Energy consumption and environmental burden analysis of cassava tuber production in Ogbomoso southwest Nigeria

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Abstract. The behavior of an agricultural system can be understood better by considering its economic and environmental analysis. In order to reduce environmental load of energy uses, there is need for improved energy conversion and utilization. In this research, the energy consumption pattern in cassava production, and its environment burden were considered. Data of resources consumption were collected from cassava cultivation field and relevant research institutions, and converted to their energy value. Selected environmental impacts categories of the crop were determined using life cycle assessment model according to ISO 14040-14043 series. The results from the findings showed that crop protection, planting operation, land preparation, harvesting and packing consumed 16764.83, 5057.32, 5011.46 and 294MJ/ha which represented 61.80%, 18.64%, 18.48% and 1.08% respectively of the total energy consumption. Other energetic parameters and their value determined in cassava production were, energy productivity (1.47 kg/MJ), energy ratio (8.95) and net energy gain (215672.39 MJ/ha). The percentage nonrenewable energy and renewable energy consumed were 78.40% and 21.60% respectively. The environmental impacts associated with cassava production include global warming potential (GWP) (8.025E+01 kg CO2 equiv.), acidification potential (AP) (1.8892E-02 kg SO2 equiv), eutrophication potential (EP) (6.7375E-01 kg NO3 equiv.), and ozone layer depletion potentials (OLDP) (2.9981E-04 kg RII equiv.) The results obtained established cassava tuber as energy crop, and its production has negative impact on the environment. Non-renewable energy utilization in the crop production should be targeted for reduction.

1. Introduction
Cassava is widely cultivated in some continents of the world such as; Latin America, Africa and Asia. Globally, it is an important food component of every day calories of several millions of people in about 105 nations [1]. Next after rice and maize comes cassava among major food crops in developing countries of the world and the production stood at 249 million tons in 2010 [2] The last decade has witnessed tremendous growth in cassava output in Africa than other major producing regions due to increase in cultivation. Nigeria assumed the position of the largest producer of cassava in the world with a peak production of 45 million metric tons from an area of 4.12 million hectares by the year 2015. Cassava is majorly cultivated in the southern part and central regions of Nigeria, representing almost 70% portion of tuber crop production in West Africa [3]. Its production and processing require energy use in form of fossil energy (petroleum fuel), pesticide, herbicide,
fertilizer. The use of these materials release waste and emission pollutant into the production environment.

There have been several studies on energy use and environmental impact in the production of agricultural crops such as; three energy crops (rapeseed, sunflower and sweet sorghum)\cite{4}; rice \cite{5}; eggplant \cite{6}; wheat \cite{7}; sugar beet \cite{8,9}; corn\cite{10}; Potato \cite{11} but there is scanty information on research about energy consumption and environmental burden of cassava cultivation, most importantly in Nigeria, the largest producer in the world. Therefore, this study evaluated the energy consumption scenario during cassava production and its environmental burden in Ogbomoso, South West Nigeria. The information provided could be used by Nigeria government to promote sound energy use policy and sustainable environment in cassava production.

2. Materials and Methods

2.1 Study Location and Data Collection

The popular improved cassava varieties (TMS 0326) cultivated in Southwest, Nigeria was selected for this study and 1ha land area of cassava production was chosen for easy data collection. Cassava cultivation involves four different operations, which are; land preparation, planting, crop protection and harvesting. Three forms of energy were used for each of these operations; thermal, manual and other sequestered energy. Data of resources used in cassava production which are site-specific, were collected from the field of cultivation, and relevant research institutions (IITA, Ibadan, Nigeria and LAUTECH Agricultural Teaching and Research Farm, Ogbomoso), and this is presented in Table 1. The background data on energy sequestered on fertilizer and herbicide production, fossil fuel used, equipment and other materials were collected from relevant literature. Energy coefficients used to determine energy value of resources consumed and their sources is presented in table 2. Basic energetic parameters (manual, thermal, other sequestered energy) were determined from the product of resources used and their energy coefficients and presented in table 3. The energy value of the machine used during cassava production was estimated with the formula given by Yaldiz et al. \cite{12}

\[
ME = \frac{WxE}{TxEFC}
\]

