A biomass energy flow chart for Fiji

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Abstract – Terrestrial above ground biomass production and utilization was analyzed for Fiji for the years 2003-2012. The total production of biomass was estimated to be 72.67 PJ of which 24% is from food, 44% of agricultural residues, 10% dung and 22% from forestry. Of the 72.67 PJ biomass produced only 11% was used as fuel, 12% as industrial wood and 24% as food. The unutilized biomass resulted into a loss of 38.5 PJ of energy (44 GJ per capita or 2.56Mt of wood equivalent) which is 53% of the total biomass theoretically produced. Scrutiny of the availability and use of biomass resources is important if biomass energy is to be used on a sustainable basis. Lack of detailed literature in this area in Fiji potentially opens a path for further detailed studies to understand the full contribution of biomass to future sustainable energy supply.

Keywords: Biomass, energy flow, fuelwood, energy, residues, Fiji

1. Introduction

Fiji is a small island nation situated between 177ºE and 178ºW Longitude and 12º to 22º S Latitude in the Pacific comprising of over 300 islands, spread over a land mass of 18,272 km^2. The largest island is Viti Levu, which covers 10,390 km^2, followed by Vanua Levu with 5538 km^2. Together they account for 87 percent of the land area and 90 percent of the population. The larger islands, especially Viti Levu, Vanua Levu, Taveuni, Kadavu and the Lomaiviti group, are quite mountainous and of volcanic origin.

Fiji has 1,827,000 ha of total land area of which 815,000 ha (45%) are forests, approximately 10% is arable, 4% is under permanent crops, 10% is under permanent pastures, and 31% under other land-use categories [1]. Although bagasse has been used as a primary energy source for many years, methodologies for assessing the potential of other sources of biomass energy potential are still developing in Fiji. Sugar production has been an industry in Fiji from 1872 [2] and since then it has played an important role in the country's economy and has been providing biomass (bagasse) energy for all four sugar mills, with surplus electricity production being exported to grid.

From the 769,439 MWh electricity generated nationally in 2008 [3], 66.8% is from renewable energy resources and the other 33.2% is met from imported petroleum for diesel generators. From the renewable energy sources 4.1% is met from biomass which is supported by bagasse and wood chips. Figure 1 below depicts the energy consumption of 41.7 PJ [4] by sector in Fiji and figure 2 shows the electrical energy supported by different sources.

The objective of this research is to assess the biomass potential by means of a biomass energy flow chart. Terrestrial above ground biomass production and usage in Fiji was analyzed for ten years from years 2003-2012 using FAOSTAT-derived data [6] and specific energy values were derived from past work [7-10].

Agriculture, forestry and livestock were three main areas of biomass production under investigation. A total biomass production, available theoretical energy, present utilization level and potential available biomass residue from agriculture and forestry was calculated. All biomass energy flows were followed from its production at source and harvested through to end use and clustered into an end use group such as food, fuel and residues.

2. Methods

2.1. Data Source

The following approach was utilized to estimate the total theoretical biomass available.

- Data on agricultural production (food), forestry removals and livestock production were obtained from FAOSTAT, 2014.

2.2. *Production data (agriculture, livestock and forestry)*

Crop production data consist of annual average for the years 2003-2012 [6]. The data source were verified with other sources to provide more inclusive assessment [11, 12]. Crop residues and by-product were derived using technical coefficient and conversion factors obtained from various sources after verification [7-10, 13-15]. The lack of inclusive field data for Fiji lead to the use of conversion factors and heating values derived from field studies in countries with similar production characteristics.

Annual dung production was established from the livestock population and calculated using coefficients verified using various sources which take into consideration the production of fresh dung per animal, the dry material content and seasonal factors [8, 10, 16]. Livestock population data was derived from FAOSTAT.

Potentially recoverable residues from forestry and agricultural lands used were estimated using the method recommended in literature by [10]. The uncollectable residues were considered where possible including efficiency of collection, however the economics of the process were not considered. Previous literature [10] indicated that only 60% of total above ground wood cut results as commercial stem wood.

The production and the flow of biomass in the form of food, industrial materials, fuel, etc. used the end-use analysis method in which known production values were used to estimate the end use of energy flows.

