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Crop residues as alternative to fuel for power generation in Rwanda

NDIZIHIWE Prosper[a*] , Burnet Mkandawire[b], Kayibanda Venant[c]

[a]*University of Rwanda, KK 737 Street, Gikondo, Kigali, Rwanda*
[b]*University of Malawi, Bag303Chichiri Lilongwe, Malawi*
[c]*University of Rwanda, KK 737 Street, Gikondo, Kigali, Rwanda*

Abstract

One of the big questions that the world is facing nowadays is climate change caused by global warming due to greenhouse gases (GHG). This degradation is based on ejected gases in the atmosphere. Reduction of the use of fossil fuel as the source of energy is critical in reducing those gases and reduction of importation costs. Consideration of local resources that would be the source of energy is one of the ways. This work investigates the contribution that crop residues of rice and maize would have on energy demand in Rwanda once they are used. Historical data of yearly energy demand and production of both maize and rice have been used. Calorific values have been determined from a laboratory experiment. The results show that they can contribute about a half to the Rwandan total energy consumption. Fossil fuel can completely be replaced by crop restudies in energy generation if the maximum of residues is collected. Under constraint that only half of the residues can be collected in practice, a small value of the fossil fuel can still be used. Analysis also has shown the dependence of residues species on the calorific values.

Keywords: Calorific value, energy, fossil fuel, maize and rice, Kilowatt-hour

1. Introduction

Many countries even developed ones are using coal and natural gas to generate the maximum of their energies [1]. Current technology of generating the power using these gases is followed by different problems including emission of green gases to the atmosphere, low efficiency, and high cost due to its importation [2].

In Rwanda, the energy demand is increasing with time as shown in Fig. 1. There are thermal plants that are contributing to the total quantity of power generated as presented in Fig. 2. Rwanda is the country where 70% of the population is living by agriculture and 59% of the land is used for agriculture activities [3]. Indeed, the government of Rwanda is working to improve agriculture activities, for increasing production [4], and the statistics show that increase as shown by Fig. 3 and Fig. 4. Presented crops in the Figs (maize and rice) are among the selected ones to be focused on, in different areas [5]. The production from agriculture goes together with its residues.

Some studies have been done so far and proven that different plants have remarkable calorific values which tell that they can produce heat energy. S. Bentsen et al [6] modeled the residue from crops as

$$RPR_{maize} = 2.656e^{(-0.000103*Y)} \tag{1}$$

$$RPR_{rice} = 2.45e^{(-0.000084*Y)} \tag{2}$$

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Corresponding author. *E-mail address*: *ndizihiweprosper@gmail.com*

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Equation (1) and (2) are generalized by equation (3)

$$RPR_c = \alpha e^{(\beta Y)} \tag{3}$$

where RPR is the Residue to Product Ratio and Y, the crop yield, manuscript c stands for any crop, and α and β are constants. The value of the Lower Heating Value (LHV) of the crop is found by bomb calorimetry measurement in the laboratory. The quantity of the residues is determined by

$$R_c = Y * RPR_c \tag{4}$$

$$R_c = Y * \alpha e^{\beta Y} \tag{5}$$

The value of LHV of the crop is found by bomb calorimeter measurement in the laboratory.

The quantity of the residues is determined by

$$E_c = Y * \alpha e^{\beta Y} * LHV_c \tag{6}$$

The total energy (E) generated from residue (E_c) is calculated by the relation

The concern is to have the value of LHV, Marlair et al [7] analyzed some the heat output of some fuel considering the composition and obtained the formula

$$LHV = c_1 C + c_2 H + c_3 S - c_4 O + c_5 N \tag{7}$$

Where c_1, c_2, c_3, c_4 and c_5 are coefficients, C, H, S, O, and N are weight percentages of the respective element. In other literature S. Acar et al [8], A Demirbas ¸and A.Hilal Demirbas [9]; the relation of the Higher Heating Value (HHV) is established as a function of the composition element of the fuel as in equation (8).

$$LHV = \alpha_o + \sum_{i=1}^{n} \alpha_\mathrm{i}\,\mathrm{Ch_i} + \mathrm{e_1} \tag{8}$$

Where for example on the case of Dulong formed by atoms C,H,O and S

$$CV = 33.8C + 144.153H - 18.019O + 9.412S \tag{9}$$

Based on the physical state

$$LHV = \beta_o + \beta_1 \rho + \mathrm{e_2} \tag{10}$$

Based on the structural composition

$$LHV = \gamma_o + \gamma_1 L + \mathrm{e_3} \tag{11}$$

α, β, γ: constants, Ch: Any chemical element percentage, ρ: Density, L: Lignin polymer and e: the error.

