Energy input in the production of ethanol from cassava

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Abstract

Energy play an influencing role in the development of key sectors of the nation's economy such as industry, transport and agriculture. Ethanol from cassava, a potential alternative and renewable fuel of the future, may required far more energy during its creation than its energy content after production.The energy requirement in the production of ethanol from cassava was determined, and pattern of energy consumption was investigated. A small scale dry-mill production process was set up for the production of the ethanol. Mathematical expressions were used to evaluate the energy requirement for each of the unit operations. Total energy input and output of cassava ethanol production were 38394.50MJ/ha and 28431.95MJ/ha, respectively. Energy use was 0.74, energy productivity was 0.034 and the Net Energy Value (NEV) was 0.75. This indicated that energy was not efficiently used and the fact that the NEV was less than 1.0 means that cassava ethanol production is not feasible from energetic standpoint and at a small scale level.

Keywords

Energy input; Ethanol; Cassava; Energy use; Net energy value; Energy productivity

Introduction

Bio-ethanol is a distilled liquid produced by fermention of sugars from sugar plants and cereal crops. It is a liquid fuel that can be used as a substitute in internal combustion engines, due to non-renewable nature of fossil fuels, global climate issues, energy crisis, increase in crude oil prices and various environmental problems associated with their exploration, production and use [1, 2]. Also, ethanol is used in the production of potable alcohol and utilized in chemical and pharmaceutical industries [3].

Reports from the previous assessment of the feedstock availability for biofuels production in Nigeria indicated that the country has the potential to be a major biofuels-producer [4]. Alternative sources such as agricultural residues from sorghum straw, millet straw and maize stalks, which are usually burnt on the farm has been explored as other abundant sources of feedstock for cellulosic ethanol production in Nigeria [5]. Other authors have also explored various other feedstock such as cocoyam, cassava, yam, mixtures of cassava peels and livestock wastes and cow dung for biofuels production in Nigeria [6-8].

Bioethanol production from cassava (*Manihotesculenta Crantz*) has very high potential in Nigeria as well as in many other African countries. This is atrributed to yield (9960 kg/ha) and productivity (1.18MJ/kg) obtainable from cassava production [9, 10]. Apart from that, the carbohydrate content of cassava is approximately 40 and 25 percent higher than rice and maize, respectively, making it a suitable raw material for industrial production of ethanol [11].

Ethanol fuel from cassava, touted as an alternative and renewable fuel of the future, may consume far more energy during its creation than its energy content after production. Therefore there is need to carry out analysis of energy requirement in its production from cassava. Methodological energy analysis of energy input in each unit operation of the production system is useful to identify high energy consuming areas. Also, it allows plant operators to compare cost of energy input and energy efficiency in an existing production process with that of a new production line within the same company or another factory. This paper examines the energy requirement in the production of ethanol from cassava in each of the stages of production.

Material and method

A small scale wet mill production process was set up. The production processes are made up of a series of processing steps, the energy components (electrical, internal combustion engine (thermal), and manual) for each of the unit operation was estimated for the production of ethanol from cassava. The Net Energy Value (NEV) was determined. Estimating the energy input for determining the NEV of ethanol from cassava involves adding up all the nonrenewable energy required to grow cassava and to process it into ethanol. Energy determination was limited to primary energy input.

Processing technology and method of energy evaluation of cassava production

The type and magnitude of the energy consumed is a function of the process and the technology employed. Quantitative data on operating conditions was required for each unit operation to quantify the energy demands for operation. Table 1 summarizes the production technologies under study of the ethanol production.

Table 1. Production techniques at each stages of production of the cassava ethanol

S/N	Operation	Equipment and principle adopted
1	Peeling	Manual peeled, with the use of knife
2	Washing	Manual washing, with bowl and brush.
3	Chipping	100kg/hr chipping machine with diesel engine
4	Milling and liquefaction	Burr mill Capacity: 40kg/hr 2 hp internal combustion engine
5	Distillation	Simple Distillation 1800 Watt heating Element Thermostat control Thermometer

The energy evaluation methods for each unit operation are as depicted in Figure 1.'

