Energy Analysis of Small-Scale Ethanol Production from Cassava: A Case Study of the Cassakero Project in Nigeria

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Abstract: The Federal Government of Nigeria recently announced the replacement of kerosene household cooking fuel with ethanol produced from cassava feedstock. The project was called "cassakero". The cassakero project aims to install 10,000 units of small-scale bio-ethanol refineries, operated by small-scale agro-processors across the country. The aim of this article is to present the results of an energy analysis of the ethanol cooking fuel produced from cassava feedstock by small-scale processors under Nigerian conditions Results show that for small-scale cassava ethanol production with the use of agrochemicals is: 11.61 MJ/l for total energy input, a Net Energy Ratio of 1.20, 2.29 MJ/l for Net Energy Gain, and 11.01 MJ/l for Net Renewable Energy Value. Without the use of agrochemicals ethanol production is 10.38 MJ/l for total energy input, a Net Energy Ratio of 1. 34, 3.52 MJ/l for Net Energy Gain, and 12.25 MJ/l for Net Renewable Energy Value. This is the first time that energy analysis has been carried out for small-scale cassava ethanol production under Nigerian conditions.

Keywords: Bioethanol, biofuel, cassakero, cooking fuel, energy analysis, kerosene substitution, renewable energy.

1. INTRODUCTION

The Federal Government of Nigeria (FGN) in November 2009 announced the replacement of kerosene (paraffin) household cooking and lighting fuel with ethanol produced from cassava feedstock in a project called cassakero. The replacement of paraffin created an immediate demand of 3.75 billion litres of ethanol per annum [1]. Since 2007 when Nigeria entered the biofuel race by releasing her national policy on biofuel [2], the current ethanol demand for the implementation of E10 policy and replacement of cooking paraffin is 5.14 billion litres per annum [3]. The country has a total installed capacity for ethanol production of about 134 million litres per annum [3, 4]. Currently, not all the plants are fully operational. The bulk of the current production is produced by Alconi/Nosak, UNIKEM and Intercontinental Distilleries (118.6 million litres representing nearly 90% of the total production) which rely on imported crude ethanol precursors from Brazil. Only the Allied Atlantic Distilleries Ltd, which commenced operations in 1999, is producing 30,000 litres per day of ethanol from locally sourced cassava feedstock [3].

Since the National policy on Biofuels was released in 2007, about 20 large-scale integrated bio-ethanol projects have been announced [3, 4]. There are potential benefits to the communities, including opportunities for employment, business and other non-farm benefits. However, there are several challenges associated with large scale bio-ethanol plants, such as depriving the rural community of their agricultural land, and domination of smallholder farmers and processors [5]. Malik *et al*. [6] reported that large-scale bio-ethanol factories dominate the Asia markets, while the smallholder ethanol processors face the risk of being neglected. A similar challenge is beginning to emerge in Nigeria as well, yet the much orchestrated benefits of biofuel to the rural people are dependent on the full and active participation of smallholders. The small-scale processors are also constrained by lack of energy efficient technologies for ethanol conversion and financing of operations. More worrisome is that electricity in rural Nigeria, from where the smallholders operate, is grossly inadequate and of poor quality. Power interruptions occur several times in a day without any prior notice. Also, there are total blackouts for days and even months [7]. Worse still, some of the rural areas are not even linked to the national grid. Due to inadequate power generation and supply infrastructure, less than 45% of Nigerians are connected to the national grid [8].

The cassakero project aims to install 10,000 units of small scale bio-ethanol refineries across the entire country to produce the daily ethanol cooking fuel requirement for 4 million families. The initial target would be to establish 1,000 units of small-scale bio-refineries to produce 400,000 litres of ethanol daily over the next year, which would be increased to 4 million litres within four years. The refineries would be established in rural areas to assure the steady supply of feedstocks. The project also involves the

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establishment of an out-growers-based feedstock supply system that will produce 8 million tonnes of cassava at an average yield of 20 tonnes/ hectare/year from 400,000 hectares nationwide. The feedstock supply alone could benefit over 250,000 cassava farmers across the country. The construction work of the first batch of small-scale ethanol refineries under this project has commenced in Edo State in three communities, Auchi, Benin and Ehor [3].