M Aniszewska and A Gendek [10] compared the heat combustion and calorific value of the cone and wood from selected forest species of tree. The work aimed to choose the plant that could be used as primary solid fuel. They measured the beat of combustion of each species and compare it with the corresponding calorific value. The result has shown that the cone has a calorific value ranged from 17.-19 MJ/Kg and is higher than other species of wood. In Rwanda, there is no same type of plant, which makes the authors look at the case on Rwanda.

S Acar and A Ayanoglu [8] determined the high heating value (HHV) of biomass using the study of the correlation of HHV and contents elements of the biomass/fuel. The aim was to determine the simple way of estimating HHV since the use of bomb calorimetry requires various equipment and is timeconsuming. They came up with the relation of linear equations of HHV as a function of Moisture content, Carbon, Hydrogen, Carbon among others. The crop residues in the investigation contain those organic elements [11]. So, it gives curiosity to oversee how much can be results from maize and rice in Rwanda.

A Demirbas and A Hilal [9] estimated the calorific value of the lignocellulosic plant. The research has shown that there is a strong positive correlation of the content of hydrogen and carbon content and that the ash content reduces the calorific value. Lignocellulosic fuel/plant are not available in good quantity in Rwanda, however, others can be investigated.

A Lunguleasa et al [12] evaluated the calorific value of tropical wood wastes. They used an oxygen bomb calorimeter at different moisture content and density. They found that one kind “

Guaiac” has high HHV (21200-20700 kJ/kg) than others. The density affects positively the HHV but the moisture and ash are negative to the HHV. It is interesting to investigate the values of wastes in Rwanda.

This work is aimed to investigate how much energy can be generated from maize and rice yield residues available in Rwanda.

2. Methodology

This study is on the residues from maize and rice only. The total energy demand projections were based on data from Rwanda Energy Group (REG). The Data on yield production were collected from the National Institute of Statistics of Rwanda (NISR) to estimate the energy that can be from each crop in a specific region. The data of energy demand will be used to observe the contribution in the percentage of the crop residues. Data of energy generated by fossil fuel are collected from REG to compare with the generation from crop residuals. Estimations of the crop residue are based on equations from (1) to (5), and the quantity of energy by (6).

Computation of the calorific value and moisture is conducted by laboratory experiment with parr6400 bomb calorimeter according to the PN-ISO 1928:2002 standards [13]. Samples of maize and rice residues have been inserted using mill for a particle of 1 mm, and fragmented object dried in laboratory dryer SLW 115 TOP for 24 h at temperature 104±1 ℃ until the dry mass is received. The research is based on the complete combustion of 1 g samples in an oxygen atmosphere, under 2.8 MPa pressure, and determination of water temperature increase in the calorimetric vessel. Combustion took place in a calorimeter bomb placed in this vessel and submerged in water of volume 2.7 dm3 (KL-10 calorimeter).

Estimation of the heat energy to be generated by tones of each king of the residues is then quantified, comparing with the annual quantity of the residual that would be produced in the country. And finally, compare the power production from those residues with that generated by the traditional.