Where;

- ME = machine energy input (MJ/ha)
- W = equipment weight (kg)
- E = energy due to manufacturing of the machine/equipment (MJ/kg)
- EFC = Effective area capacity (ha/h)
- T = Economic life of the equipment (h)

Other energetic parameters considered in cassava tuber production were calculated with the following equations:

Energy ratio (ER) = \[
\frac{\text{Energy Output (MJha}^{-1})}{\text{Energy Input (MJha}^{-1})}
\]

Energy productivity (EP) = \[
\frac{\text{Total Crop harvested (kg)}}{\text{Total Energy Input (MJ)}}
\]

Specific Energy (ES) = \[
\frac{\text{Total Energy Input (MJ)}}{\text{Total Crop harvested (kg)}}
\]

Net Energy Gain (NEG) = Output Energy (MJha\(^{-1}\)) – Input Energy (MJha\(^{-1}\))

Renewable Energy = Human labour + Planting material energy content (MJha\(^{-1}\))

Non-renewable Energy = Fuel + Chemical Fertilizers + machine energy sequestered

2.2 Life cycle Assessment Model for the Environmental Burden

The determination of environmental impact of cassava tuber production was done using procedure for performing LCAs in the ISO 14040-14043 series. LCA study involves four main phases, namely; goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation of results.

Environmental burden of cassava tuber production considered in this study include; global warming potential (GWP), stratospheric ozone layer depletion (OLD), acidification potential (AP) and eutrophication potential (EP).
2.2.1 Goal and scope of the study. The study identified and quantified the environmental burden in cassava cultivation and considered possible efforts at reducing the impact. The functional unit chosen for the study was 1 ha land area for easy data collection.

2.2.2 Life cycle inventory (LCI) analysis. In this second phase of LCA, the inventory analysis of resources input and output was carried out. This involved collection and analysis of data which were obtained from primary and secondary sources. Primary data, also regarded as foreground data were collected from field of cultivation and research institutions, while secondary data were collected from literatures (background data) which include data on energy sequestered on fertilizer and pesticide production, fossil fuel used, equipment and other material.

The data collected were transformed to values with respect to the functional unit. Basic energetic parameters and emission generated were quantified, and these were modeled into environmental burden.

2.2.3 Emission and environmental impact calculation. The emission and environmental impacts were determined using calculation-based methodologies with the following equation:

\[
\text{Emission} = \text{activity data} \times \text{emission factor}
\]

Activity data = the quantity of energy use such as; fuel type consumption, metered electricity consumption, annual vehicle speed

Emission factor = default emission factor for the emission type

\[
\text{Impact category indicator}_i = \sum_j \left( E_j \times \text{or} \times R_j \right) \times \text{CF}_{i,j}
\]

Where:
Impact category indicator = indicator value per functional unit for the impact category, \( E_j \) or \( R_j \) = release of emission or consumption of resource \( j \) per functional unit, \( \text{CF}_{i,j} \) = Characterization factor for emission or resource \( j \) contributing to impact category \( i \)

3. Results and Discussion

3.1 Results from Inventory of Resources Used

The energy values of input used and output from cassava production per hectare were determined and the results are shown in table 3. Nitrogen component of mineral fertilizer (NPK) accounted for highest value of energy input, 10,413 MJ/ha (38.4%) of resources used. This was as a result of effect of continuous cropping system on the soil prevalent in cassava growing dominant region of southwest Nigeria, which requires a supplement of nitrogenous nutrient for a good yield. Nitrogen is an important nutrient required by plant for development and fruiting. Cassava stem cuttings for planting, 4931.88 MJ/ha (18.2%) and diesel fuel for tractor operation, 3660.15 MJ/ha (13.5%) were other high resources consumption contributor to cassava cultivation. Other resources input in cassava cultivation such as machinery components (tractor, plough, harrow and ridger) and other mineral fertilizer components (phosphorus and potassium) were minimal, with values of 4.1%, 8.6% and 6.7% respectively. The application of herbicide also contributed substantially to resources consumption in cassava tuber production, 6.9%. The use of labour input which was 3.4% represents a very minute part of resources contribution in the cultivation of the crop.