2.3. *General Assumption*

The assumptions below apply to the entire article unless otherwise stated.

i.) Agricultural crop and above ground biomass production were considered by this research - water surfaces were not included as biomass energy production in this study.

ii.) All roundwood volumes were assumed to be solid with the conversion equivalence of $1m^3$ of solid roundwood = 1.3 tonne [7, 10] iii.) The following energy values (GJ/t air dry, 20% moisture content) assume direct combustion: 1 tonne fuelwood = 15 GJ; 1 tonne of stemwood = 15 GJ; 1 tonne forest and tree harvesting residues = 15 GJ; 1 tonne charcoal = 31 GJ and conversion efficiency of fuelwood to charcoal = 15 % by weight [7, 10].

iv.) The term "end use" refers to the gross biomass energy devoted to specific use such as food, fuel etc.

3. Results

3.1. Primary production established on agriculture, forestry and livestock

3.1.1. Agricultural production (annual crop and residues)

Average annual agricultural production (crop and residue) totaled 6,799,752 tonnes, with a potential energy of 49.1 PJ. The sum of average annual crop production in Fiji excluding residues was about 2,737,139 tonnes (40% of total agricultural production) as represented in table 1 resulting into a potential energy of 17.18 PJ (35% of potential energy for total agricultural production). Sugarcane was by far the most dominant crop in Fiji providing approximately 88% (2.42Mt) of the total crop harvest in terms of mass and approximately 74% (12.8 PJ) in terms of energy potential. Coconut and root & tubers were the second and third largest by comparison having the energy potential of 22% (3.7 PJ) and 2% (0.3PJ) respectively. The sum of average annual crop residue theoretically available as a biomass energy resource represents 60% (4,062,613 tonnes) of total agricultural production. Potential energy from crop residues is around 65% (31.95 PJ) of the total agricultural production as represented in table 1. Sugarcane was by far was the most dominant residue providing 95% (3.8 Mt) of the total residue harvested by mass and 93% (29.8 PJ) of the total energy potential. Fruits and coconuts were the second and third largest by comparison having the energy potential of 3.2% (1.0 PJ) and 2.5% (0.8 PJ) respectively.

3.1.2. Livestock and human (Dung production and energy potential)

Considerable areas are given to livestock for grazing in Fiji due to commercial beef farming and dairy farming but in terms of biomass production, meat and dairy are negligible. Animal and human waste (dung) however theoretically represent a pool of energy which is considerably large and untapped as shown in table 2. This source of energy is mostly ignored for social reasons in favor of wood but the unutilized dung energy is substantial and has a potential to support 7.74 PJ of energy which attracts attention. *Forestry (Woodland production and industrial use category)*

Figure 3 shows the forest production and its end use. Total wood cut was 1,052,544 tonnes with an energy content of 15.78 PJ. Removals include wood cut for fuelwood & charcoal and industrial use which was by mass 621,526 tonnes with an energy content of 9,472,895 PJ. Most of the fuelwood used in the country are from branches, twigs and portions left behind during production process of timber and poles.

3.2. End Use analysis of available biomass

3.2.1. Agricultural crop resources

The total crop resources available is 49.14 PJ which claims 68 % of the total biomass production as represented in figure 4. The harvesting and processing of residues from food and other crops were classified as sugarcane residue and other agricultural residue. The total food production was 17.18 PJ and total available crop residue was 31.95 PJ.

3.2.2. Livestock and human waste (dung)

The dung utilization is very small and largely used for domestic purpose. Some of the uses include farm manure, feedstock for biogas in a digester and combustion for open fire. It is estimated that less than 1 % is utilized for energy production. The energy content for the total dung utilized (<1% as shown in figure 3) is 0.7 PJ assuming direct combustion.

3.2.3. Wood resources

The total wood removed was 9.47 PJ which accounts for 13% of the total wood cut, from which 0.6 PJ was used as fuelwood & charcoal and 8.8 PJ was used as industrial roundwood. It is apparent that from the total wood cut (15.78 PJ) 9% which is 6.3 PJ is lost as a residue often left on site to rot or burnt on site.

4. Discussion

4.1. Biomass energy production (agriculture, livestock and forestry)

The annual biomass energy of 72.67 PJ can be produced from agriculture, livestock and forestry which can be regarded as theoretically available for utilization as shown in figure 3. However, only around 47% of the theoretical available biomass energy is used in the material form such as; fuel, food timber etc. The other 53% is the unused portion is a result of losses during harvesting and processing, charcoal conversion and residue losses from agriculture and forestry. A total of 8.12 PJ of biomass was directly used for energy as presented in figure 3.

