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Biomass Conversion to Energy in Tanzania: A Critique

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1. Introduction

The United Republic of Tanzania (URT) is the largest country in East Africa in terms of size and population. It is made up by Tanzania Mainland and the island of Zanzibar. It is bordered by the Democratic Republic of Congo, Rwanda and Burundi in the west; Zambia, Malawi and Mozambique in the Southern part, Uganda and Kenya in the Northern side and the Indian Ocean on the East. The country lies between meridians 30°E and 40°E and parallels 1°S and 12°S.

It has an area of 945,000 Square Kilometres. While about 62,000 square Kilometres of the land is covered by water, including three fresh trans-boundary lakes of Victoria, Tanganyika and Nyasa. Woodlands accounts for 33,500 square Kilometres [1] and arable land suitable for agriculture is concentrated in central part and Southern Highlands of the country, covering about 44 million hectares.

According to URT, Economic survey report 2009 [2], the Tanzanian population was estimated to be 41,915,799 of which 21,311,150, that is about 50.8 percent, were female, while 20,604,730 about 49.2 percent were male. Tanzania mainland had an estimated population of 40,683,294, while Zanzibar had an estimated population of 1,232,505. The population distribution indicated that 31,143,439 of people, about 74.3 percent live in rural areas, while 10,772,360 people about 25.7 percent live in urban areas. These estimates are based on the population growth rate of 2.9 percent per annum established out of the Population and Housing Census of the years 2002. [3]

Hydropower, Coal and Petroleum are Tanzania's main source of commercial energy. However, solid biomass energy such as agro residue, forestry residue and wood fuels are used throughout the country and they account for 88 percent of total energy consumption in rural and semi-urban areas [4] while modern commercial energy contribute about 2 percent. Of

the 24 mainland regions, Dar es Salaam region has the greatest access to electricity; however, less than 50 percent of all households in the regions are connected.

The conventional energy sector, and in particular the electricity sector has not lived up to expectations of the Tanzanians. The sector is mainly characterized, among other problems, by unreliability power supply, low access levels at about 15% [5] low capacity utilization and availability factor; deficient maintenance of generation transmission facilities and equipment; poor procurement of spare parts due to liquidity problems; and high transmission and distribution losses at 20% [6] are typical problems.

Provision of electricity is largely confined to urban middle and upper income groups as well as the formal commercial and industrial sub-sector. At the moment the energy sector is characterized by large and increasing import of liquid petroleum products, which account for significant proportions of export earnings. Liquid petroleum is used in electricity generation and in the transport sector. The transport sector is the major consumer of liquid petroleum product accounting to about 60% of total consumption. The high liquid petroleum products import bill expose the country's energy sector to the external energy price shocks. Renewable energy such as ethanol would assist in mitigating the negative impact of high liquid petroleum fuel imports

Tanzania is endowed with substantial renewable energy resources [4]. The renewable resource potential in the country has not been fully exploited, but only to limited investment level;. Rural Energy Agency (REA) is making initiatives to disseminate information as the importance of renewable energy in the energy balance of the country. In addition, technical and financial barriers have contributed to the low levels of uptake of Renewable Energy Technologies (RETs) in the country. However, these constrains are being addressed by REA.

2. The Introduction and the Problem

The objective of this chapter is to discuss the potential and implementation of biomass conversion to energy in Tanzania. Generally, the feasibility as well as suitability of the various categories of biomass to energy conversions in the country is presented. Detailed descriptions of potential conversion routes are included with their possible and existing scope of implementation. The most recent statistical data of food, commercial agricultural crops as source of biomass energy are reported from the available sources. Tanzania has abundant and diverse indigenous energy resources which are yet to be fully exploited. The sources include; hydropower, mini-hydro, natural gas, coal, petroleum, wind, solar, and geothermal.

2.1. Hydropower sources

The generation capacity of electricity was on a 60:40 hydro/thermal proportion before 2005. Following introduction and expanded use of natural gas usage in power generation, the hydro-thermal mix is now standing at 41:59 (including the emergency plants).Up to June 2012, electricity installed capacity is about 1,375.74 [7]of which represent about 41 percent is from hydropower sources. The other percentage is from thermal and oil.

Out of Tanzania's 41.9 million inhabitants, so far only 14 percent of urban and 2 percent of rural areas are electrified [5], which means that less than 12 percent have access to grid-based electricity or other forms of commercial electricity. The national electricity connectivity is about 14%; though, it is expected that electricity demand will triple by 2020[8]. On the supply side, TANESCO increased connections by almost 66,000 in 2010 bringing the total number of its customers to 868,953 by the end of 2010. REA currently (2011) implements grid extension projects initially benefitting 20,000 new customers [9]. In the current setting demand will therefore even more outpace supply.

Moreover, Tanzania's electricity sector faces another important challenge since it is heavily dependent on hydropower, which means that energy provision cannot be ascertained in times of drought. This was clearly visible in the years 2010/2011, where re-curing droughts effectively removed around 420 MW from a system of around 900 MW, forcing the country to endure a programme of load shedding coupled with unplanned outages. With consequently suppressed sales the country's utility TANESCO financial situation became increasingly parlous (on top of economic losses for non-productivity to the country as a whole).

This led to the design of an 572 MW Emergency Power Plan at the end of 2011, to be fully fuelled by liquid fossil fuels (HFO, JetA1, diesel) at (fuel) costs varying from 30-43 ct/kWh. These are to be financed by TANESCO tariff revenues and through government guaranteed loans, leading to an increasing weaker financial position of TANESCO. There is quite some critique on the EPP because it does not take into account planned natural gas supply projects, dispersed capacity owned by the private sector, and power projects to be commissioned already in the short and medium term. In general there is a disconnect between expected power demand (both unconstrained -1089 MW- and constrained) and the total generation capacity (1855 MW) proposed by the EPP.[9]

2.2. Micro/Mini-hydro

It is estimated that 32 GWh per year [10] is generated from smaller systems, many of which are private schemes run by religious missionaries. The potential for micro/mini-hydro is large [4]; however, exploitation is still low because of barriers hindering full exploitation of these potentials.

2.3. Natural Gas

Tanzania has so far made five onshore and shallow water discoveries of natural gas fields in the vicinity of SongoSongo Island, Mnazi bay, Mkuranga, Kiliwani North and Nyuni. Out of the five discoveries, only two gas fields, SongoSongo and Mnazi bay are producing. Mkuranga and Nyuni gas fields have not been assessed. It is estimated that about 27 trillion [11] cubic feet gas is available in the country. Natural gas is expected to become a reliable and economical source of energy to replace petroleum in the near future.