3.2 Results of energy scenario based on operations involved in cassava tuber production

The result of energy scenario with respect to each of the operations involved in cassava cultivation is presented in table 4. Crop protection operation had the highest percentage of energy used which is 61.80%. This is due to the energy sequestered in the manufacture of fertilizer and herbicide applied in the cassava cultivation. Although manual energy input cut across all the operations involved in terms of operation of machinery, physical application of muscles and control of activities, it represents just 3.42% of the sum of energy used when compared to other energy involved (thermal and sequestered).

Land preparation and planting operation were closely similar in terms of energy consumption, 18.48% and 18.64% respectively. Land preparation made use of thermal, manual and
sequestered energy respectively, while energy equivalent in the cassava stem cuttings was the only component which accounted for the energy used in planting operation.

3.3 Other energetic parameters determined in cassava tuber production
The energy equivalent of cassava tuber output per hectare was 242800 MJ/ha. In Table 5, the results of the energetic parameters determined in cassava tuber production, were; direct energy (diesel fuel and manual energy) 4587.23 MJ/ha (16.9% of total energy input) while indirect energy input was 22540.38 MJ/ha (83.1% of total). This obviously shows that indirect energy which was from sequestered energy in the production of input such as; machinery, chemicals inputs, stem cuttings for cultivation constituted major energy used, and this should be a good target for resources consumption reduction in energy management activities. Energy productivity (EP) which indicated yield per unit of energy input was 1.47 kg/MJ.
| S/No | Operation          | Implement | Labour (man-hr) | Weight of equipment (kg/ha) | Fossil fuel Diesel (L) | Other Resources Used (L, kg) | Output (kg) |
|------|--------------------|-----------|-----------------|-----------------------------|------------------------|----------------------------|--------------|
|      | **Land Preparation** |           |                 |                             |                        |                            |              |
| 1.   | Land Clearing      | Manual    | 80              | -                           |                        |                            |              |
|      | Power source       | Tractor   | -               | 4.2                         | -                      |                            | -            |
|      | for implement      |           |                 |                             |                        |                            |              |
|      | Ploughing          | Disc plough | 4              | 1.67                        | 25                     | -                          | -            |
|      | Harrowing          | Disc Harrow | 3              | 0.67                        | 20                     | -                          | -            |
|      | Ridging            | Disc Ridger | 2              | 1.33                        | 20                     | -                          | -            |
|      | **Total**          |           | 89              | 7.87                        | 65                     | -                          | -            |
| 2.   | **Planting**       | Manual    | 64              | -                           |                        |                            |              |
|      | **Total**          |           | 64              | -                           |                        |                            | 812.5 kg (stem cutting) |
| 3.   | **Crop Protection**| Manual    | 12              | -                           |                        |                            |              |
|      | Pre-emergence Herbicide application | Manual | 8              | -                           | -                      | 4 kg (Primextra)           | -            |
|      | Weeding            | Manual    | 150             | -                           | -                      | -                          | -            |
|      | **Total**          |           | 170             | -                           | (400,4) kg             |                            | -            |
| 4.   | **Harvesting**     | Manual    | 150             | -                           | -                      |                            | 40000kg (cassava Tuber)  |
|      | Harvesting & Packing | Manual | 150             | -                           | -                      | -                          | 40000kg |
|      | **Total**          |           | 150             | -                           | -                      | -                          |              |
Table 2. Energy Equivalent Used for Inputs and Outputs in Cassava Production and their Source