The annual estimate per capita consumption of all types of biomass (including food) was 39 GJ which is equivalent to 2.6 tonnes of wood, though a total of 83 GJ (5.5 t of wood equivalent) of biomass per capita was theoretically available as shown in figure 3. The estimate of 2012 population figure of 875,000 was used to calculate the per capita energy consumption.

Sugarcane residue comprises of 41% of the total biomass energy theoretically available from harvesting (figure 3) while wood comprises of 22%, Dung 10% and other agricultural crop residue comprises 3% as represented in figures 3 and 4. Sugarcane residues by far is the most promising source of energy theoretically available with an energy content of 29 PJ which is 69% of the total energy consumed in 2004.

4.1.1. Utilization of biomass energy

The national annual fuelwood consumption was 0.63 GJ per capita from this study. However the national consumption of biomass directly as fuel was 9.28 GJ per capita which is equivalent to 0.61 tonnes of wood. Previous study carried by [17] suggest that 54% of the rural population uses wood and wood residues as important fuel sources in Fiji. An increase on the usage of fossil fuels and hydropower by urban and semi-urban areas was noted significantly but it is assumed that fuelwood consumption in rural areas has been underestimated.

Sugarcane bagasse is by far the most promising source of biomass energy in Fiji currently utilized meeting the energy requirement of 4 sugar mills and the surplus on grid electricity. An average of 726,480 tonnes of bagasse is utilized annually to generate 6.7 PJ of energy. Dung is mostly utilized in biogas digesters for producing biogas as a fuel for cooking and lighting with the resulting digestate being used as a soil improver or food for milkfish production. However, despite many successful demonstration projects the technology is not yet widely used and only less than 1% (0.72 PJ) of available potential is utilized.

4.2. Losses

The total losses account for 53% of the theoretically available total biomass. The energy content in the losses amounts to 38.5 PJ as shown in figure 3. The losses can be categorized as conversion losses and unutilized residues. The conversion losses are 6.3 PJ which is lost during harvesting and processing of roundwood. Dung and agricultural residues are unutilized biomass resulting into loss of 7 PJ and 25.18 PJ energy respectively.

4.3. Opportunity for improved utilization

4.3.1. Residues and dung

The total of annual production of agricultural residues and dung per capita was 8.8 GJ and 36 GJ respectively. Only 9.38% (0.92 PJ) dung and 21% (6.7 PJ) agricultural residue was utilized which is very low. If dung and agricultural residue alone is considered as a fuel, they together can provide 37.5 PJ of energy which is equivalent to 2.6 Mt of wood if their total production is utilized. Currently dung and agricultural residue provide 7.4 PJ of energy.

The recoverable forestry residue theoretically available is 6.31 PJ which is equivalent to 421,017 tonnes of wood. The recoverable forestry residue and agricultural residue together have 31.50 PJ of energy (36 GJ per capita which are either recycled in the land or burnt) form a major potential energy source. It is common practice to burn theses residues on site inefficiently to clear the area.

4.3.2. Conversion and utilization losses

Many losses occur as a result of low conversion and appliance efficiency. Efforts towards efficiency gain should be the priority during the complete utilization chain from harvesting through to end usage. In the case of burning wood in open fire for cooking and burning wood in improved plancha (wood stove), previous study [18] suggest that 40% of the wood can be saved in improved plancha. Studies carried out by Karekezi and Walubengo in ref. [9] also states that open fire is only about 10% efficient.

Therefore if the total wood harvested (removals) excluding residues which has 9.47 PJ on energy is burnt in open fire, considering the 10% efficiency only 0.95 PJ will be effectively used or approximately 252,610 tonnes of additional wood will be required to generate 9.47 PJ of energy when comparing open fire and improved wood stove.

5. Conclusion

This study shows that largest use of biomass in Fiji by far is as food source, followed by industrial wood and bagasse. It has also been highlighted that biomass energy sources are underutilized such as agricultural & forestry residues and dung. There are significant opportunities to increase the use of all types of residues with the use of efficient collection and conversion methods.

There are many factors which govern the choice of biofuels as it highly depends on the conversion technologies. For many rural households, factors such as income level and availability of fuelwood has a direct impact. In many areas where users of fuelwood is high, households face fuelwood scarcity. Therefore switch to crop residue or dung from fuelwood may result into lack of choice for better fuel due to unavailability of improved technology.

Strategies to improve the technology for the efficient use of dung and agricultural residue may address the problem of underutilization.