2.4. Coal

Coal reserves in Tanzania are estimated at about 1,200 million tonnes of which 304 million tonnes are proven [12]. Coal sites include Kiwira, Mchuchuma/Katewaka on the south east of Lake Nyasa, and Ngaka in Ruvuma region. Coal has been used in limited quantities for electricity generation as well as in some industries such as cement factories. Low coal consumption in the country is due to part to huge investment costs and quality of the coal itself. However, there is a plan to generate 600 MW from Mchuchuma coal mine in the near future.

2.5. Petroleum

Imported petroleum and related products are widely used in the transport and industrial sector. It also used to generate electricity in isolated grid-diesel power stations that have and installed capacity of 33.8 MW [10]. Petroleum and related by-products are imported by a single company and regulated by EWURA, which controls the price and standard.

2.6. Wind

Based on the available information much of the wind resources in Tanzania is located in the central part of the country, North-East part, and Southern part [4]. Currently wind energy is used to pump water for irrigation and to meet domestic and livestock water needs [10]. Very limited number of attempts has been made to install wind turbine for electricity generation. However, efforts are underway to utilize wind energy in electricity generation. Several companies like Geo-Wind Power (T) limited, Wind East Africa/ Six Telecoms, and Sino-Tanzania Renewable Energy Limited have been licenced to generate electricity of about 500 MW from wind [7].

2.7. Solar

Solar has not been utilized fully as energy sources even though the country being one of the solar belts, that is being a county with 2800-3500 hours of sunshine per year and a global radiation of 4-7 kWh/m² per day. Despite the huge solar potential, solar energy has predominately been used only for drying process. In the recent years solar PV technology has been promoted as an energy solution especially in rural areas where there is no access to the national grid. It is anticipated that in the near future, solar as a source of energy will play a great role in rural electrification.

2.8. Geothermal

The country is endowed with a huge geothermal potential, which has not yet exploited [13]. Geothermal power is a reliable, low-cost, environmental friendly, alternative energy supply, indigenous, renewable energy source and suitable for electricity generation. Estimations by analogue method [14] show that the geothermal potential in the country is about 650 MW of which most of the prospects are located within the East African Rift Valley system. Geothermal resource exploitation is a capital intensive investment; hence, private investment is not expected to come in before obtaining detail information on the resources, particularly on

their economic viability as potential geothermal energy resource. It is anticipated that the country in order to move from surface assessments to further detailed investigation, public and donor fund will be required.

Other energy sources are petroleum, which makes up 8 percent of total primary energy consumption, natural gas 2.4 percent, and hydropower 1.2 percent. About 6.6 percent of primary energy needs to be imported, primarily from Uganda (8 MW) and Zambia (5 MW) [15]

2.9. Wood fuel and other biomass fuels

Tanzania's energy supply depends mainly on biomass. Since 85-88 percent of the population are not connected to the electricity grid, the overwhelming majority of households use fire wood and charcoal for cooking. As a total, biomass makes up to 88 percent [4] of the total primary energy consumption in Tanzania. Unfortunately, this leads to the deforestation of 100,000 ha per year, of which is very serious since only about a quarter of the Tanzanian land is re-forested

About 50% of the population lives in poverty, out of which 35% is unable to access all of the basic needs including energy services. The poor spend about 35% of their household income on energy while the well-off spends only 14%. Lack of access to modern energy services creates a vicious cycle of poverty for rural communities due to continued limited production opportunities and social facilities. This situation creates a very big challenge to the country. There is a need; to look for an alternative means for assisting the rural poor to have opportunities of accessing to modern energy for reason of alleviating poverty. This chapter is proposing biomass to be one of the alternatives of energy resource which can be employed in modern form to change the situation.

3. Literature review

Biomass is a term used to define all organic matter that is derived from plants as well as animals. Biomass resources include wood and wood waste, agricultural crops and their waste products, municipal and city solid waste, and wastes from food processing, aquatic plants and algae.

Biomass is mainly composed of cellulose suitability of a particular biomass as a potential for energy generation depends on such characteristic; moisture content, calorific value, fixed carbon, oxygen, hydrogen, nitrogen volatiles, as contents, and cellulose/lignin ratio. Generally, cellulose is the largest fraction and constitutes about 38-50% of the biomass by weight. These characteristics are important to determine efficient biomass utilization and are provided in the paper.

Biomass is considered to be one of the key renewable energy resources of the future at both small- and large-scale levels. It already supplies 14 per cent of the world's energy, and if many future projects being assessed, could be implemented, increase the role of biomass in the overall energy system. On average, biomass produces 38 per cent of the primary energy

in developing countries (90 per cent in some countries), where it is the largest single energy source like Tanzania. Biomass energy is likely to remain an important global energy source in the next century

Biomass is generally and wrongly regarded as a low-status fuel, and rarely finds its way into energy statistics. Nevertheless, biomass can lay claim to being considered as a renewable equivalent to fossil fuels. It offers considerable flexibility of fuel supply due to the range and diversity of fuels which can be produced. It can be converted into liquid and gaseous fuels and to electricity via gas turbines; it can also serve as a feedstock for direct combustion in modern devices, ranging from very-small-scale domestic boilers to multi-megawatt size power plants.

Biomass-energy systems can increase the energy available for economic development without contributing to the greenhouse effect since it is not a net emitter of CO_2 to the atmosphere when it is produced and used sustainably. It also has other benign environmental attributes such as lower sulphur and NO_x emissions and can help rehabilitate degraded lands.

Despite its wide use, biomass is usually used so inefficiently like firewood (Figure 1) that only a small percentage of useful energy is obtained. The overall energy efficiency in traditional use is only about 5-15 per cent, and biomass is often less convenient to use compared with fossil fuels. It can also be a health hazard in some circumstances; for example, cooking stoves can release particulates, CO , NO_x , formaldehyde, and other organic compounds in poorly-ventilated homes. Furthermore, the traditional uses of biomass energy, i.e., burning fuel wood, animal dung and crop residues, are often associated with the increasing scarcity of hand-gathered wood, nutrient depletion, and the problems of deforestation and desertification



Figure 1. Women carrying firewood in rural Tanzania



Figure 2. Biomass heaps (bagasse) in rural areas

There is an enormous biomass potential in the country such (Figure 2) as bagasse that can be tapped by improving the utilization of existing resources and by increasing plant productivity. Bioenergy can be modernized through the application of advanced technology to convert raw biomass into modern, easy-to-use energy carriers (such as electricity, liquid or gaseous fuels, or processed solid fuels). Therefore, much more useful energy could be extracted from biomass. The present lack of access to convenient energy sources limits the quality of life of millions of people, particularly in rural areas. Since biomass is a single most important energy resource in these areas its use should be enhanced to provide for increasing energy needs. Growing biomass is a rural, labour-intensive activity, and can, therefore, create jobs in rural areas and help to reduce rural-to-urban migration, whilst, at the same time, providing convenient energy carriers to help promote other rural industries.