Energy balance analysis is used to assess fuel performance. Leng *et al.* [9] reported that energy conversion efficiency is a key indicator to evaluate the eco-performance of a renewable energy source. Fuel conversion requires material and energy input such as water, feedstock, electricity, agrochemicals (fertilizer, pesticides) etc. The process of energy conversion generates air emissions including greenhouse gases, solid wastes and liquid effluents. Except these issues are carefully addressed in a balanced manner, the eco-performance of biofuels could be jeopardized. The energy balance of ethanol is the difference between the energy content of ethanol and the energy input for the production of the ethanol fuel [10], which is also referred to as net energy gain (NEG) or net energy value (NEV) by other authors [11-13]. But energy balance analysis also includes other indices such as net energy ratio (NER). NER is the ratio of the energy content of the fuel to the energy input for the production of the fuel. NER is used to compare the energy balance of different fuel systems /feedstocks. NER values above 1 indicate positive energy balance i.e. energy savings, while values below 1 indicate negative energy balance. However, some authors have reported the limitations of NER and NEV as indicators of energy conversion efficiency. Nguyen *et al.* [10] suggested a better indicator, net renewable energy value (NREV) as an appropriate instrument to assess energy balance. Notwithstanding the importance of energy analysis, none has been carried out for small-scale ethanol production in Nigeria. This is the main thrust of this study. This research could therefore be beneficial to energy researchers, policy makers and the biofuel industry at large.

2. METHODOLOGY

The methodology used in this study is based on the ISO 14040:2006 and ISO 14044:2006, but limited to energy balance analysis (input and output).

2.1. Goal and Scope Definition Including Assumptions and Limitations

In line with ISO 14040:2006/14044:2006 requirements; the functional unit of this study is 1 litre of 50% ethanol (low concentration ethanol) produced from cassava feedstock (the rest 50% is made of water). During the study, primary data were collected from cassava farmers, flour processing centres, and small scale ethanol conversion distilleries. Literature sources for the various energy conversions for the various inputs are shown in Table **1**.

2.2. Energy Analysis

Ethanol production from cassava feedstock involves four major steps: cassava cultivation, cassava tuber processing to flour, cassava flour conversion to

Table 1: Data Sources and Energy Conversions (Dry Weight)

	Energy sources	units	Energy, MJ/unit	References
Inputs	Seed stem	kg	14	[14]
	NPK fertilizer	kg	111	[15]
	Organic fertilizer	kg	0.28	[16]
	Herbicide	L	53.4	[15]
	Diesel	L	56.31	[17-21]
	Gasoline	L	31.2	[22]
	Wood	kg	18	[14]
	Electrical energy	kwh	3.6	[10, 17, 18, 23]
output	Stem	kg	14	[14]
	Tubers	kg	19·10	[24]
	Peelings, bagasse, pulp	kg	19·10	[24]
	Biogas	kg	15.6	[25]

ethanol, and transportation of raw materials and products. The detailed discussion of each stage can be found in Ohimain [5], while a summary of the cassava ethanol value chain including energy and material input is presented in section 2.2.1.

2.2.1. Energy and Material Input

Energy and material input for cassava ethanol include fertilizers (NPK and compost), agrochemicals (especially herbicides), fuel for transportation, and electricity for cassava processing and ethanol conversion. The planting material (seed) for cassava cultivation is the stem. Cassava stem used as planting materials is typically obtained from farm wastes during harvest. About 10% of total stem produced is used for planting purposes. Because of poor storability of cassava stem, unlike cereal grains, the usual practice is to prepare a new cassava farm ready for planting in time to coincide with harvest in order to maintain the viability of the stems. About 60 bundles of 100 cm long cassava stems (cut to 25 cm) are required to plant one hectare.

Another vital input to cassava farming in Nigeria is fertilizer. Typically, the average farmer uses mostly organic fertilizer produced from the compost of the previous harvest. In cassava farms, this consists of 90% of the stems, leaves, and peelings if the cassava is processed at the farm. Fadare *et al*. [26] estimated the energy requirement for the production of organic compost in Nigeria to be 0.28 MJ/kg. Similarly, Erdal *et al*. [27] and Kizilaslan [17] reported an energy conversion value of 303.10 MJ/tonne of organic compost, which translated to about 0.3 MJ/kg. It is known that organic compost is poor in minerals, particularly phosphate and potassium; hence NPK is sometimes used by a few farmers, while the majority of farmers embark on shifting cultivation. About 100 kg of nitrogen, 50 kg of phosphate, and 50 kg of potash fertilizer are used to cultivate 1 ha cassava farm. Stout *et al*. [15] estimated the direct energy input for the production, packing, distribution, and application of NPK fertilizer in Africa to be 111 MJ/kg. However, a more recent estimate by Kim and Dale [28] is used for this assessment.