3. Results and Interpretation

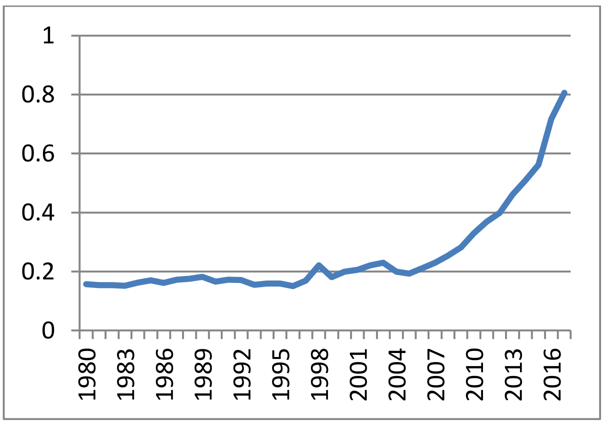

Fig. 1. Energy consumption in billion Kilowatt-hour vs years in Rwanda

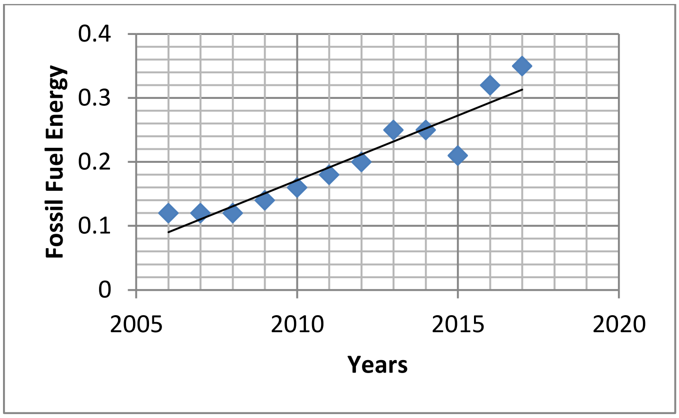

Fig. 2. Fossil fuel sources in billion Kilowatt-hour

Fig. 1 show how energy demand or consumption increases; It comparison with and Fig 2 indicates much fossil fuel has a big role.

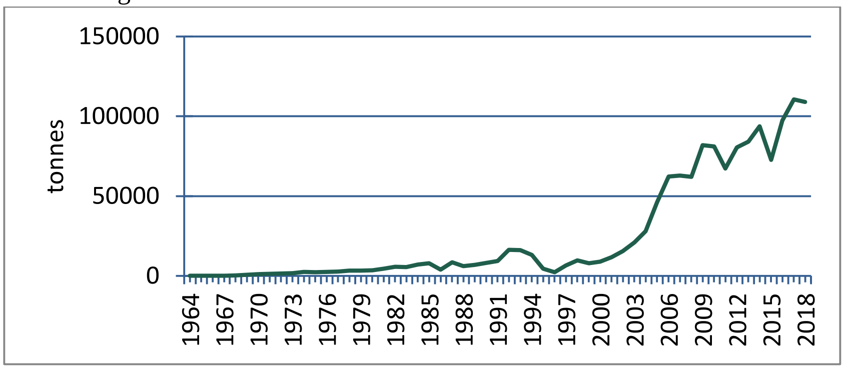

Fig. 3. Historical rice production in Rwanda

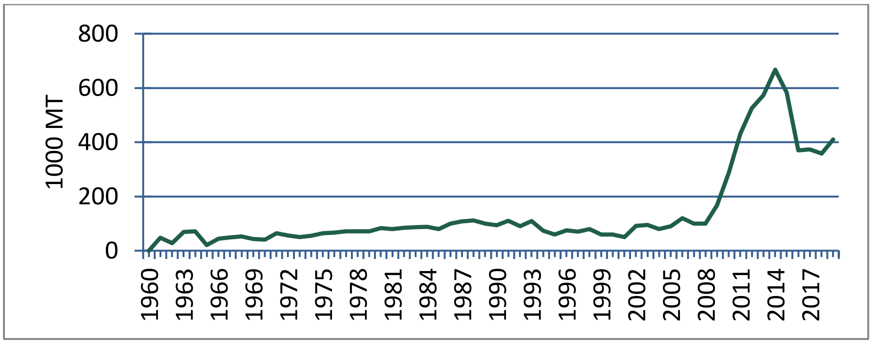

Fig. 4. Historical Maize Production in Rwanda

Computation from equation (1) the quantity of the crop restudies as follows Fig. 3 and Fig. 4 show the inclement of the harvest production of both crops. Computation using equation (1) gives the quantity of the crop restudies as follows