Enhanced biomass availability on a sustainable basis requires support and development of new biomass systems in which production, conversion and utilization are performed efficiently in an environmentally sustainable manner. Efforts to modernize biomass energy should concentrate on those applications for which there are favorable prospects of rapid market development, e.g., biogas, the generation of electricity from residues and biomass plantations through the gasifier/dual-fuel engines route or using advanced gas turbines fired by gasified biomass, and the production of alcohol fuels from sugarcane.

4. Methodology

The methodology used towards accomplishing the project on biomass conversion to energy in Tanzania involved analytical approach, data collection, and analysis.

4.1. Analytical approach

A comprehensive study and review of documents relevant to biomass resources, conversion and application in the country, and other African countries, Asia, Latino America, United States of America (USA), Europe, the Middle East and China were made. The aims of the study were to find available and valuable information on the subject. In addition, situation analysis and brain storming on application of biomass, conversion methods with biomass entrepreneurs were discussed.

4.2. Data collection and analysis

Questionnaires were prepared and used in data collection. Interviews were held with leaders at the Regional, City, municipal, wards and subward levels on biomass conversion to modern energy instead of using raw biomass. Interviewees at this level were held with, Mayors, Municipal Directors, and City and Municipal Solid Waste Management experts from all the city councils. Others included relevant Ministries of Health, Lands and Human Settlements Development and Industries. The interviews were undertaken during day times in weekdays and weekends. Interviews were conducted in a tranquil and friendly atmosphere. The information disclosed by the interviewees was treated as confidential.

5. Results

The following findings were obtained from the analytical approach and the interviews:

5.1. Biomass potential

5.1.1. Agricultural biomass

Agriculture is the mainstay of the economy; it employs about 80% of the work force and account for over 50% of gross domestic product (GDP) at factor cost and over 50% of foreign exchange earnings. It is also the major source of food supply and raw materials for industrial sector. Furthermore, it provides the market for industrial sector. Agricultural sector development has been undertaken with the objective of increasing production of food and cash crops in order to improve food security generate and raise income levels to alleviate poverty. Major food crops cultivated in the country include maize, rice, sorghum, cassava, groundnuts, cowpeas, banana, soya beans and sweet potatoes. A part from food crops, commercial crops cultivated include: cotton, sisal, coffee, coconut pineapples, palm oil, cocoa, sugarcane about 80% of farms in the country are less than 2 % owned by small scale holders. All of these crops contribute to biomass potential in the country.

5.1.1.1. Cash crops

Production of main cash crops has been fluctuating depending on whether conditions, availability and usage of agricultural inputs and fluctuation in the World Market. Table 1 gives the trend of cash crops produced in the past 4 years.

CROP	YEARS			
	2006	2007	2008	2009
Cotton	130,565,000	199,954,000	200,662,000	267,004,200
Tobacco	50,617,400	50,784,000	55,356,000	60,990,000
Sugar	290,863,000	279,494,000	276,605,000	279,850,000
Tea	31,348,000	34,763,000	34,770,000	33,160,000
Pyrethrum	2,046,800	1,000,000	1,500,000	3,320,000
Coffee	1,049,900	33,708,000	58,053,000	40,000,000
Sisal	30,847,000	33,039,000	33,000,000	26,363,000
Cashew nut	88,213,000	92,573,000	99,017,000	74,169,000

Table 1. Production of Cash crops in kg (Source: Ministry of Agriculture and Cooperatives (URT))

5.1.1.2. Food Crops

Production of main food crops has been fluctuating depending on whether conditions, availability and usage of agricultural inputs and fluctuation in the World Market. Table 2 gives the trend of food crops produced in the past 4 years.

CROP	YEARS			
	2006	2007	2008	2009
Maize	2,423,000	3,302,000	3,555,000	3,324,200
Rice	805,400	872,000	875,000	885,610
Wheat	109,500	83,000	92,000	93,690
Millet	941,500	1,165,000	1,064,000	203,580
Cassava	2,052,800	1,733,000	1,797,000	1,758,790
Beans	1,049,900	1,156,000	1,125,000	1,183,880
Banana	1,169,200	1,027,000	982,000	990,540
Sweet potato	1,396,400	1,322,000	1,379,000	1,381,120

Table 2. Production of food crops in kg (Source: Ministry of Agriculture and Cooperatives (URT))

5.1.1.3. Oilseed crops

Production of various important oil seeds such as Simsim, groundnuts, sunflower, palm oil and soya for food and *Jatropha* for petroleum producing continued to be emphasized. Already a policy on *Jatropha* production for biofuel is in place [4]. Table 3 gives production of oil seed crops for the past 5 years.

CROP	YEARS			
	2006	2007	2008	2009
Sunflower	373,391,000	369,803,000	418,317,000	466,831,000
Groundnuts	783,775,000	408,058,000	396,769,000	385,480,000
Simsim	221,421,000	155,794,000	46,767,000	115,895,000
Soya	5,000,000	3,000,000	3,450,000	3,900,000

Table 3. Production of oilseed crops

There are factors, which determine whether a crop is suitable for energy use. The main material of interest during processing as an energy source relate to moisture contents, calorific value, proportions of fixed carbon dioxide and volatiles, ash content, alkali metal content and cellulose-to-lignin ratio.

5.1.2. Agriculture crop residues

A large amount of agricultural residues are produced in the country. These constitute a potential biomass feedstock for energy conversion. Generally agricultural residue is used to describe all organic materials which are produced as by-product from the harvesting or processing of agricultural crops. These residues can be further categorized into two groups. The first group consisting of the residues which are generated in the field at the time of harvest or field based residues such as rice straw, sugar cane tops etc.

The second group is of those residues that are co-produced during processing or well known as processing based residues e.g. rice husk, cashewnut husk, coffee husk, bagasse, etc. the availability of the first category residue for energy conversion or application is usually low since collection is difficult and they have other uses as fertilizer, animal feeds, etc. Experience has shown that most of the first category residues are left or burnt in the farms. However, the secondary category residues are usually available in relatively large quantities at the processing site or mill and may be used as captive energy source for the same processing mill involving no or little transportation and handling costs. Figure 3 gives selected agricultural residue estimated potential in the country.

These residues have a high potential for energy production and therefore contribute to the energy balance of the country. Major residues generated from harvesting and processing of maize/corn is potential biofuel feedstock. Similarly, the stalk of sorghum which is rich in

sugar is a potential feedstock for ethanol production. Figures 4-7 show some of the crops and their corresponding residues available in the country at the moment

Oil palm plantations can be found in Kigoma Region, along the shore of Lake Tanganyika, Western Tanzania. There are three main residues from oil palm processing, namely: empty fruit bunches, shells (Figure 5) and fronds. Empty fruit, bunches are rich in potassium and they can be used as fertilizer. The shells can be used for production of carbon and heating. The fronds are usually used for mulching.