An important component of cassava farming in Nigeria is weeding. The majority of farmers do not use any form of herbicide for weed control. During farm preparation, the cleared farm is burnt typically, which is less effective than the application of a total herbicide. Also, some weed seeds survive the fire treatment. Farm burning has several detrimental effects including the loss of organic matter/compost, and carbon dioxide is released into the atmosphere instead of being fixed in the soil as inorganic carbon. Also, fire can be detrimental to important soil flora and microorganisms, which are essential in nutrient cycle and sustenance of soil fertility. On the other hand, total herbicide treatment can also have detrimental effects on non-target soil organisms, and has the capacity to contaminate water sources [29, 30]. When total herbicide is not used during land preparation, it is recommended that a pre-emergent herbicide is used three days after planting. With the International Institute for Tropical Agriculture (IITA) recommended planting density of 1m x 1m, when fully grown, the cassava forms a dense canopy, which suppress further weed growth. Most rural farmers in Nigeria use neither pre- nor post-emergence herbicide; they weed the farms manually. Stout *et al*. [15] estimated the direct energy input for the production, packing, distribution and application of herbicides in Africa to be 8.3 MJ/kg. This we considered as too low because of the values presented by other authors. For example, Kim and Dale [28] used 429.27 MJ/kg, while Ozkan *et al*. [19] and Erdal *et al*. [22] used a conversion of 238 MJ/kg. In view of all these, we therefore opt to use 429.27 MJ/kg for computation. The use of tractors in Nigerian farms is still not widespread, but manual energy is the common practice.

There have been conflicting reports about the average national yield of cassava tubers produced in Nigeria. The Food and Agricultural Organization [31, 32] recorded 10.8 tonnes/ha, which is the value that most other researchers are reporting for Nigeria [33]. Other studies have reported a wide range of values. The National Bureau of Statistics [34] reported 12 tonnes/ha. From field studies, Nweke *et al*. [35] reported a yield of 13.41 tonnes/ha and 19.44 tonnes/ha for local and improved cassava varieties respectively even without the use of inorganic fertilizer. Field data collected from the south-south geo-political zone during the period 2000-2002, shows that yield of cassava ranges from 9.39-15.93 tonnes/ha with an average of about 12 tonnes/ha, which has now increased to 25 tonnes/ha with the adoption of improved varieties and modern agronomic practices [36]. Okaiyeto and Lamidi [37] reported that the use of improved cassava cultivars has boosted yields in the range of 25-40 tonnes/ha. Therefore, the cassakero project targeting 20 tonnes/ha is in line with current practices. Cassava tuber has a gross energy of 19.10 MJ/kg [24].

The conversion of electrical energy is consistent in literature. A value of 3.6 MJ/KWh is widely reported [10, 17, 18, 23]. Notwithstanding, after accounting for losses during electricity generation in Nigeria and the Nigerian electricity mix, a factor of 7.387 was used for electricity conversion. In Nigeria, farms are located typically in rural areas far away from the national grid, and electrical energy is typically not used. However, electrical energy is a major input both in the cassava processing centre and ethanol conversion plants. Electricity supply in Nigeria is poor, unstable and unreliable; therefore most manufacturers resort to the use of gasoline and diesel powered generators [7]. Adenikinju [38] reported that self generated electricity accounted for 42% of total electricity in Nigeria. The Nigerian energy grid mix consists of 64.4% of the electricity produced from petroleum, and 35.6% from hydropower (Table **2**). In this study, hydropower is considered a renewable source of energy and excluded the potential environmental impacts associated with river damming.

The energy used for the processing of 1000 kg cassava feedstock to flour is 346.40 MJ [40]. It should be noted that the energy from sunlight, which is used for the drying of cassava flour, is considered free. Typically, for every tonne of cassava tuber processed about 250 kg flour is obtained, though Jekayinfa and Olajide [40] reported 200kg/tonne, but other reports, including Nweke *et al.* [35], Knipscheer *et al.* [41], Philips *et al.* [32], and unpublished data from a cassava processing centre (Rohi Biotechnologies Ltd, Igarra cassava factory, Edo State, Nigeria), shows 250 kg cassava flour per tonne of raw cassava tuber. Hence, 250 kg flour is used for material and energy balance computations. Wastes produced per tonne of cassava tuber are cassava peelings (100 kg) and effluent water (650 litres). Balogun and Bawa [24] reported that cassava peels made up 11·8% of the tuber, in most cases it is 10%, which is what we used in computations in this paper. Jekayinfa and Olajide [40] reported 680 litres of waste water is produced per tonne of cassava tuber.