| Item (Input/output) | Unit       | Energy Equivalent (MJ/unit) | Reference                                      |
|---------------------|------------|-----------------------------|------------------------------------------------|
| **Labour**          |            |                             |                                                 |
| Diesel Fuel         | L          | 56.31                       | Ojha and Michael [15]                          |
| Electricity         | kW.hr      | 11.93                       | Ojha and Michael [15]                          |
| Coal                | kg         | 29.60                       |                                                 |
| Firewood            | kg         | 20.50                       |                                                 |
| **Machinery**       |            |                             |                                                 |
| Tractor             | kg         | 138.00                      | Ortiz-Canavate and Hernanz, [16]               |
| Disc Plough         | kg         | 180.00                      | Ortiz-Canavate and Hernanz, [16]               |
| Disc Harrow         | kg         | 149.00                      | Ortiz-Canavate and Hernanz, [16]               |
| Ridger              | kg         | 148.00                      | Ortiz-Canavate and Hernanz, [16]               |
| **Fertilizer**      |            |                             |                                                 |
| Nitrogen            | kg         | 78.11                       | Ortiz-Canavate and Hernanz, [16]               |
| Potassium (K₂O)     | kg         | 13.70                       | Ortiz-Canavate and Hernanz, [16]               |
| Phosphorus (P₂O₅)   | kg         | 17.40                       | Ortiz-Canavate and Hernanz, [16]               |
| **Chemical**        |            |                             |                                                 |
| Herbicide (Atrazine + Metolachor) | kg | 468.00 | Ortiz-Canavate and Hernanz, [16] |
| **Output**          |            |                             |                                                 |
| Cassava root        | kg         | 6.07                        | CIGR                                           |
Table 3. Energy Value of Input used in and Output from Cassava Production per Hectare

| Item                     | Quantity/ha | Energy (MJ/unit) equivalent | Energy value of input (MJ/ha) | %      |
|--------------------------|-------------|----------------------------|------------------------------|--------|
| **INPUT**                |             |                            |                              |        |
| 1. Direct Energy use     |             |                            |                              |        |
| Labour                   | 473 h       | 1.96                       | 927.08                       | 3.4    |
| Diesel                   | 65 L        | 56.31                      | 3660.15                      | 13.5   |
| 2. Indirect Energy       |             |                            |                              |        |
| (a) Machinery            |             |                            |                              |        |
| Tractor                  | 4.2 kg      | 138                        | 579.60                       | 2.1    |
| Plough                   | 1.67 kg     | 180                        | 300.60                       | 1.1    |
| Harrow                   | 0.67 kg     | 149                        | 99.83                        | 0.4    |
| Ridger                   | 1.33 kg     | 148                        | 196.84                       | 0.7    |
| (b) Fertilizer           |             |                            |                              |        |
| Nitrogen                 | 133.33 kg   | 78.1                       | 10413.07                     | 38.4   |
| Phosphorus (P₂O₅)        | 133.33 kg   | 17.4                       | 2319.94                      | 8.6    |
| Potassium (k₂O)          | 133.33 kg   | 13.7                       | 1826.62                      | 6.7    |
| (c) Herbicide            | 4.0 kg      | 468                        | 1872.00                      | 6.9    |
| (Primextra)              |             |                            |                              |        |
| (d) Cassava Stem Cuttings| 812.5 kg    | 6.07                       | 4931.88                      | 18.2   |
| **Total Input**          |             |                            | 27127.61                     | 100    |
| **Output**               |             |                            |                              |        |
| 1. Cassava Tuber         | 40,000 kg   | 6.07                       | 242800                       |        |

Table 4. Total Energy Used in Cassava Production on Operation Basis

| Operation               | Thermal Energy (MJ/ha) | Manual Energy (MJ/ha) | Other Energy Sequestered (MJ/ha) | Total Energy (MJ/ha) | Percentage Energy (%) |
|-------------------------|------------------------|-----------------------|----------------------------------|----------------------|-----------------------|
| **1. Land Preparation**|                        |                       |                                  |                      |                       |
| Machinery Production    | -                      | -                     | 1176.87                          | 1176.87              | 4.34                  |
| Land Clearing           | -                      | 156.80                | -                                | 156.80               | 0.58                  |
| Ploughing               | 1407.75                | 7.84                  | -                                | 1415.59              | 5.22                  |
| Harrowing               | 1126.20                | 5.88                  | -                                | 1132.08              | 4.17                  |
| Ridging                 | 1126.20                | 3.92                  | -                                | 1130.12              | 4.16                  |
| **Total**               | 3660.15                | 174.44                | 1176.87                          | 5011.46              | 18.48                 |
| **2. Planting**         |                        |                       |                                  |                      |                       |
| Planting                | -                      | 125.44                | 4931.88                          | 5057.32              | 18.64                 |
| **Total**               | -                      | 125.44                | 4931.88                          | 5057.32              | 18.64                 |
3. Crop Protection