Coffee production in the country is increasing. The husk (Figure 6), which is the main residue generated during processing, can be utilized as an organic fertilizer as well as a source of energy. When compressed it can be used in modern energy generation; at the moment coffee husks are disposed by burning.

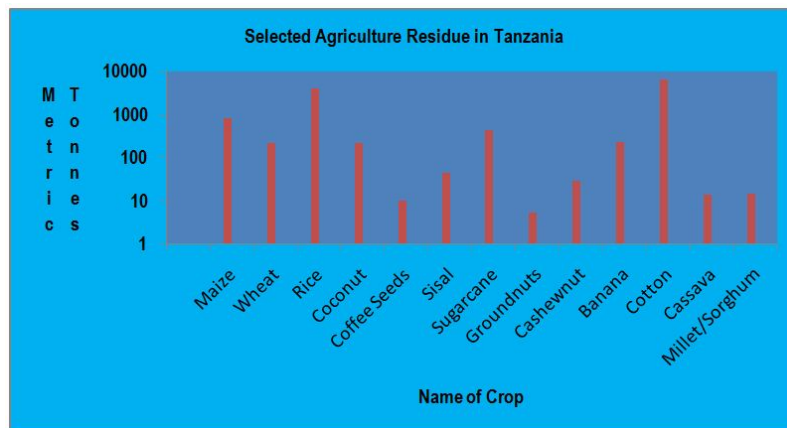


Figure 3. Selected agriculture residue potential in Tanzania (Source: National Bureau of Statistics, 2006)



Figure 4. Rice husk (Crop residue)



Figure 5. Palm Oil Shell



Figure 6. Coffee husk (Source of energy)



Figure 7. Coconut shells

The residue from coconut harvestings are mainly the husk and shells. These residues (Figure 7) are a potential source of energy generation. Large plantation of coconut tree can be seen in the coastal area of Tanzania and in Zanzibar

The main residues generated from harvesting and processing sugarcane namely, the tops, baggase and molasses are also sources of energy. However, only bagasse is utilized in co-generation of electricity. The tops and molasses are underutilized even though they are potential source of energy. Biomass contains sugars that are deemed uneconomical to remove. The recent and development in technology can assist in reducing sugar concentrate and hence the residue can be potential source of energy generation.

Rice husk is underutilized, efforts are underway to use rice husk in briquette production. At the moment rice husk are used by brick makers to burn their bricks. Moving across the country in particularly in rice growing areas, large amount of rice husk are seen unutilized. Rice straws are virtually unutilized and could serve as major source of energy in the country.

During harvesting period, most of agricultural residues are burnt on the farms to facilitate the harvesting process or as pest a control measure e.g. cotton some of the residues are also used as a substitute for firewood. However, at the moment there is no adequate information about the share of the agricultural residue in modern energy generation.

5.1.3. Residue chemical composition

Residue chemical composition of some of the agriculture residue was analysed, and the aim of the analysis was to establish if these residues have the characteristics as feedstock for conversion to usable energy using gasification method. The chemical compositions used in the analysis were: proximate analysis (%) dry basis, ultimate analysis (%) dry basis and heating value. Tables 4, 5 and 6 give the proximate, ultimate analyses and higher heating values.

Other agro-residues: Cotton stalks, cassava stalks and straws are mainly used as local fuels in rural areas. Besides, the residues can be used in production of ethanol. Table 7 gives cellulose, Hemicelluloses, lignin and theatrical yield (litres/tones) from some of agro-residue.

Experience gained from agriculture sector, particularly agricultural activities show that the agricultural crops generate considerable amount of residue which can be harnessed for modern energy generation. Annual evaluation of total amount of residue that originates from agricultural activities (Figure 3) is about 13 million tonnes; residues with higher potential for modern energy generation are:

- Maize stalk and straw about 8 million tones
- Rice husk and straw about 4.1 million tones
- Wheat straw about 232,400 tonnes
- Sisal tole and flume 46,080 tonnes
- Bagasse is 447,030 tonnes

Condition	Residue type								
	Rice husk	Rice Bran	Coffee husk	Sisal leaf	Sisal pole	Sisal boles	Palm branch	Palm Stem	Sugarcane Bagasse
Moisture	8.80	7.80	10.10	8.50	10.10	7.50	8.10	9.10	9.00
Volatile Matter	59.20	64.60	83.20	80.20	79.30	84.10	79.60	81.20	75.8
Fixed Carbon	14.60	14.20	14.30	12.60	14.60	12.80	12.60	15.30	20.1
Ash Content	26.20	21.20	2.50	7.20	6.10	3.10	7.80	3.50	4.2

Table 4. Proximate analysis (%), dry basis –Source CEET (2008)

Elements	Residue type								
	Rice husk	Rice Bran	Coffee husk	Sisal leaf	Sisal pole	Sisal boles	Palm branch	Palm Stem	Sugarcane Bagasse
C	35.60	37.80	49.40	47.00	47.00	48.00	45.60	47.50	48.10
H	4.50	5.00	6.10	5.70	6.00	6.00	5.60	5.90	5.90
N	0.19	0.55	0.81	0.14	1.66	0.10	0.19	0.28	0.15
O	33.40	35.40	41.20	39.90	39.10	42.70	39.30	42.50	42.40
Cl	0.08	0.09	0.03	0.04	0.05	0.06	1.33	0.18	0.07
S	0.02	0.05	0.07	0.03	0.13	0.03	0.16	0.13	0.02

Table 5. Ultimate analysis (%), dry basis- Source CEET (2008)

Elements	Residue type								
	Rice husk	Rice Bran	Coffee Husk	Sisal Leaf	Sisal Pole	Sisal Boles	Palm Branch	Palm Stem	Sugarcane Bagasse
HHV [MJ/kg]	13.24	13.93	18.34	17.23	17.20	17.35	16.24	17.38	17.33

Table 6. Heating values

Agro Residues	Cellulose	Hemicellulose	Lignin	Theoretical ethanol yield per litres
Rice straw	41.36	20.36	12.06	39.75
Rice Husk	44.06	17.85	17.20	392.33
Maize cob	36.80	27.90	11.15	418.21
Maize husk	43.39	19.58	22.82	407.03
Ground nut straw	36.55	13.94	31.28	319.96
Sugarcane baggage	33.60	29.00	18.50	404.64

Table 7. Other chemical component

5.1.4. Economic and environmental implications of biomass

Advantages of using crop residues as energy source are twofold: economic and environmental.

Economic: For the farmer, agricultural residues can be a cash crop. Traditionally, farmers burnt agricultural residue or left them in the field. The market ability of crop residues will boost local/village economies by providing jobs and services.