The processing of 250 kg cassava flour to ethanol involves the input of 220 g each of σ amylase and glucosidase enzymes. About 50 kg of yeast produced from previous fermentation process is typically recycled into the fermentation broth. Also, 220 g of triple superphosphate and 20 g of magnesium sulphate are added to the fermentation broth. The energy input for the production of these salts is considered insignificant because only trace amounts are used in the composition of the fermentation broth. About 1074 litres of water is added and at the end of the fermentation and distillation about 274 litres of low concentration ethanol is produced along with 90.5 kg of carbon dioxide, 1095.5 litres of wastewater, and 32.5 kg (dry weight) of solid waste containing yeast and cassava fibre/pulp. The solid waste containing yeast, which is commonly referred to as dried distillers grain with soluble (DDGS), is a good human and animal feed material because of the high protein content. In Thailand, about 10-15% of the original root weight ends up as solid wastes after cassava starch processing, which contained 68% residual starch and 27% fibre on a dry weight basis [42], 2000), and with the incorporation of yeast after fermentation, it becomes an excellent feed material. Attempts have been made to produce several useful products from cassava bagasse including organic acids, flavour and aroma compounds, and mushrooms using solid state fermentation [43].

For every litre of ethanol produced, electricity is required for fermentation (about 9 KWh), for distillation (3 KWh), and dehydration and other functions including denaturation and conversion of ethanol to cooking fuel (20 KWh) [44]. This adds up to 115.2 MJ per tonne of raw cassava tuber, which also translates to 0.84 MJ per litre of ethanol produced. In rural Nigeria, about 6.4 kg of hardwood is used to directly fire the fermenters and makeshift distiller/boilers to produce concentrated ethanol. In Brazil, it has been reported that 1.9 kg of fuel wood is required to produce 7 kg of steam per litre of ethanol [44], whereas in the US, 2 kg of wood is used [45]. The small-scale distillation of ethanol is a

Table 2: Nigerian Electricity Mix and their Renewability

Source	% contribution	Renewability
Gas	39.8	Fossil /non renewable
Hydropower	35.6	Renewable
Oil	24.8	Fossil /non renewable
Coal	0.4	Fossil /non renewable

Source: Ikeme and Ebohon [39].

long tradition in rural Nigeria involving the use of makeshift rudimentary equipment and fuel wood as the energy source for the production of traditional alcoholic beverages from fermented oil palm and raffia palm juice (Figure **1**). This equipment, often with limited process controls is unable to produce anhydrous ethanol, but it is able to distil ethanol to 50-70%. It saved energy required for the partial distillation to 50% and will not require subsequent dehydration stages. Only about 0.45 kg of wood is required (per litre of ethanol produced) for the partial distillation for the production of low concentration ethanol. In India, low concentration cooking fuel running on 50% ethanol-water mixture has been developed and used in rural household cooking fuel [46-48].

Cassava processing wastes in addition to peels include stillage and effluents having a high BOD and COD, which are now commonly treated and used for biogas production. Using cassava peels only yielded 2.29 L/mass of slurry, while in combination with animal wastes such as cow dung in a ratio 1:1 yielded 4.88 L/mass [25]. In Thailand, a cassava processing factory generates about 16.5 m^3 of biogas, which is equivalent to 10.25 m^3 of methane per cubic meter of wastewater [49]. The heating value of biogas is 15.6 MJ/l [25], or 22 MJ/m^3 [50], whereas the heating value of methane, which made up about 60% of the biogas produced from cassava wastes, is 35.9 MJ/m^3 [49].

2.2.2. Transportation Energy

Diesel fuel is used by trucks for the transportation of cassava farm produce, flour and ethanol. Gasoline powered light vehicles (2 tonnes capacity) are also used, especially for the transportation of farm produce to the market or cassava processing centres. Ten tonne diesel powered truks are used to convey ethanol to the blending plants located in the depots. The energy input for diesel production is one of the few input values that are consistent in the literature; a value of 56.31MJ/l is widely reported [17-21]. The energy content of gasoline is 31.2 MJ/L [22].