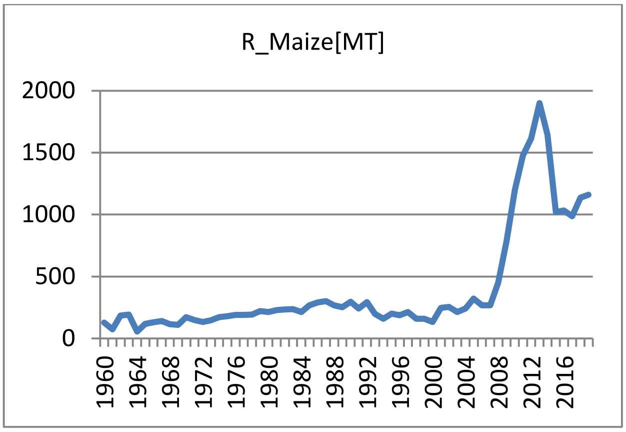

Fig. 5. Historical maize residues

Fig. 5 indicates that crop residues vary proportionally with the variation of the harvest.

Table 1. Tested gross and net calorific values of maize and sugarcane bagasse

Crop Residues	Trial Number	Gross Calorific Value (MJ/kg)			Net Calorific Value (MJ/kg)		
		Measure	Av	SD	Measure	Av	SD
Rice	1	13.92	13.42	0.36	13.59	12.57	0.38
	2	13.11			12.30		
	3	13.29			12.51		
	4	13.19			12.09		
	5	13.09			12.07		
	6	13.94			12.89		
Maize	1	16.47	17.29	0.45	15.67	16.41	0.44
	2	18.13			17.15		
	3	17.31			16.54		
	4	16.24			15.76		
	5	17.63			16.59		
	6	17.97			16.75		
Sugarcane bagasse	1	17.53	16.55	0.41	16.1	15.16	0.39
	2	15.71			14.4		
	3	16.82			15.4		
	4	16.19			14.8		
	5	15.76			14.4		
	6	17.3			15.9		

The averages of the calorific value from Table 1 for each crop are used to estimate the energy which would be generated by using equation (6). Net Calorific value or Lower Heating Value is the same as Lower Heating Value, Gross Calorific Value is like High Heating Value [14].

Mega Joules from Table 1 are converted in KWh to have the same unities by $1MJ = 0.277778KWh$ [15].

Table 2 shows the characteristics of tested samples. From the literature calorific value presented in Table 1 would be improved by reducing ash content and moisture. For example for the case of the sugarcane sample, moisture is high (61.29%); so the corresponding average calorific value ($15.16Mj/Kg$)

can be more improved by reducing moisture content.

Table 2. Samples characteristics

Crop residues	Total Moisture content (%)	Surface Moisture (%)	Ash Content (%)	Volatile matter (%)	Test method
Rice	11.01	7.58	20.15	67.47	CIMR-QAS-WI-17
Maize	15.81	11.13	2.13	84.14	CIMR-QAS-WI-17
Sugarcane	61.29	51.26	2.15	83.99	CIMR-QAS-WI-17

Mega Joules from Table 1 are converted in KWh to have the same unities by 1MJ=0.277778KWh [15].

From the table, the averages of the calorific value for each crop are used to estimate the energy which would be generated by using equation (6).

Table 3. Correlation result for content dependence analysis

	Carbon	Hydrogen	Oxygen	Sulfur	Nitrogen	Ash	Moisture	LHV
Carbon	1							
Hydrogen	-0.02744	1						
Oxygen	-0.81544	-0.42934	1					
Sulfur	0.715625	-0.08665	-0.54252	1				
Nitrogen	-0.11775	0.910002	-0.41113	-0.29494	1			
Ash	-0.48858	-0.34899	0.402759	-0.12576	-0.15287	1		
Moisture%	-0.19794	-0.27846	0.101001	0.300753	-0.20549	0.523584823	1	
LHV	0.419074	0.573301	0.29589	-0.17345	-0.09740	-0.389885903	-0.561048064	1

Table 3 shows that Ash, Moisture and sulfur are negative on calorific values, Nitrogen has a very small negative impact. For the case of Oxygen, the effect is positive however it is always important to consider that its quantity when determining the value of the air-fuel ratio or the mass of the air to optimally fire the boiler.