Environment: the burning of agricultural residues causes air pollution, soil erosion and a decrease in soil biological activity, which eventually leads to low yields. Burning of agricultural residues yield smoke and other pollutants, which adversely affect air quantity, visibility and human and environmental health

5.1.5. Challenges with agricultural residues are

- Agricultural resources in the country are largely un-organized, scattered and not evenly distributed.
- Collection, storage, pre-processing and distribution are a big challenge because of low land holdings and low level of mechanization in complete value chain.
- Exact data on consumption of agriculture- residues in the country is not well known. Hence, more studies are needed
- Overall agro-residue conversion is low through existing technology;
- Agriculture-residue is marginalized in the country;

5.1.6. Agriculture waste

Apart from agricultural residue from the farms, in Urban and semi-urban areas certain other residues and waste water also constitute a potential source of energy. The agro-processing industries such as fruit processing and vegetable, urban vegetable market places (Figure 8 and 9), road sweepings and road side are areas, which generates significant biomass waste. The management of these wastes are in hands of poor farmers, un-organized sector, rural and semi-urban households. Hence, large amount of these wastes are left to rot in open space resulting into air pollution. Good management of these wastes can contribute to energy generation in the country.



Figure 8. Surplus Tomato Left as Waste



Figure 9. Heaps of Food waste in Urban Tanzania

5.1.7. Forestry residues

Forest residues and wood waste represent a large potential resource for energy generation. They include forest thinning, primary mill residues, (Sao hill forest). Forest residues are left in the forest by harvesting operations (Figure 10) the residue could be collected after timber harvest and used for energy purposes.

The primary advantage of using forest residue for power generation is that an existing collection infrastructure is already set up to harvest wood. Companies that harvest wood already own equipment and transport options that could be extended to collecting forest residue.

Manufacturing operations that produce mill residues usually include sawmills (Urban sawmill), pulp and paper mills (Mufindi paper mills) and other millwork companies involved in producing pulp and other related material.

Primary mill residues are usually in the form of bark, chips, saw dust, slabs etc. These primary mill residues are relatively homogenous and concentrated at one source. Nearly 98 percent of all primary residues in the country are currently used as fuel.



Figure 10. Forest harvesting waste at Sao Hill

There about 80,000 hectares of state owned plantation forest that are mostly linked to state owned wood based panel industry and the pulp and paper industry. It is estimated that there are 25,000 hectares of private owned plantations. In addition, more than 75,000 hectares belongs to villagers, local government, NGOs and civil societies. Hence, the estimate forest residue potential m^3 per year is about 205,400 tonnes. The residue can be used for modern energy conversion.

5.1.8. City and Municipal solid waste (CMW)

Millions of tons of household waste are collected each year with the vast majority, disposed affirm open fields. Table 9 gives quantity of solid waste collected in Tanzania by region. Biomass resource in solid waste comprises paper and plastic. City and Municipal solid waste (CMW) can be converted into energy by direct combustion, or by natural anaerobic digestion in the land fill.

On other land fill sites the gas produced by natural anaerobic digestion, which is approximately 50% methane and 50% carbon dioxide can be collected form the stored material, scrubbed and cleaned before feeding into internal combustion engines or gas turbines to generate heat and power.

The above compiled data clearly shows that large scope exist in the country for the exploitation of bio-crops for their conversion to bio-fuel, e.g. bio-diesel, ethanol, by thermo conversion and bio-chemical conversion routes.

Apart from energy crops, a huge potential exist for energy generation from the various industrial wasters available in the country by bio-chemical routes. Similar, other biomass wastes such as forest residue, crop residue, animal manure and city and municipal waste (Figure 16) also bear a large potential for modern energy generation using bio-chemical as well as thermo-chemical routes. Hence biomass conversion to modern energy such as electricity and fuels may be rewarding for a future developed Tanzania.

5.1.9. Animal Waste

Rural population burn dried animal dung as a fuel, and this is a major source of energy. If a programme is instituted to use the dung as raw material for biogas production, it could benefit the livestock keepers. India for example has pursued a programme to generate biogas from gas with some success. However, at the moment there are more than 6,000 small scale biogas plants operating. The number is small compared to number of livestock the country having (Table 8).

The advantage, from an environmental aspect is that methane that would be released is captured and used to generate heat for cooking purposes. This could reduce the pressure on forests and deforestation. Methane is about twenty times more potent than carbon dioxide as a greenhouse gas and oxidising it while producing usable heat make sense from a climate point of view.

The solid residue remaining from fermentation process could be used as fertilizer in growing other biomass sources such as maize, wheat, cassava, etc.

The challenge is how to quantify the energy potential from animal waste in the country. Advanced investigation is needed. Figure 11 shows cow dung, which is used as source of energy in rural areas.



Figure 11. Cow dung

Decomposition of animal manure can occur either in an aerobic or anaerobic environment. Usually under aerobic condition, carbon dioxide (CO_2) and stabilized organic material are produced. While under anaerobic conditions, methane (CH_4), carbon dioxide (CO_2) and stabilized organic material are produced. Basing on statistical data given in Table 9 the quantity of animal manure produced annually can be substantial for generation of methane (CH_4) and hence energy potential of animal manure is significant. At the moment there are more than 6,000 biogas plants in the country, which use animal manure as their raw material.

Name of Livestock	YEARS			
	2006	2007	2010	2011
Cattle	18,500,000	19,100,000	19,200,000	21,300,000
Goats	13,500,000	13,600,000	13,700,000	14,000,000
Sheep	3,500,000	3,600,000	3,600,000	3,800,000
Chicken	30,000,000	31,000,000	33,000,000	40,000,000

Table 8. Livestock statistic for the country

5.1.10. Food Industry Wastes

The hotels, restaurants, Schools, and community kitchens produce a lot of waste such as vegetable peels, uneaten food, e.g. rice, bread, vegetables, etc., plate and dish washings, fruits and vegetable rejects. Similarly, a huge amount of wastes are generated from confectionary industry. Solid waste from these industries include peelings and scraps from fruits and vegetables, food that does not meet quality control standards, pulp and fibre from sugar and starch extraction, filter sludge and coffee grounds are disposed of and left to rot in the open space. However, all of these wastes make potential feedstock for biogas generation by anaerobic digestion. Usually these wastes are disposed of in landfill dumps [16].

Liquid wastes are generated by washing meat, fruit and vegetables, blanching fruit and vegetables, pre-cooking meats, poultry and fish, cleaning and processing operations and wine making. These wastewaters contain sugars, starches and other dissolved and solid organic matter. There is a potential for these industrial wastes to be anaerobically digested to produce biogas or fermented to produce ethanol.

5.1.11. Industrial Waste

Such waste consists of lawn and tree trimmings, whole tree trunks, wood pallets and any other construction and demolition wastes made from timber (Figure 12). The rejected woody material can be collected after a construction or demolition project and turned into mulch, compost or used to fuel bioenergy plants



Figure 12. Wood waste in Mwanza Municipality

Industrial waste such as bagasse (Figure 13) from sugar plants find application in co-generation process, which generates electricity that is used by the same plant. The excess is supplied to the nation grid



Figure 13. A heap of bagasse at Sugar Factory

6. Benefit of biomass utilization

Biomass is renewable, potentially sustainable and relatively environmentally benign source of energy. It is free from carbon dioxide. Thus, the substitution of fossil fuels for energy generation using biomass will result into a net reduction of greenhouse gas emissions and the replacement of a non-renewable energy source.