Energy input for the transportation of cassava tubers to processing centres and ethanol conversion centres, and for the distribution of ethanol cooking fuel was estimated based on unpublished data from a cassava processing company (Rohi Biotechnologies Ltd.) and was used in the assessment. Cassava processing centres are located relatively close to cassava farms, within distances less than 10km. Nigeria is a large country of about one million square km. Hence, with the planned establishment of 10,000 units of small-scale ethanol refineries nationwide, the

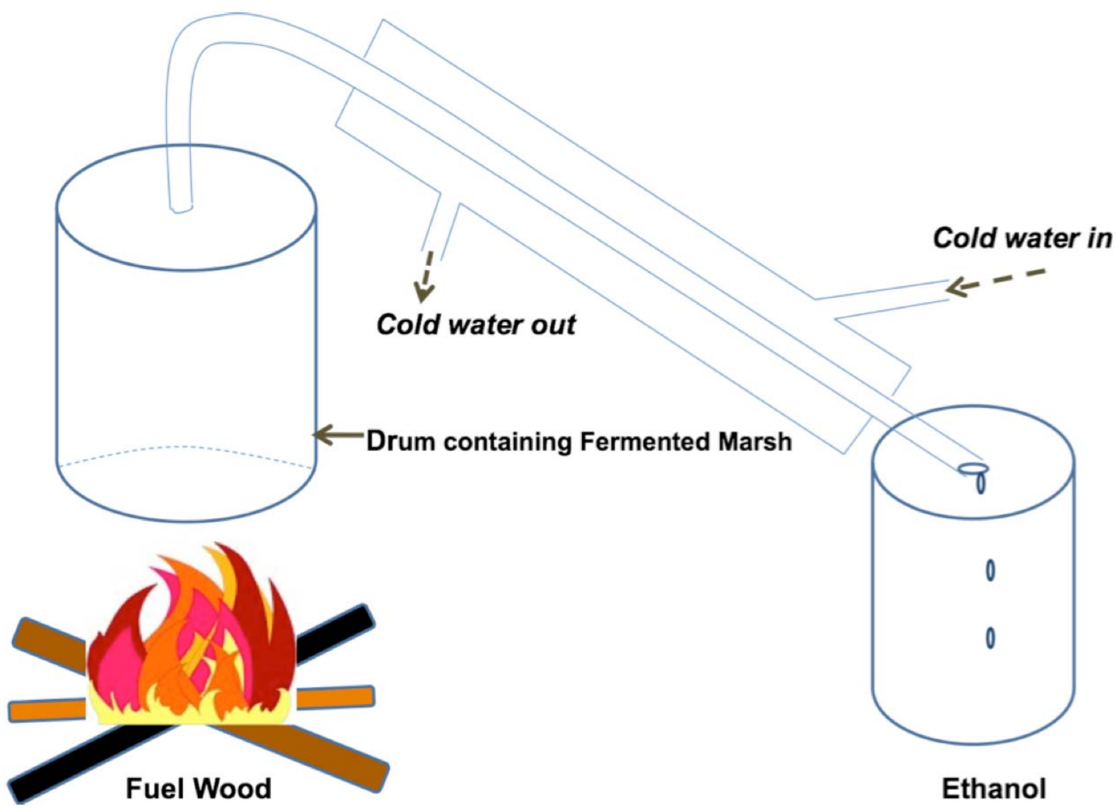

Figure 1: Small-scale distillation of ethanol using rudimentary equipment.

travel distance to these ethanol conversion centres will be about 100 km. Fuel consumption in Nigeria is an average of 9 km/l of fossil fuel for light trucks [51] and 3.5 km/l for 10 tonne diesel trucks [13], hence about 1.11 litres of gasoline will be consumed for transporting cassava from farms to the processing centres. 56.31 litres of diesel for the transportation of cassava flour to ethanol conversion centres. Another 56.31 litres will be consumed during the transportation ethanol from ethanol conversion centres to the nearest depot, and for the distribution of ethanol fuel to customers.

2.2.3. Energy Balance Computation

This assessment is based on the energy input for the production of 1 L of 50% ethanol compared to the energy contained in the ethanol itself, i.e. the heating value of ethanol. The following indicators were used to assess energy performance;

- Net Energy ratio (NER) = Energy output/ energy input [13], which is also referred to as fuel energy ratio (FER) in some literature [52]
- Net Energy gain (NEG), or net energy value (NEV) = Energy output- Energy input [10-13]
- Net renewable energy value (NREV) = Energy output- fossil Energy input [10, 11]
- Energy resource conservation, percentage renewable= renewable energy inputs/total energy inputs * 100 [53]

The heating value of anhydrous ethanol is well documented in the literature as 23 MJ/kg, or 21.2 MJ/l [13, 54, 55], though Dai *et al*. [11] reported 21.85 MJ/l. Adeniyi *et al*. [56], under experimental conditions reported that the heating value of ethanol produced from cassava starch is 22 MJ/kg. Robinson [57] reported that the energy content of low concentration ethanol is 19.6 MJ/kg at a density of 0.71 kg/l, which is equivalent to 13.9 MJ/l. Ethanol will replace the current cooking fuel, kerosene, which has a high heating value (HHV) of 46.2 MJ/kg (40.2 MJ/l), and a low heating value (LHV) of 43 MJ/kg (37.3 MJ/l).