Peeling

Four women were employed to peel the cassava, the time taken for each of the woman to peel 10, 20, 30, 40 kg samples was recorded. The procedure was replicated four times. The value obtained from each replicate was then recorded. The energy consumed was obtained from the expression in equation 1 [12].

$E_{pe} = 3.6\,(0.068\ N\ T_a)$ MJ (1)

where 0.068 = Energy input of an average adult female, MJ/h.; *N* is the number of labour involved in the operation; Ta =time taken for the operation.

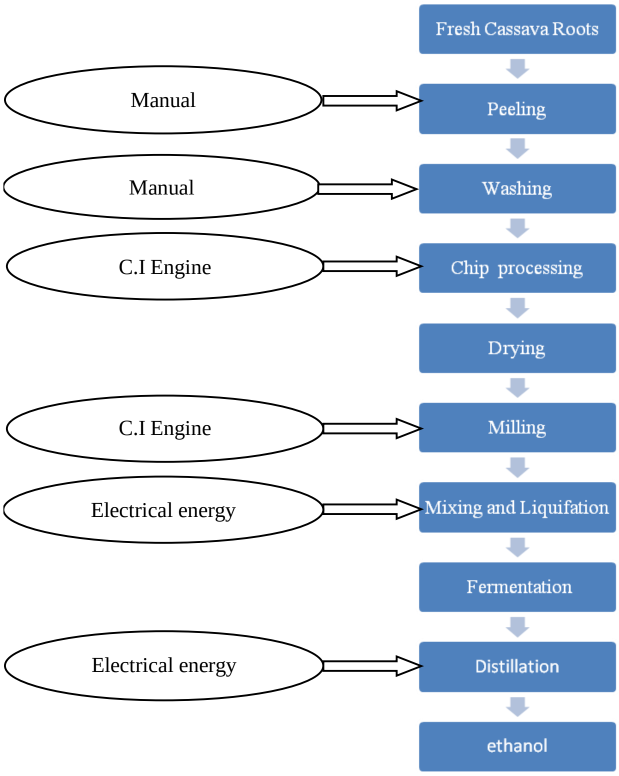

Figure 1. *Energy flow of the production processes*

Washing

The cassava tuber was washed clean after peeling. This was done manually by hand with a light tooth brush. The time and number of labour involved in the operation was obtained and the energy consumed was estimated using the expression in equation 2.

$E_{wash} = 3.6\,(0.068\ N\ T_a)$ MJ (2)

Chipping

The cassava was chipped by 100 kg/hr chipping machine with diesel engine. The quantity of fuel used to chip each samples was measured and recorded, and this was repeated three times for the remaining replicates. The tank was filled to full capacity before the commencement of chipping process. The quantity of fuel used to refill the tank is the quantity of diesel fuel used for chipping that particular sample. The energy consumed was estimated from equation 3.

$$E_c = 42.3F + 3.6\,(0.075\;N\;T_a)\ \text{MJ} \qquad (3)$$

where F = quantity of petrol used, litres

The chipped cassava was then sun dried to remove the moisture content.

Milling

The dried chips were milled by a 2hp burr mill. This makes fuel energy and human labour the input energy. The quantity of petrol fuel used in milling each sample and their replicates were measured and recorded. The energy consumed was estimated from equation 4.

$$E_m = 47.8D + 3.6\,(0.075\;N\;T_a)\ \text{MJ} \qquad (4)$$

where D = quantity of diesel used per unit operation, L.