| Activity                  | Value 1   | Value 2   | Value 3   | Value 4   |
|---------------------------|-----------|-----------|-----------|-----------|
| Fertilizer Application    | 23.52     | -         | 23.52     | 0.09      |
| N                         | -         | -         | 10413.07  | 10413.07  | 38.39 |
| P<sub>2</sub>O<sub>5</sub> | -         | -         | 2319.94   | 2319.94   | 8.55  |
| K<sub>2</sub>O            | -         | -         | 1826.62   | 1826.62   | 6.73  |
| Herbicide Application    | -         | -         | 15.68     | 1872.00   | 6.96  |
| Weeding                  | 294.00    | -         | 1887.68   | 1.08      |
| **Total**                | -         | 333.20    | 16431.63  | 61.80     |

4. Harvesting

| Activity                  | Value 1   | Value 2   | Value 3   | Value 4   |
|---------------------------|-----------|-----------|-----------|-----------|
| Harvesting and packing    | 294.00    | -         | 294.00    | 1.08      |
| **Total**                | -         | 294.00    | 294.00    | 1.08      |

Grand total

| Energy consumed           | 3660.15   | 927.08    | 22540.38  | 27127.61  | 100   |

Percentage used of total energy (%)

|                        | 13.49     | 3.42      | 83.09     | 100       |

Table 5. Other Energetic Parameters in Cassava Production

| Item                        | Value       | %          |
|-----------------------------|-------------|------------|
| Direct Energy               | 4587.23 (MJ/ha) | 16.9      |
| Indirect Energy             | 22540.38 (MJ/ha) | 83.1      |
| Energy Productivity (EP)    | 1.47 (kg/MJ) | -         |
| Energy Ratio (ER)           | 8.95        | -         |
| Specific Energy             | 0.68 (MJ/Kg) | -         |
| Net Energy Gain (NEG)       | 215672.39 (MJ/ha) | -         |
| Renewable Energy            | 5858.96 (MJ/ha) | 21.6      |
| Non-renewable Energy        | 21268.65 (MJ/ha) | 78.4      |
### Table 6. Total Emission Generated During Cassava Production Operation

| Operation          | CO₂     | NOₓ     | SO₂     | CO      | N₂O     | CH₄     | Soil pollution | Water pollution | Air pollution |
|--------------------|---------|---------|---------|---------|---------|---------|----------------|-----------------|--------------|
| LAND PREPARATION   | 7.3200E+03 | 3.2282E-01 | 3.5049E-02 | 3.0253E-01 | 9.2640E-08 | 5.2110E-06 | -              | -               | -            |
| PLANTING           | -       | -       | -       | -       | -       | -       | -              | -               | -            |
| CROP PROTECTION    | 2.5231E+02 | 2.6666E+01 | -       | -       | 2.2713E+02 | 4.8428E+00 | 7.7963E-02 | 3.9545E-03 | 1.3750E-01 |
| HARVESTING         | -       | -       | -       | -       | -       | -       | -              | -               | -            |
| Total Emission     | 7.5723E+03 | 2.6989E+01 | 3.5049E-02 | 3.0253E-01 | 2.713E+02 | 4.8428E+00 | 7.7963E-02 | 3.9545E-03 | 1.3750E-01 |
Table 7. Characterization results for emission in cassava production per hectare

| Environmental Impact Category | Total impact score | Units       |
|-------------------------------|-------------------|-------------|
| Global Warming                | 8.0267E+01        | kg CO₂ equivalent |
| Acidification                 | 1.8892E-02        | kg SO₂ equivalent |
| Eutrophication                | 6.7375E-01        | kg NO₃⁻ equivalent |
| Ozone layer depletion         | 2.9981E-04        | kg RIFC equivalent |