3. RESULTS AND DISCUSSION

Results of the energy analysis (Tables **3-5**) show the total energy required to produce and distribute a litre of low concentration ethanol under Nigerian conditions by small-scale processors is 11.61MJ with agrochemical input, and 10.38 without agrochemicals, excluding credits from co-products (by-products and energy derived from cassava processing wastes e.g. spent yeast, biogas, fertilizer). In both scenarios, the ethanol conversion phase is the most energy intensive, accounting for 74.42% with agrochemical input, and 83.26% without. Raw cassava tuber processing to flour accounted for 9.63% with agrochemicals, and 10.78% without, of the total energy input. The cassava farming phase accounted for 10.83% and 0.25% of the total energy input in the scenario with and without agrochemical input respectively. The large difference in the energy input of the two scenarios is expected because agrochemicals represent the major source of energy input in farming systems. The results of this study are in line with other previous studies, where the ethanol conversion stage is the most energy intensive. For example, Papong and Malakul [13] recorded 24.92 MJ for the production of 1L of cassava ethanol in Thailand, with the ethanol conversion stage accounting for over 77% of the total energy input. Other studies from Thailand and China recorded different input energy values for the production of 1litre ethanol using cassava feedstock including 15.85 MJ/l [10], 16.732 MJ/l [11], and 12.06 MJ/l [23]. In all these studies, the ethanol conversion stage is the most energy intensive.

Table **5** presents a breakdown of the various forms of energy input for the conversion of cassava tubers to ethanol. Direct energy in the form of gasoline, diesel, wood, and electricity accounted for nearly 90% of the total energy input in the scenario with agrochemicals, and 100% without. Indirect energy, which consists of energy used in the manufacturing of fertilizers and herbicides accounted for 10.61% in the scenario with agrochemicals, and absent in the scenario without agrochemicals. Renewable energy input, which consists of energy for the production of organic fertilizer, wood, and hydro-electricity, represents 75.13% of the total energy input in the scenario with agrochemicals, and 84.05% in the scenario without agrochemicals, whereas fossil energy accounted for the remainder energy input in both scenarios. Notwithstanding the high energy input, the results of the scenario with agrochemical input are 1.20 NER, 2.29 MJ/l NEG, and 11.01 MJ/l NREV, whereas without agrochemical inputs they were 1.34 NER, 3.52 MJ/l NEG, and 12.25 MJ/l NREV (Table **4**).

These results show that the production of ethanol from cassava feedstock in Nigeria by smallholder is energy efficient, because the NER is greater than 1 even without allocation of credits to the co-products, which include biogas, fertilizer, and animal feed. This value is close to the results obtained by Nwanchukwu

Table 3: Energy Input for the Production of One Litre Fuel Ethanol without Co-Products Allocation

		units	Energy, MJ/unit	input quantity	Energy use, MJ/l	Renewability
Cassava farming	N fertilizer	kg	32	100	0.58	Fossil
	P fertilizer	kg	19.01	50	0.17	Fossil
	K fertilizer	kg	9.07	50	0.08	Fossil
	Organic fertilizer	kg	0.28	500	0.03	Renewable
	Herbicide	l	429.27	5	0.39	Fossil
Cassava processing to flour	Mechanical energy	MJ	7.387	306.43	1.12	mixed
Conversion to ethanol	Liquefaction, Saccharification and fermentation	kg	18	0.45	8.10	renewable
	Denaturation and other functions including water production, wastewater treatment	kwh	7.387	20	0.54	mixed
Transportation	gasoline (cassava harvest from farm to processing/ethanol conversion centre)	l	31.2	1.11	0.01	Fossil
	Diesel (Ethanol to depot)	l	56.31	28.57	0.29	Fossil
	Diesel (Distribution of fuel to consumers)	l	56.31	28.57	0.29	Fossil
TOTAL					11.61	