With careful planning at national and local level, the biomass energy can become highly important for the Fiji's biomass energy sector. The utilization of sugarcane residues by mills will boost the energy generation and can be exported to grid electricity which can contribute in the reduction in the use of petroleum to generate the same energy. Comparing the studies of Fiji's biomass energy sector with other studies, [7-9, 13], the methodology used appears to be correct. The biomass flow chart constructed identifies potential biomass which are not utilized and provides perspective of the present role of biomass system in meeting the requirements sustainably.

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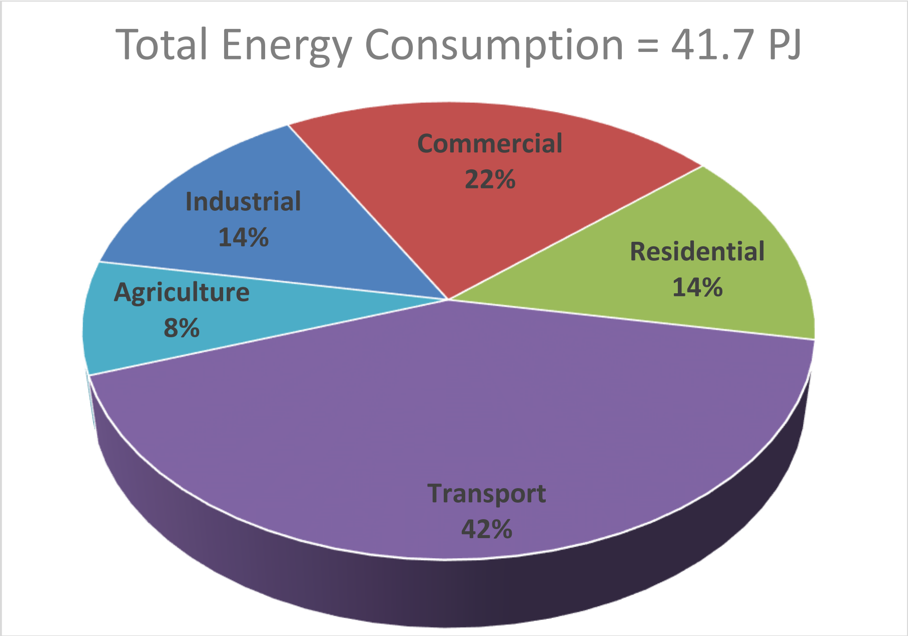


Figure 1: Energy consumption by sector [5]