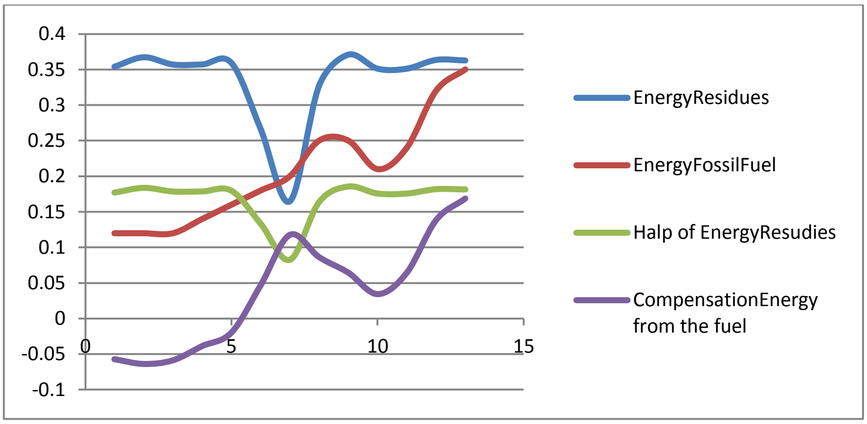

Fig. 6. Comparison of energy from residues and from Fossil Fuel [Billion KWh]

Fig 6 indicates how much residues can contribute compared with consumption from the fossil fuel. With the constraint that a half of the residues can be collected, one can that a small value of the fuel would be used to achieve the same generation.

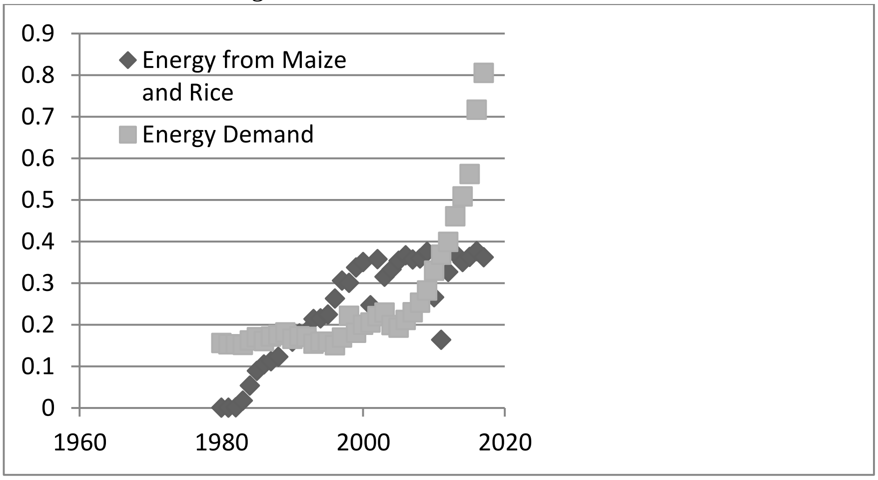

Fig. 7. Comparison of the total energy consumption and the maize-rice energy [Billion Kwh]

Fig. 7 shows that in some cases depending on energy demand and the harvests, the total energy required can all be generated from crop residues. From 2010 the energy demand has exponential increase, but the same Fig shows the contribution of crop residues of about 45%.

4. Conclusion

The contribution of the crop residues of energy demand is demonstrated in this work especially in Fig 7. Recent research and the current on has proven that as the moisture content reduces, the calorific value increased as indicated by Table 3, so Table 2 shows the higher moisture mainly for sugarcane, it would be reduced. Comparison of Fig 2, Fig 6 and Fig 7 indicates that fossil fuel can completely be replaced by crop restudies in energy generation if the maximum of residues is collected. The problem is that these crops are distributed in different places of the country, which gives a task of having a mechanism for putting them together. Under this constraint, a small value of the fossil fuel can still be used. A business study is also important to compare the two looking at the cost.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

A did the literature, analyzed the data and experimented. B provided all guidance on how the work would be step by step. C intervened technically in experiment and computation.

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