Table 4: Cassava Ethanol Processing Energy Share and Indices

		Scenario with inorganic fertilizer and herbicides			Scenario without inorganic fertilizer and herbicides		
		Energy input, MJ/L	%	Indices	Energy input, MJ/L	%	Indices
Cassava ethanol processing phases	Cassava farming (MJ/l)	1.26	10.832	-	0.03	0.246	-
	Cassava processing (MJ/)	1.12	9.634	-	1.12	10.778	-
	Conversion to ethanol (MJ/l)	8.64	74.422	-	8.64	83.257	-
	Transportation (MJ/l)	0.59	5.112	-	0.59	5.719	-
Energy indices	NER	-	-	1.20	-	-	1.34
	NEG	-	-	2.29	-	-	3.52
	NREV	-	-	11.01	-	-	12.25

Table 5: Form of Energy Input

		Scenario with inorganic fertilizer and herbicides		Scenario without inorganic fertilizer and herbicides	
Form of energy	Definition	MJ/l of ethanol	% of total energy	MJ/l of ethanol	% of total energy
Direct energy	diesel, gasoline, electricity, wood	10.38	89.39	10.38	100.00
Indirect energy	inorganic fertilizers, herbicide	1.23	10.61	0.00	0.00
Renewable energy	hydro-electricity, wood energy, organic fertilizer	8.72	75.13	8.72	84.05
Non- renewable energy (fossil)	Diesel, gasoline, herbicide, inorganic fertilizer, electricity from petroleum	2.89	24.87	1.65	15.95
Total energy*		11.61		10.38	

*The total energy input is the sum of the fossil and renewable energy (or direct energy and indirect energy).

and Lewis [14] on cassava ethanol production in Nigeria, which ranged from a NER of 1.1 – 1.4 depending on the agronomic practices, with the ratio being lower under mechanized farming with the use of agro-chemicals than labour intensive farming without the use of agro-chemicals. Because the NER is close to 1.0, the results suggest that the small-scale bioethanol production from cassava feedstocks is marginally energy efficient. Sanden and Karlstrom [58] advised that environmental assessments of emerging technologies should not only include effects resulting from marginal change of the current system, but should also consider marginal contributions to radical system change. The NEV can, however, be increased and optimized through the utilization of cassava processing wastes for energy and other useful purposes. In a recent study, Ohimain *et al.* [59] reported that huge volumes of wastes are generated during the processing of cassava tubers to garri (a toasted granule). The study revealed that only 34% of the raw cassava tubers are converted to garri, while wastes including liquid effluent, gaseous emissions and solid wastes accounted for the rest 66%. Cassava peelings and bagasse can be used for the production of fertilizer [16], animal feed [24], or as fuel to run steam turbines for power generation [49]. Also, the cassava effluent and stillage generated can be converted to biogas *via* microbial anaerobic digestion [25]. Biogas can also be used as fuel for gas turbines for power generation [49]. Cassava processing wastes have been used as raw materials for several industrial applications for the production of mushrooms, single cell protein, enzymes, organic acids, amino acids, and other bulk chemicals [42].

Results of the sensitivity study that was carried out by increasing and decreasing all the input energy by 10% also reveal that the cassava ethanol is still efficient (Figure **2**). Since most of the input data were obtained from literature, concerns over the uncertainties and possible errors have been raised. However, comparing the result to other studies shows a high level of agreement. Dai *et al*. [11] similarly obtained a net energy ratio of 1.545, a net energy value of 7.475 MJ/l, and a NREV of 7.881 MJ/l while working on cassava ethanol in China. Nguyen *et al.* [10] recorded a NEV of 8.8 and a NREV of 9.15 MJ/l. Leng *et al*. [9] recorded a NER of 1.28. Papong and Malakul [13] recorded 1.11 for NER and 19.03 MJ/l for NEG.

Cassava is one of the most important food crops in Nigeria and the whole of Africa [35]. Nigerians consume cassava daily, with some people eating it more than once in a day [32]. Cassava use is increasing in Nigeria owing to Government policies that have focused on the industrialization of the crop for the production of animal feed, baking flour, and high fructose syrup. The emergence of cassava as a feedstock for the production of fuel ethanol could conflict with food resources, causing hike in food prices, which could benefit the rural farmers, but could be detrimental on human nutrition. Cassava is the cheapest source of food crop in terms of price/calories and was regarded as a hunger fighter and the last hope of the 'common man' [35]. This important feature of cassava is gradually eroding due to price increase as a result of the multiple uses of the crop. It should be noted that other countries such as Thailand, Brazil, and China, where cassava is used as feedstock for ethanol production, the crop is not their major staple.