Mixing and liquefaction

Energy input at this stage includes electrical and human labour. The milled cassava was cooked to liquefy the starch in the mill. The starch slurry was cooked using 1800 Watt electric cooker and liquefied by endogenous enzymes which consist of α- and β- amylases at a high temperature (95^{o}C and pH = 6). The temperature was measured by a thermometer and pH measured by pH meter. The liquefied slurry is then adjusted for further hydrolysis to glucose by saccharifying enzymes at a lower temperature (60^{o}C and pH of 4 to 4.5). The time required in doing this was then recorded for each samples and their replicates. The milled cassava was then transferred into a bucket and 500, 1000, 1500, 2000 ml of N- hexane C_6H_{14} was added to the samples of 10, 20, 30, 40 kg, respectively to the liquefied mash to aid the fermentation. The mash was thoroughly stirred to achieve even an mixture with the hexane. The energy input was estimated from equation 5.

$$E_{ml} = 3.6\,(nPt + 3.6\,(0.075\;N\;T_a)\ \text{MJ} \qquad (5)$$

where n = appliance efficiency; *P* = rated horse power of appliance, KW; t = hours of operation, h. Conversion of 1Kwh to 3.6 MJ was used.

Distillation

The energy input at this stage was electrical energy. The decanted liquid was distilled in the laboratory at 78.5^{o}C by using 1800 Watt cooker as the heating sources. The temperature was control with the aid of a thermostat incorporated in the cooker. The time used in distilling each samples was then recorded.

E_d= 3.6 (nPt) MJ (6)

Total energy input for production of cassava ethanol E_T is the sum of the components involved in each process. Thus the total energy E_T becomes:

$E_T = E_{pe} + E_{wash} + E_c + E_m + E_{ml} + E_d$ (7)

Other related energy indicators was estimated using equations 8 - 12.

Energy use efficiency = Energy Output (MJ/ha) / Energy Input (MJ/ha) (8)

Energy productivity = Ethanol Output (MJ/ha) / Energy Input (MJ/ha) (9)

Net energy = = Energy Output (MJ/ha) - Energy Input (MJ/ha) (10)

The energy output = Yield × Energy Equivalent (11)

Net energy value = Energy in ethanol expressed as higher heating value / Energy content of all non-biological input (12)

Results and discussion

As shown in Table 2, 1335.33 litres of ethanol was obtained from one hectare of cassava plantation, while 129.0 litres was obtained from one kilogramme of cassava (Table 3). Previous study assert that a tonne of fresh cassava tubers yields about 150 litres of ethanol [13]. The 129.9 litres/kg of ethanol obtained in this present study was less than 150 litres obtained in the previous study. The variation in ethanol content of cassava root can be explained by the variety used, age at maturity, processing techniques and technologies used, and the scale of production.

The total energy input in the production of ethanol from cassava tuber was 38,394.50MJ/kg, as shown in Table 2. Distillation and mixing were found to be the major consuming energy input of 18,292.22 (48.96%) and 11,267.37 (29.34%) MJ/kg, respectively; while washing as found to be the least energy consuming unit operation of 143.44 (0.37%) MJ/ha. However, the energy content (output) from 1335.33 litres/ha of ethanol produced was 28,431.95 MJ/ha, which was lower than the energy input as shown in Table 2. This shows that more energy input is needed to produced ethanol of which the energy value is lower than the input energy. This is as reflected in the energy use efficiency of 0.74, indicating that the energy was not efficiently used. This value is lower than 7.48 and 8.80 obtained from previous studies by Dai et al. and Thu Lan Thi [14,15].

Table 2. Energy input of the production of cassava - ethanol per hectare

Energy input (MJ)	
Stages	**Energy input**
Peeling	425.18
Washing	143.44
Chipping	7230.19
Milling	11267.37
Mixing and Liquefaction	1036.12
Distillation	18292.22
Energy Input	38394.50
Yield (litre)	1335.33
Energy Output	28431.95