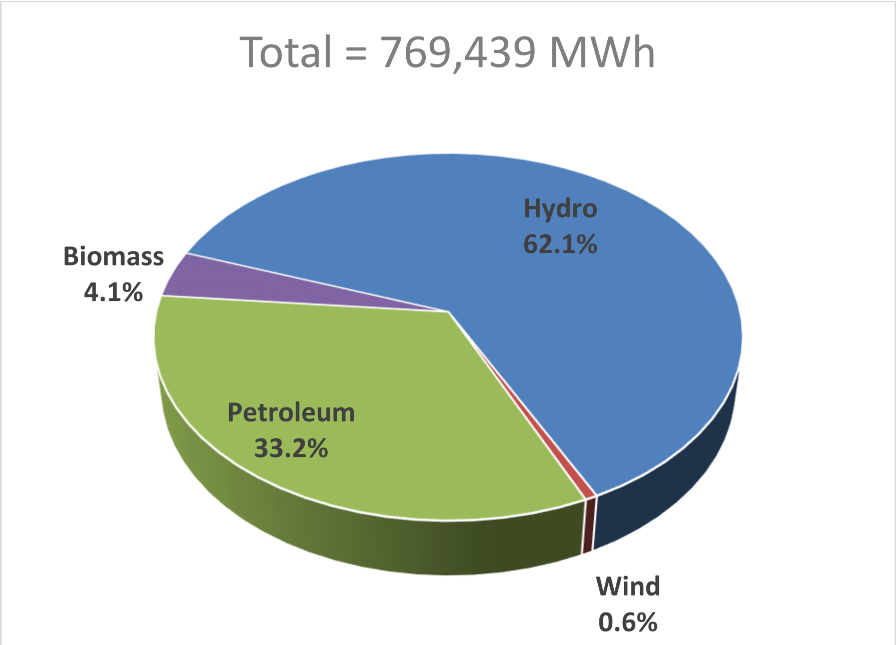
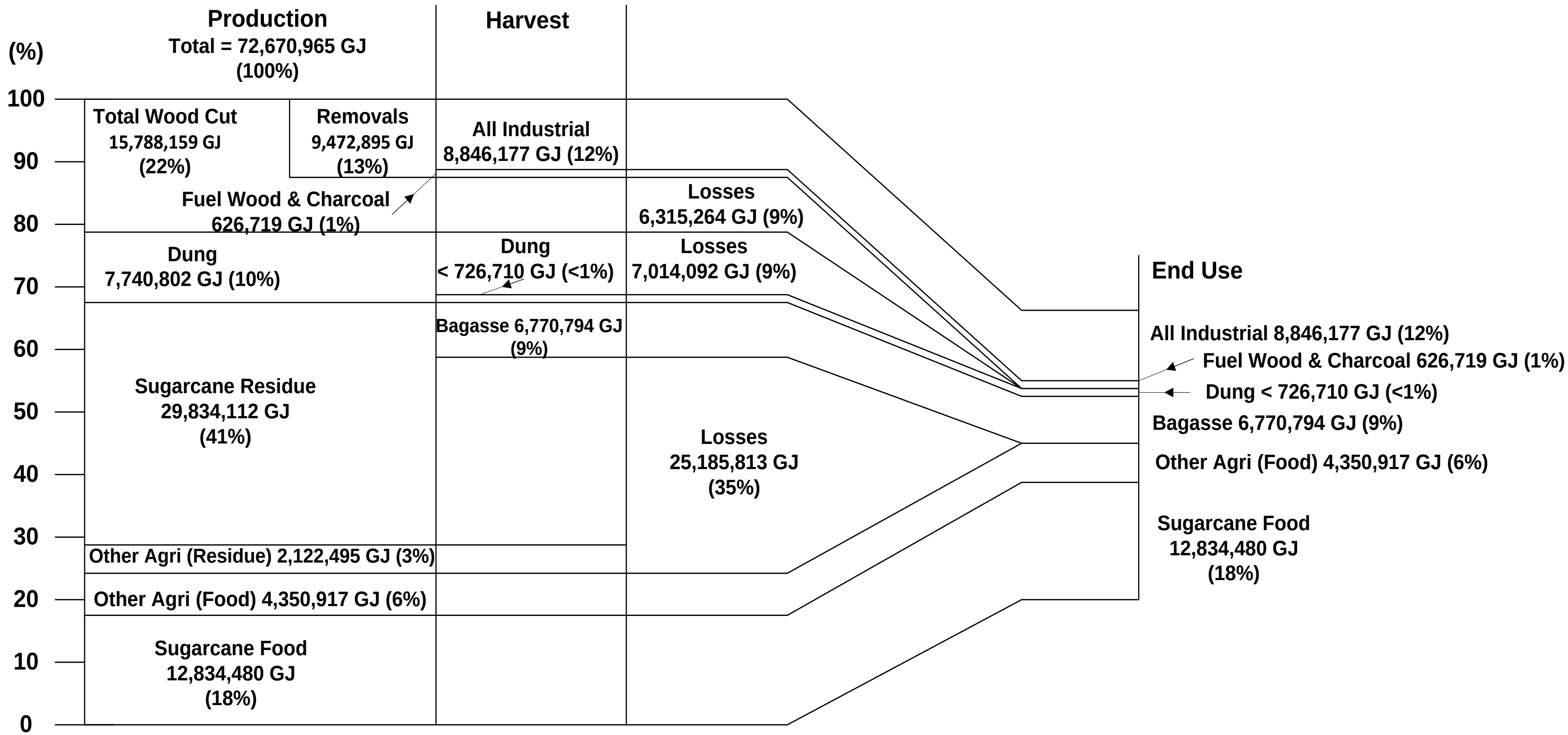


Figure 2: Electrical energy supported by different sources [3]



Based on annual average (2003-2012) FAOSTAT (www.fao.org)

The scale is based on the total biomass harvested in agriculture and forestry.