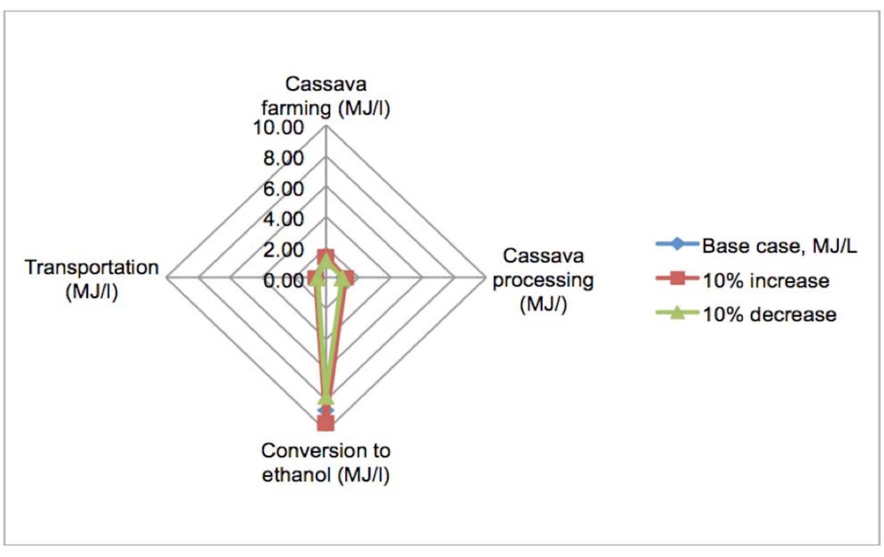

Figure 2: Sensitivity analysis of varying the input energy.

Proponents of the cassakero project planned to establish 400,000 ha of new cassava farms in order to mitigate the potential food versus fuel effects that could arise when cassava is used for ethanol production in Nigeria. However, the expansion of cassava farms into forests, as a result of ethanol production could destroy virgin forests and wildlife, thus threatening sustainability and biodiversity. Ironically, interest in producing fuel ethanol from biomass is an attempt to make transportation and cooking fuel more sustainable [60]. Uilein *et al*. [61] reported that the utilization of renewable energy has led to ecological advantages compared to fossil fuel, but it has also come with ecological disadvantages, particularly with respect to intensive land use [62]. Though, farm mechanization and application of modern agricultural practices, have increased yield of cassava produced in Nigeria [63], it has also come with environmental challenges associated with agricultural intensification. Hence, there is the need for trade-off and balance between food, fuel, biodiversity, and sustainability. However, life cycle economic assessment of cassava ethanol production in China revealed that cassava fuel ethanol production is sustainable [64].

5. CONCLUSION

An energy analysis of ethanol production by smallholders in rural Nigeria was carried out. Results show that direct energy in the form of gasoline, diesel fuel, and electricity accounted for nearly 90% of the total energy input, while indirect energy accounted for 10.61% in the scenario with agrochemical input. Renewable energy input represents 75.13%, whereas 24.87% of the energy input is fossil fuel in the scenario with agrochemical input. Smallholder cassava ethanol production, with the use of agrochemicals is the following: 11.61MJ/l total energy input, 1.20 NER, 2.29MJ/l NEG, and 1101MJ/l NREV: while without the use of agrochemicals is: 10.38MJ/l total energy input, and, 1.34 NER, 3.52MJ/l NEG, and 12.25MJ/l NREV. This suggests that the scenario without the use of agrochemicals, as commonly practiced in Nigeria, is more energy efficient. However, without the use of agrochemicals farmers suffer the risk of lower ethanol production due to reduced crop yield of 10.8-12 tonnes/ha compared to 20tonnes/ha when agrochemicals are used for feedstock cultivation. This result is in agreement with other studies showing that the ethanol production in Nigeria is marginally energy efficient.

Notwithstanding the positive energy indices, ethanol production from cassava feedstocks by smallholder processors could face other challenges such as lack of funds, poor electricity, water and other social infrastructure and environmental challenges, which could threaten the eco-performance of ethanol fuel. For instance, during the production of gari (a roasted granule and the food product from cassava) by smallholder processors, the resulting solid and liquid wastes are freely discharged into the environment without any form of treatment. And due to weak environmental law enforcement, this practice has continued unabated. Also, the use of cassava feedstock for fuel production could compete with food sources, which could lead to hike in food prices resulting in malnutrition. Besides, the expansion of cassava farms into virgin forests could cause other environmental problems such as the release of trapped CO_2, destruction of wildlife habitat and pollution of water sources especially if agrochemicals are applied. The use of wood for ethanol distillation could further threaten forests and associated wildlife. Except these aforementioned challenges are well addressed, the entrance of Nigeria into biofuel race could become unsustainable.

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