Biomass fuels have negligible sulphur content and, hence, do not contribute to sulphur dioxide emissions, which cause acid rain. The combustion of biomass produces less ash than coal combustion, and the ash produced can be used as a soil additive on farm target.

Biomass is a domestic resource, which is not subject to world price fluctuations or supply uncertainties. If well developed in the country, the use of biofuels, such as ethanol and biodiesel, reduces the economic pressures of importing petroleum products.

6.1. Environmental impact of biomass energy

Biomass energy generation systems raise some environmental issues that must be addressed. Issues such as air pollution, impact on forests, and impact due to crop cultivation must be addressed case by case. Produced and consumed in a sustainable fashion, and there is no net contribution of carbon dioxide to global warming when fossil fuels are burnt, carbon dioxide is released that has been stored underground for millions of years, making a net contribution to atmospheric greenhouse gases. Hence, if managed carefully, biomass energy

has significant environmental advantage over the use of fossil fuels. An appropriate level of biomass energy use can have less environmental impact than our current use of fossil fuels.

6.2. Barriers

Main barriers to wide spread uses of biomass in the country for modern power generation are:

- Cost
- Low conversion efficiency;
- Feed stock availability;
- Lack of internalization of external costs in power generations;
- Dependence on technology advances from outside instead of development of indigenous technology;
- Competition for feed stock use; and
- Lack of supply logistics.

6.3. Risks

Risks associated with widespread use of biomass are:

- Intensive framing;
- Fertilizers and chemical uses; and
- Biodiversity conservation

7. Biomass conversion

Biomass feedstock can be converted into useful forms of energy using a number of different processes. This is possible in the country because there is potential biomass that could be used for the process. However, before conversion processes can be initiated, factors that influence the choice of conversion [17] have to be established. The critical factors are:-

- The type and quantity of biomass feedstock;
- The desired form of energy i.e. end-use requirements ;
- Environmental standards;
- Economic conditions;
- Project specific factors.

Biomass can be converted into three main products [18]. Two related to energy i.e. power or heat generation and transportation, and one as a chemical feedstock. Conversion of biomass

to energy is usually undertaken using two main technologies: Thermo – chemical and biochemical. Within thermo-chemical conversion four process options are available. The processes are: Direct combustion, Gasification, pyrolysis and liquefaction. Thermo-chemical conversion route is given in Figure 14.

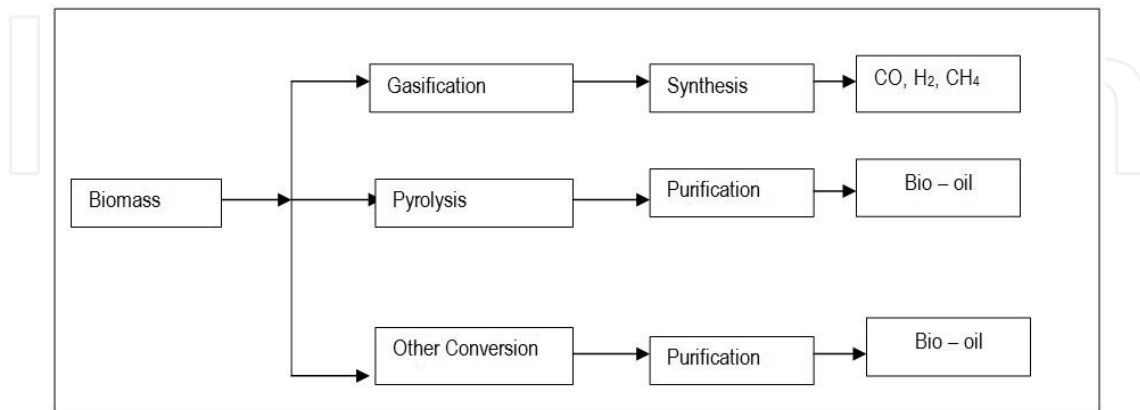


Figure 14. Biomass thermo-chemical conversion route

7.1. Thermo-Chemical conversion

7.1.1. Gasification

Gasification is the conversion of biomass into a combustible gas mixture by the partial oxidation of biomass at high temperature [19] resulting in production of (CO), H₂, and trace of Methane (CH₄). The mixture of these gases is called producer gas. Producer gas can be used to run internal combustion engine, also it can be used as substitute for furnace oil in direct heat applications. The gas can be used to produce methanol-an extremely attractive chemical which is used as a fuel for heat engines as well as chemical feed stock for industries. Since any biomass material can undergo gasification, this process is much more attractive than ethanol production or biogas where only selected materials can produce the fuel. Gasification conversion is suitable for Tanzanian environment.

7.1.2. Pyrolysis

Pyrolysis is the process of converting biomass to liquid termed bio-oil, solid and gaseous fraction, by heating the biomass in the absence of air to around 500°C. Pyrolysis is used to produce predominantly bio-oil. The product i.e. bio-oil can be used in engines and turbine. Obstacle of Pyrolysis is the water dilution [20] of the bio-oil and it's corrosively due to the broad range of organic and inorganic compounds. Hence, the application of bio-oil as a raw material for electricity generation technology is difficult [21].

7.1.3. Other conversions

Other conversions include direct combustion of biomass and liquefaction.

Direct combustion is the process of burning biomass in air. It is used to convert the chemical energy stored in biomass into heat, mechanical power, or electricity using items such as stoves, furnaces, boilers steam turbines, turbo-generators, etc. However, direct combustion does not a fuel suitable for use in gas turbine, etc.

Liquefaction is a process, which tries to clear the large biomass feedstock macro molecules by applying high pressure and how level of heat. Common process parameters of temperature in the range 200-400°C and pressure ranges of 50-200 bar [19, 22], the main products of liquefaction are liquid fuels with similar consistency like that of pyrolysis processes. Given that Liquefaction require high pressure reactor there are only a few commercially available Liquefaction processes. [22].

Ranking of thermo-chemical conversion technology

Table 9 summarizes the findings of performance of thermo-chemical conversion technology and ranking the applicability. The assessments vary from very poor (-), good (+) and very good (+++).

ACTION	PROCESS		
	Gasification	Pyrolysis	Other conversion
Conversion level	+++	++	++
Simplicity	++	++	-
Plant cost	++	++	-
Applicability to scale	+++	++	-
Conversion time	+	+	+

Table 9. Ranking of thermo-chemical conversion Technology

From Table 9, it can be concluded that Gasification process has very good conversion level and applicability. Hence, the process is suitable biomass conversion technology in the country.