Table 3. Energy input in the ethanol conversion per kilogram

Unit Operation Energy Input	**Energy Input (MJ/kg)**				
	Mill 1	**Mill 2**	**Mill 3**	**Mill 4**	**Average**
Peeling					
Manual energy	42.4	39.5	39.2	44.0	41.2
Cleaning					
Manual energy	11.3	11.1	11.8	14.5	12.1
Chipping					
Manual energy	7.50	7.4	7.2	7.1	7.3
Fuel energy	740.2	723.3	685.1	693.5	710.5
Milling					
Manual energy	11.3	12.4	11.3	11.6	11.6
Fuel energy	1137.0	1156.6	1148.0	1180.2	1155.5
Liquefaction and mixing					
Manual energy	12.6	12.7	12.5	12.6	12.6
Electrical energy	87.1	88.9	99.1	87.8	90.7
Energy input (MJ/kg)	1766.8	1767.8	1770.7	1772.2	1769.3
Yield (litres)	128.0	132.4	128.6	127.2	129.0

The pattern of energy use in ethanol production from cassava indicated that thermal in the form of fuel energy was the predominant energy use totaling 1866MJ/kg (91.4)% of the total energy, while manual and eletrical energy were 85.0 (4.2%) and 90.7MJ/kg (4.4%), respectively. Energy productivity obtained was 0.034 and the net energy value was 0.75. This indicated that energy was not efficiently used and the fact that the NEV was less than 1.0 means that cassava ethanol production is unfeasible from energetic standpoint and is indicative of excess of fossil energy used to produce cassava ethanol.

Energy can be efficiently used in large scale production where a reduced energy will be used in chipping, milling and distillation to reduce the energy input in this stages of production (Figure 2). Small scale producer of ethanol in Nigeria will be using more energy to produce ethanol, the use of ethanol as an alternative fuel would be realisitic if ethanol is produced in large scale locally so as to reduce the price.

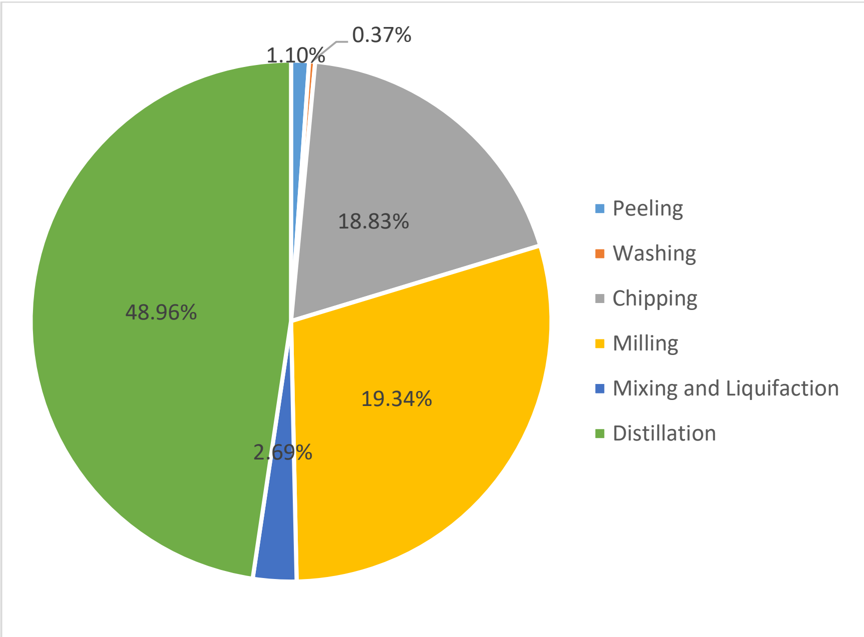

Figure 2. *Pie chat of the unit operation of energy input in the production of ethanolfrom cassava*

Conclusions

The total energy input in the production of ethanol from cassava tuber was 38,394.50MJ/ha with the ouput energy value of 28,4031.95MJ/ha. Thermal energy in the form of fuel energy accounted for 91.4% of the total energy used making it the predominant energy input. The energy use and energy productivity were 0.74 and 0.034, respectively. The net energy value was 0.75. This indicated that energy was not efficiently used because NEV was less than 1.0. It is concluded that production of ethanol from cassava is not feasible from energetic stand point at a small scale level.