Figure 1. Comparison of the Total Scores of the Selected Impact Categories

This could be improved by reducing the sequestered energy to produce the inputs or increasing the yield of cassava tuber obtained, which confirms what other researchers in energy analysis postulated that, “the output energy should be greater than the input in order to make the system energetically sound” [13]; [14]. A value greater than unity as obtained for cassava production in the study has shown that there is a judicious use of input in the process. The energy ratio (ER) was 8.95; it is an index that shows a positive effect of the resources input on the cassava yield output.
The specific energy (ES) which was 0.68 MJ/kg further elucidate that per kilogram of cassava yield, energy has been efficiently used. Net energy gain (NEG) which represents the balance between the total energy output and energy expended in production per hectare was 215672.39 MJ/ha and this established cassava tuber as an energy crop with high net energy gain (NEG).

The non-renewable energy used was 78.4% of total energy input (21268.63MJ/ha) while renewable energy took the remaining portion of 21.6% (5858.96 MJ/ha). Large portion of non-renewable energy in cassava production demands for a judicious use of resources such as replacing mineral fertilizer with organic/bio fertilizer and thereby cut down on resources depletion.

3.4 Life Cycle Environmental Impact Assessment in Cassava Production

Emission generated from cassava production activities were modeled into selected four environmental impact categories; global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and Ozone layer depletion. Table 6 shows different emission generated per hectare of cassava production. Emissions were generated from land preparation (ploughing, harrowing and ridging) and crop protection operation (fertilizer and herbicide application).

CO₂ was the highest emission generated, which was 7.5723E+03 kg and this was followed by N₂O, NOₓ, CH₄ and CO respectively (2.2713E+02, 2.6989E + 01, 4.8428E+00 and 3.0253E-01kg). Emissions from herbicide contribute mostly to water body pollution. The total impact scores for each environmental group are presented in Table 7 showing global warming potential having the highest score of 8.026E+01 kg CO₂ equivalent, and contributing 92.59% to the total. The operations that contributed to global warming potential were; ploughing, harrowing, ridging and the use of NPK inorganic fertilizer. Ploughing operation has the highest emission contribution to global warming potential representing 36.0%. The high emission generation from ploughing operation was as a result of energy-intensive nature of the task which requires high diesel fuel consumption. This corroborated the submission of Ojha and Michael [15], that primary tillage operation uses more energy for crop production than any other operation, and this has prompted research into finding appropriate and new tillage systems in agricultural activities [16].

Eutrophication contributed next to the total environmental impact after global warming as shown in Fig 1. The percentage contribution was 7.38% which was the result of water pollution caused by run-off from fertilizer, and emission of NOₓ and N₂O. Eutrophication is a process of deposition of excess nutrients in water body environment which leads to algal blooms and anoxia, and makes nearby water not suitable for human and animal consumption, and other industrial uses. Heavy fertilizer application, particularly inorganic fertilizer causes nutrient run-off and percolation to the soil. The polluting nutrient washed into the nearby water leads to eutrophication. The adoption of precision fertilizer application method and controlled use of manure application would reduce eutrophication effect to the minimal.

Acidification and Ozone layer depletion contribution to total impact scores in cassava production were 0.02% and 0.0003% respectively as shown also in Fig.1 Acidification resulted from the emission of NOₓ, which impacts air quality leading to occurrence of acid rain and pollution of the surrounding air. Ozone layer depletion potential was as a result of emission to air and soil from primextra herbicide during crop protection operation for weed control.

4. Conclusion

Findings from the energetic parameter analysis of cassava tuber cultivation in Ogbomoso, Southwest Nigeria has shown that the crop is energetically sound, which means it could produce more energy than consume, with EP value of 1.47 kg/MJ and NEG value of 215672.39 MJ/ha. This further established the crop’s importance as both energy and food crop, which can ensure food security particularly in the third world nations. Therefore, aggressive cultivation and production of cassava tuber is recommended. However, effort should be directed at reducing the use of direct energy in cassava cultivation such as fossil fuel, thereby minimizing the environmental burden caused by the crop production, particularly global warming potential.

Conflict of Interest: The authors hereby declare that they have no conflict of interest.
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