7.2. Bio-chemical conversion

Water diluted biomass such as sludge, manure, vegetable waste are difficult to be converted by thermo- chemical conversion process due to difficulties in vaporizing the water present in the biomass. Hence, for feed stock with significantly more than 50% moisture content, it is usually not to apply thermo-chemical technology at comparatively at low temperature is an economic alternative solution.

Two main processes are employed: anaerobic digestion, where biomass is converted by bacteria, and fermentation using yeast to convert biomass. Anaerobic digestion is the standard solution for treating very high dilution levels of biomass, fermentation is used to biomass containing lower amount of water. [20].

7.2.1. Anaerobic digestion

Anaerobic digestion is process of converting of organic material directly into a gas teemed biogas. Biogas is a mixture of methane (CH_4) and carbon dioxide (CO_2) with other small quantities of gases such as hydrogen sulphide (H_2S) [23]. Anaerobic digestion is a proven technology and is widely used for treating high moisture content organic waste [19]. Biogas a product from anaerobic digestion can be used directly in gas turbine to generate electricity, and can be upgraded to higher quality i.e. natural gas quality by removing carbon dioxide (CO_2).

By- product of anaerobic digestion are settled fibre, which can be used as soil conditioning and liquid fertilizer, which can be used in the farms directly without additional treatment [24-25].

7.2.2. Fermentation

Fermentation process converts biomass into ethanol by the metabolism of microorganisms [26, 20]. The fermentation process is normally anaerobic, but also aerobic process can be feasible. The process consists of two notable steps. First, biomass starch, the sugars are fermented to ethanol using yeast.

The solid residues from fermentation, which still consists of amount of biomass, can then be used for direct combustion or gasification. Typically sugarcane and sugar beet (in Europe) are can theoretically fermented [27].

The final fermentation product allows easier handling and storage when compared to gases produced from anaerobic digestion. However, the intensive feedstock pre-treatment, the necessary temperatures and diluted intermediate product obtained, the fermentation process is complex than anaerobic digestion.

Despite the advantages of storage and transportation, fermentation process is less suitable for micro-scale energy production than gas production technologies. Besides, a major environmental impact of fermentation is the waste water of fermentation process. Treating the waste water can be very energy intensive. The high contents of Nitrate and phosphates in the waste water might influence the development of certain species such as algae.

Ranking of bio-chemical conversion technology

Table 10 summarizes the findings of performance of bio-chemical conversion technology and ranking the applicability. The assessments vary from very poor (-), good (+) and very good (+++).

From the above ranking, it is evident that anaerobic diction is more promising as a biomass conversion technology in the country, especially due to its simplicity.

Gasification and anaerobic digestion are promising conversion technologies in the country. Anaerobic digestion is an excellent technology to produce biogas from wastes in a very small scale i.e. at house hold level. The produced gas (biogas) can be utilized as cooking gas, transportation fuel, and for electricity generation. Gasification is a more demanding technology in small- scale projects with special feed stock requirements.

ACTION	PROCESS	
	Anaerobic digestion	Fermentation
Conversion level	++	++
Simplicity	+++	-
Plant cost	+++	-
Applicability	+++	-
Conversion time	+	++

Table 10. Ranking of bio chemical conversion Technology:

Direct combustion is an ancient technology for heat production purposes. It is a common technology in the country. Pyrolysis is a technology that can be used in large-scale for commercial purposes. The product from pyrolysis i.e. pyrolysis oil, is demanding to upgrade to transport fuel. The pyrolysis oil can be used for combined heat and power generation; however, the pyrolysis process is inefficient.

Fermentation process is a commercial technology but competes with food production. The produced ethanol can be used for heat and power generation and preferably as transportation fuel.

Sensitization on the use of these conversion technologies in the country is required. At the same time training institution should be involved in more research and development aiming at improving the technologies. With this approach, it is clear that the potential of biomass available in the country could contribute to energy mix of the country.

Thermo-chemical and bio-chemical biomass technologies can be summarized in Tables 11 and 12.

	CONVERSION TECHNOLOGY		
	Gasification	Pyrolysis	Direct combustion
Input material	Energy crops, bio waste, Forest, forest product	Energy Crops, mill wood waste, Urban organic waste	Biomass, wood waste
Product	Syngas	Pyrolysis	Heat
By product	Char	Gases and char	Ash
Post treatment	Particulates and tars removal	Oxygen removal	Name
Applications	Synthetic fuel production	Fuel for engine	Heat production, electricity generation.
Direct Environmental Impact	Carbon dioxide, hydrogen Sulphide, NO _x	Carbon dioxide, Carbon monoxide, Methane	Fly and bottom ash, particulates
Indirect environmental Impact	Energy requirement of downstream processes	Energy requirement of downstream processes	Land use impacts of unsustainable forestry practices

Table 11. Summary of conversion technologies

	CONVERSION TECHNOLOGY		
	Anaerobic digestion	Fermentation	Others
Input material	Biowaste, Wastewaters, by-products, energy crops	Food crops and by-products, forest residues, biowaste, energy crops	-
Product	Biogas	Alcohol, Ethanol	-
By product	Rejects, water	Rejects, water and gases	-
Post treatment	Moisture removal	Water removal	-
Applications	Transportation fuel, fertilizer, CHP	Transportation fuel, animal feed, fertilizer	-
Direct Environmental Impact	Energy needs, carbon dioxide emissions	Wastewater, nitrates and phosphates	-
Indirect environmental Impact	Potential water impact of digestate spreading on land	Land use impact	-

Table 12. Summary of conversion Technologies

8. Discussion

A critical analysis of the potential of biomass as an energy source has been presented. The analysis shows that Tanzania has abundant biomass resources for modern power generation. It is evident from the analysis that a large potential exist for exploitation of available biomass to be converted into modern energy. Thus, it is the role of the government, private companies, NGOs, and individuals to increase the share of renewable energies i.e. biomass within the national energy mix. Since biomass is the most important renewable energy source used in the country, the demand for biomass as energy resource will inevitably increase in the near future.

To what extent biomass will penetrate future energy markets in the country; this depends on various aspects; e.g. availability of the resources, the costs of biomass fuels, the development of conversion technologies, cost of converted biomass energy, and social and/or institutional factors. The use of agricultural crop residues, animal waste, and industrial waste as energy sources is a promising opportunity to reduce pressure on energy supply. Since the use is, in the most cases, in compliance with sustainability criteria such as protection of resources, compatibility with environment and climate, social compatibility issues, low risk and error tolerance, and furthermore, it promotes economic efficiency.

Biomass could meet the primary energy demand of the country. And a considerable share could be used for modern power generation within the different conversion routes; the thermal- chemical conversion routes offer opportunities for those residues which are predominantly dry such as rice straw and husk. In view of the availability of waste biomass e.g. food waste, industrial waste, city and municipal solid waste (CMSW) anaerobic digestion is a promising route.

