised electrification options in SSA.

| Authors and year | Research conducted | Technology | LEC (UScents/kWh) | Key findings | Ref |
|---|---|---|---|---|---|
| Kemausuor et al., 2014 | A decision support tool estimated electrification costs for rural communities in Ghana over 10 years. | Grid extension<br>Diesel mini-grid<br>Off-grid solar PV | 57<br>102<br>112 | In addition to grid extension, an integrated energy plan using mini-grid and off-grid solutions, including RE is required to achieve electrification in Ghana | [2] |
| Adaramola et al., 2014 | Assessed costs of electrification for rural and semi-urban areas of northern Nigeria | Hybrid solar PV/battery/diesel generator standalone system | 35–38 | Hybrid systems are the most economical stand-alone system for the region of study | [8] |
| Szabó et al.,2013[a] | Applied spatial analysis for Africa to compare LECs of different electrification technologies | Diesel generator<br>Off-grid PV | 25–55<br>28–35 | SSA can only achieve electrification through a mixture of options, including a fair share of renewables and decentralised technologies | [9] |

[a] LEC values only taken for West African region.