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References

1. Graeme M., Walker V., *Science and Technology of Fuel Alcohol. Bioethanol. Transgenics are Imperative for Biofuel Crops*. Plant Science, 2010, 174, p. 246-263.
2. Nuwamanya E., Chiwona-Kaltun L., Kawuki R. S., Baguma Y., *Bio - ethanol production from non - food part of cassava (Manihot esculenta Crantz).* AMBIO Journal of Human Environment, 2011, 10, p. 1-16.
3. Jimoh S. O., Ado S. A., Ameh J. B., *Simultaneous saccharification and fermentation of yam peel to ethanol by coculture of Aspergillus niger and Saccharomyces cerevisiae.* Biol. and Journal for the Tropics, 2015, 6(1) p. 96-100.
4. Abila, N., *Biofuels adoption in Nigeria: a preliminary review of feedstock and fuel production potentials.* Management of Environmental Quality: An International Journal, 2010, 21(6), p.785-95.
5. Iye E. L. and Bilsborrow P. E., *Assessment of the availability of agricultural residues on a zonal basis for medium- to large-scale bioenergy production in Nigeria. Biomass,* Bioenerg, 2013, 48, p. 66-74.
6. Nyachaka C. J., Yawas D. S., Pam G. Y., *Production And Performance Evaluation of Bioethanol Fuel From Groundnuts Shell Waste,* American Journal of Engineering Research, year, 2(12), p. 303-312.
7. Jekayinfa S. O., Scholz V., *Laboratory Scale Preparation of Biogas from Cassava Tubers, Cassava Peels, and Palm Kernel Oil Residues*, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2013, 35(21), p. 2022-2032.
8. Adelekan B. A., Bamgboye A. I., *Comparison of Biogas Productivity of Cassava Peels Mixed with the Major Livestock Waste Types in Selected Ratios*. Afr. J. Agric. Res. (AJAR), 2009, 4(7), p. 571-577.

9. Ziska L. H., Runion G. B., Tomecek M., Prior S. A., Torbet H. A., Sicher R., *An evaluation of cassava, sweet potato and field corn as potential carbohydrate sources for bioethanol production in Alabama and Maryland*, Biomass Bioenergy, 2009, 33(11) p. 1503-1508.
10. Bamgboye, A. Isaac and Kosemani, Babajide. S., *Energy Input in the Production of Cassava*, Journal of Energy and Environment Research, 2015, 5(1), p. 42-48.
11. Tonukari N. J., *Cassava and the future of starch electronic*, Journal of Biotechnology, 2004, 7(2), p. 1-8. Available from: http://www.ejbiotechnology.info/index.php/ejbiotechnology/article/viewFile/v7n1-i02/493
12. Kuiper L., Ekmekci B., Hamelinck C., Hettinga W., Meyer S., Koop K., *Bio-ethanol from Cassava.* Ecofys Netherlands BV, 2007, Project Number PBIONL062937. www. ecofys.com. (accessed 10/03/2011).
13. Jekayinfa S. O., Bamgboye A. I., *Estimating Energy Requirement in Cashew (Anacardium Occidentale L.) Nut Processing operations,* 2006, Energy- The International Journal, 31(8/9), p. 1305-1320.
14. Dai D., Hu Z., Pu G., Li H., Wang C. T., *Energy efficiency and potentials of cassava fuel ethanol in Guangxi region of China*, Energy Conversion and Management, 2006, 47, 1686-1699.
15. Thu Lan Thi Nguyen, Shabbir H. Gheewala, Savitri Garivait, *Energy balance and GHG-abatement cost of cassava utilization for fuel ethanol in Thailand*, Energy Policy, 2007, l(35), p. 4585-4596.
16. Adelekan B. A., *Investigation of the Ethanol Productivity of Cassava Crop As A Sustainable Source of Biofuel in Tropical Countries African*. Journal of Biotechnology, 2010, 9(35), p. 5643-5650.
17. Pimentel D., Patzek T. W., *Ethanol production using Corn, Switch grass, and Wood, Biodesiel production using Soybean and sunflower. The limits of Biomas energy* Natl. Resour Res, 2005, 14, p. 65-75.