Within the biological conversion technologies, the development of power generation from biogas is at advanced stage. Currently there are more than 6,000 biogas plants in operation. More plants are expected to be in operation in the future. However, awareness on use of biogas in particular to areas with large flocks of livestock is still low. This is a challenge to the developers of biogas plants.

There is an increasing interest in gasification technologies for power generation, but a commercial implementation has not yet been received since there are still drawbacks such as system reliability, high operation and maintenance cost, which has to be solved first.

Co-generation technology is the only technology at advanced stage of implementation in the country; in particular to sugar processing plants. Electricity generated from these plants is used by the same plants and the excess is supplied to the nation grid. It is anticipated that with "Kilimo Kwanza"[28] initiatives in the pipeline, production of sugar is expected to increase in the near future; hence more electricity is expected to be generated and supplied into the grid.

Modern energy generation from biomass resources has a great potential in saving for rural energy needs with sustainable benefits. The existing biomass conversion technology such as co-generation, biogas and recently improved thermo-chemical, could be effectively utilized in the process of energy conversion from biomass.

These technologies should be used in the right way to utilize the available biomass energy potential. The power generation from biomass would make the rural areas productive. The use of local resources would also enhance the employment opportunities and income generation in the rural areas. The available biomass potential in the country should be used to take the nation towards a clear and secure energy source.

9. Conclusion

Biomass is one of the renewable energy sources that can make a significant contribution to the developing world's future energy supply. Tanzania has a large potential for biomass production. The forms in which biomass can be used for energy are diverse, Optimal resources, technologies and entire systems will be shaped by local conditions, both physical and socio-economic in nature.

Though I have mentioned it numerous times, it bears repeating that the majority of people in the country will continue using biomass as their primary energy source well into the next century. A critical issue for policy-makers concerned with public health, local environmental degradation, and global environmental change is that biomass-based energy truly can be modernized, and that such a transformation can yield multiple socioeconomic and environmental benefits. Conversion of biomass to energy carriers like electricity and transportation fuels will give biomass a commercial value, and potentially provide income for local rural economies. It will also reduce national dependence on imported fuels, and reduce the environmental and public health impacts of fossil fuel combustion. To make progress, biomass

markets and necessary infrastructure must be developed with the realization that the large-scale commoditization of biomass resources can have negative impacts to poor households that rely on it for their basic needs. Hence, measures must be taken to ensure that the poor have an opportunity to participate in, and benefit from, the development of biomass markets.

In addition, high efficiency conversion technologies and advanced fuel production systems for methanol, ethanol and hydrogen must be demonstrated and commercialized in the country. Meanwhile, and experiences in industrialized countries should be shared openly. Further, projects must not be concentrated in one region alone. Biomass is obviously a resource that intimately depends on local environmental factors, and experiences gained in other countries will not wholly apply. The benefits of modernized bioenergy systems will only be enjoyed globally if efforts are made to gain experience in a wide variety of ecological and socioeconomic venues.

Biomass can play a major role in reducing the reliance on fossil fuels by making use of thermo-chemical conversion technologies. In addition, the increased utilization of biomass-based fuels will be instrumental in safeguarding the environment, generation of new job opportunities, sustainable development and health improvements in rural areas. The development of efficient biomass handling technology, improvement of agro-forestry systems and establishment of small and large-scale biomass-based power plants can play a major role in rural development. Biomass energy could also aid in modernizing the agricultural economy. A large amount of energy is expended in the cultivation and processing of crops like sugarcane, coconut, and rice which can met by utilizing energy-rich residues for electricity production. The integration of biomass-fuelled gasifier in coal-fired power stations would be advantageous in terms of improved flexibility in response to fluctuations in biomass availability and lower investment costs. The growth of the bioenergy industry can also be achieved by laying more stress on green power marketing.

10. Recommendations

Biomass plays an important role for the energy sustainable development in the country; the potential of biomass is huge, however, its conversion to modern energy is still low. Thus, the following recommendations are proposed:

- Some difficulties which are still faced in the increase of biomass conversions should be minimized..
- Academic and Research institution should play an important role in accelerating biomass utilization and conversion to modern energy.
- The Research and Development collaboration among researchers in East Africa community (EAC) members and SADC region should be developed and realized.
- A biomass user network among East African community should be established to deal with biomass utilization.

11. Glossary

URT-United Republic of Tanzania

REA- Rural Energy Agency

RETs-Renewable Energy Technologies

TANESCO- Tanzania Electric Supply Company Limited

HFO- Heavy fuel Oil

GPD- Gross Domestic Product

C-Carbon

H-Hydrogen

N-Nitrogen

O-Oxygen

Cl-Chlorine

S-Sulphur

CH₄-Methane gas

CO- Carbon monoxide

CO₂-Carbon dioxide

NGOs-Non – Government Organizations

CMSW- City and Municipal Solid Waste

MSW-Municipal solid waste

MEM-Ministry of Energy and Minerals

CHP- Combined Heat and Power

Anaerobic- Digestion Combustible gas called biogas produced from biogas through low temperature biological processes

Bagasse-The fibre residue that remain after juice extraction from sugarcane

Bioenergyhe- conversion of biomass into useful forms of energy such as heat, electricity and liquid fuels

Biogas-The common name for a gas produced by the biological process of anaerobic (without air) digestion of organic material

Biomass-Organic, non-fossil material of biological origin constituting an exploitable energy source

Carbon Dioxide (CO₂)-The gas formed in the ordinary combustion of carbon, given out in the breathing of animals, burning of fossil fuel, etc. Human sources are very small in relation to the natural cycle

Commercial Energy-Energy supplied on commercial terms; distinguished from non-commercial energy comprising fuelwood, agricultural waste and animal dung collected usually by the user

Energy crops-Crops designed either exclusively for biomass energy feedstock or for the co-production of energy and other agricultural products

Ethanol-Clean burning high efficiency fuel produced from fermentation of biomass that can substitute for conventional liquid petroleum fuels such as gasoline and kerosene

Fossil Fuel-A device that produces electricity directly from chemical reactions in a galvanic cell wherein the reactants are replenished

Gasification-Combustible gas called producer-gas produced from biomass through a high temperature thermochemical process. Involves burning biomass without sufficient air for full combustion, but with enough air to convert the solid biomass into a gaseous fuel

Methane (CH₄)-Gas emitted from coal seams, natural wetlands, rice paddies, enteric fermentation (gases emitted by ruminant animals), biomass burning, anaerobic decay or organic waste in landfill sites, gas drilling and venting, and the activities of termites

Photovoltaic-The use of lenses or mirrors to concentrate direct solar radiation onto small areas of solar cells, or the use of flat-plate photovoltaic modules using large arrays of solar cells to convert the sun's radiation into electricity

UNIT

MW-MegaWatt

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