Figures in parenthesis indicate % total production

PJ = 10^{15} J = 10^{6} GJ

Total may not add up due to rounding

Figure 3: Biomass energy flow chart for Fiji

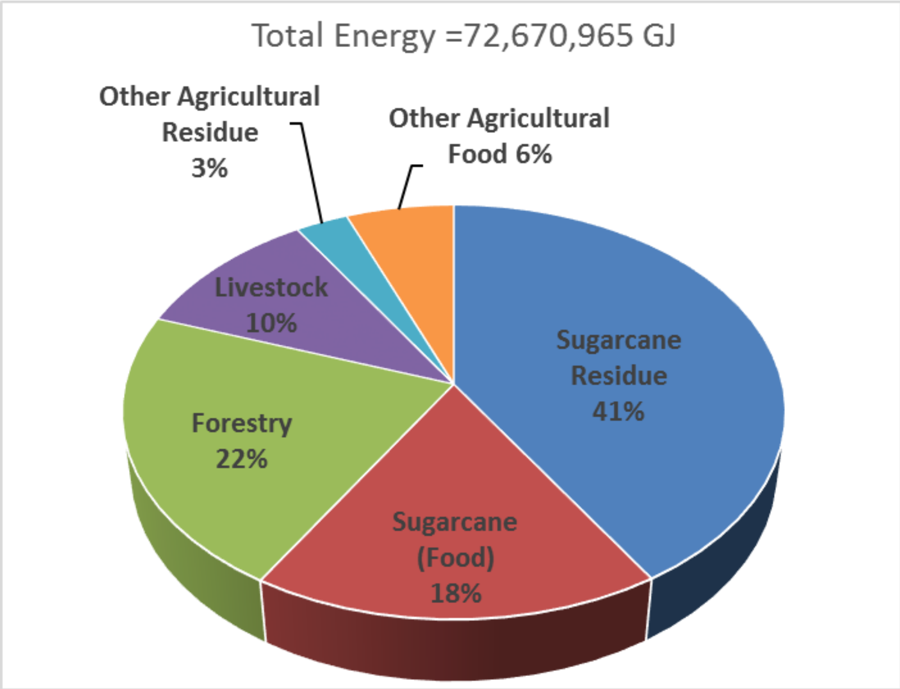


Figure 4: Average annual biomass energy theoretically available

Table 1: Annual average crop production, estimated crop residue and energy potential (2003-2012)

Crop Category	Average 10 yr annual production (tonnes)	Crop energy content (GJ/Ton)	Annual crop energy potential (GJ)	Waste factor	Average annual residue (tonnes)	Residue energy content (GJ/T)	Annual residue energy (GJ)	Total energy potential (Crop + Residue) (GJ)
Fruits	39,198	3.2	125,433	2.0	78,396	13.1	1,026,985	1,152,418
Vegetables	18,483	3.2	59,144	1.0	18,483	6.0	110,896	170,040
Maize	796	14.7	11,703	1.4	1,115	13.0	14,489	26,192
Groundnuts, with shell	252	25.0	6,305	2.1	530	16.0	8,474	14,779
Coconuts	189,125	20.0	3,782,500	0.3	62,411	13.0	811,346	4,593,846
Roots and Tubers	64,645	5.5	355,550	0.4	25,858	5.5	142,220	497,770
Sorghum	29	14.7	423	1.4	40	13.0	524	948
Sugar cane	2,421,600	5.3	12,834,480	1.6	3,874,560	7.7	29,834,112	42,668,592
Cocoa, beans	13	16.0	200	1.0	13	15.4	193	393
Coffee, green	15	7.6	112	1.0	15	14.2	209	320
Ginger	2,983	3.2	9,547	0.4	1,193	6.0	7,160	16,707

Production figures were obtained from FAOSTAT [6] and waste factor and energy content values were obtained from Refs. [7-10]. Roots and Tubers consist of potatoes, sweet potatoes, cassava and yams. Average annual residue = 10 Yr average annual production x waste factor.

Table 2: Livestock and human population, dung production and energy potential (2003-2012)

Stock	Average annual population (Heads)	Dung Production (Kg/Head/day)	Average Annual Dung (Tonnes)	Energy Content (GJ/Ton)	Annual Dung Energy Content (GJ)
Cattle	310,500	1.80	203,999	18.50	3,773,972
Chicken	4,420,000	0.06	96,798	11.00	1,064,778
Ducks	82,700	0.06	1,811	11.00	19,922
Goats	250,695	0.40	36,601	14.00	512,421
Horses	45,300	3.00	49,604	11.00	545,639
Pigs	143,110	0.80	41,788	11.00	459,669
Sheep	5,865	0.40	856	14.00	11,988
Humans	842,100	0.40	122,947	11.00	1,352,413

Stock production figures were obtained from FAOSTAT [6]. Dung production and energy content were obtained from Refs: [8, 10, 16]