The Environmental and Economical Advantages of Agricultural Wastes for Sustainability Development in Sudan

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Abstract: Like many tropical countries, Sudan has ample biomass resources that can be efficiently exploited in a manner that is both profitable and sustainable. Fuel-wood farming offers cost-effective and environmentally friendly energy solutions for Sudan, with the added benefit of providing sustainable livelihoods in rural areas. This article provides an overview of biomass energy activities and highlights future plans concerning optimum technical and economical utilisation of biomass energy available in Sudan. Results suggest that biomass energy technologies must be encouraged, promoted, implemented, and fully demonstrated in Sudan.

1 Introduction

Biomass energy includes fuelwood, agricultural residues, animal wastes, charcoal and other fuels derived from biological sources. It currently accounts for about 14% of world energy consumption. Biomass is the main source of energy for many developed and developing countries. In Sudan, energy wood is available in the form of forest chips, fuelwood, wood waste, wood pellets and it is also produced to a very limited extent from willow crops in short rotation forestry. The major part of wood harvested in the forest area approximately 108 million hectares ends up as energy wood directly or indirectly after having been used for other purposes first. In 2000, the biomass share of the total energy consumption of the country was 87%. This has hardly changed since then despite the recent exploitation of oil resources and increased refinery capacity due to the subsequent increase in demand. The possibilities of increasing fuelwood production through afforestation programmes and substitution for commercial fuels are discussed later. Biogas utilisation in the rural regions is also reviewed, emphasaising its possible contribution.

Biomass refers to solid carbonaceous material derived from plants and animals. These include the residues of agriculture and forestry, animal waste and wastes from food processing operations. A small amount of solar is used in the process of photosynthesis by plants and this trapped energy can be used in various ways. Wood and grass can be dried and then burned to release heat. Plant material particularly rich in starches and sugars such as sugarcane and wheat can be fermented to produce ethanol. Alternately, methanol, which can be produced by the distillation of biomass, contains considerable cellulose such as wood and bagasse (residue from sugarcane). Both of these alcohols can be used to fuel vehicles and machinery, and can be mixed with petrol to make a petrol/alcohol blend. Although biomass energy use is predominantly in rural areas, it also provides an important fuel source for the urban poor and many rural, small and medium scale industries. In order to meet the growing demand for energy, it is imperative to focus on efficient production and uses of biomass energy to requirements (such as electricity and liquid fuels). This production of biomass in all its forms for fuel, food and fodder demands environmentally sustainable land use and integrated planning approaches (Galal, 1997).

2 Major Energy Consuming Sectors

Sudan is still considered as one of the 25 most developing African countries. Agriculture is the backbone of economic and social development in Sudan. About 80% of the population depends on agriculture, and all other sectors are largely dependent on it. Agriculture contributes to about 41% of the gross national product (GNP) and 95% of all earnings. It determined the degree of performance growth of the national economy for the last 30 years. Special attention should therefore be given to reviewing forest resources, plantation programmes and the possibilities of substitution of fuelwood for commercial fuels or for other fuels such as biogas.

The main sources of fuelwood supply in the country can be broadly grouped into two main categories, i.e., forest sources (forests under the control of governmental forest departments) and non-forest sources (private farmland and wild lands). Women, assisted by children, almost always perform the gathering of fuelwood in rural areas of developing countries. As fuelwood became scarce, which is the case in many parts of the world, the collection time has increased and although men do not perceive it, this had many undesirable consequences, which can be clearly seen in many rural region of Sudan. This is due to women having less time for their other important social functions, such as cooking, washing, water collection, and child rearing, which may affect the nutrition and health of the entire family. Note that wood energy for many countries is one of the few locally available sources of energy, which they can afford. Hence, its substitution by imported fossil fuels, as has often been carelessly recommended, should attentively be evaluated to avoid undesirable political, economic and social consequences.

2.1 Agriculture sector

During the last decades, agriculture contributed to the Sudan GNP by about 41%, as stated above. This share remained stable until 1984-1985 when Sudan was seriously hit by drought and desertification, which led to food shortages and deforestation, and, also, by socio-economic effects caused by the civil war. This dropped the agriculture share to about 37%. Recent development due to rehabilitation programmes and improvement in agricultural sector in 1994 has raised the share again to 41%. This share was reflected in providing raw materials to local industries and an increased export earning besides raising percentage of employment among population. This sector consumes 2.5% of the total energy consumption (28% from electricity, 14.8% from fossil fuels, and the rest from biomass fuels).

2.2 Industrial sector

The industrial sector is mainly suffering from power shortages, which is the prime mover to the large, medium and small industries. The industrial sector was consuming 5.7% of the total energy consumption, distributed as 55% from petroleum products, 13% from biomass and 32% from electricity.

2.3 Transport sector

The transportation sector in the Sudan (railways, ships, boats, etc.) has not been efficient for the last two decades because of serious damage occurred to its infrastructure (roads, workshops, and maintenance centres, etc.) over a long period of time. However, as it stands, it consumes 10% of the total energy consumption and utilizes 60% of the total petroleum products supplied.

2.4 Domestic use

Household is the major energy consumer in the Sudan. It consumes 92% of the total biomass consumption in the form of firewood and charcoal. This sector also consumes 60% of the total electricity consumption, and 5.5% of petroleum products.

Fuelwood, animal wastes, agricultural crop residues, and logging wastes have been used through direct burning in Sudan for many years. These sources are often called non-commercial energy sources, but fuelwood in the Sudan is, in fact, a tradable commodity since it is the primary fuel of rural areas and the urban poor section. Traditional fuels predominate in rural areas; almost all biomass energy is consumed in the household sector for heating, cleaning and cooking needs of rural people. The preparation of three stone fires is especially very attractive to the villagers (households on the high plateau). In this method, food and plant residues are put in a large boiler with water and cooked on a traditional stove outside the house for animal feed, because cooked food and plant residues are cheaper than flour and bran. Nevertheless, this method consumes much more fuelwood than the cooking on the stoves method. On the other hand, wood is the most practical fuel for serving a large number of people because the size of the batch of food is only limited by the volume of the pot and not by the size of the stove's burner. Fuelwood is also convenient for cooking of the meal of meat.

3 Biomass Resources

Agriculture is the source of a considerable sum of hard currency that is needed for the control of balance of payment in the country's budget as well as it is the major source of raw materials for local industry. Biomass resources play a significant role in energy supply in Sudan as in all other developing countries. Biomass resources should be divided into residues and dedicated resources; the latter including firewood and charcoal from forest resources. As shown in Table 1, approximately 12.4 x 10^6 m^3 of biomass are consumed per year. Table 2 shows the division of this between the various sectors. To avoid resource depletion, Sudan is currently undergoing a re-forestation programme of 1.05 x 10^6 hectares. However, biomass residues are more economically exploitable and more environmentally benign than dedicated biomass resources (Hood, 1994). There exists a variety of readily available sources in Sudan, including agricultural residues such as sugar cane bagasse and molasses, cotton stalks, groundnut shells, tree/forest residues, aquatic weeds, and various animal wastes as shown in Table 3. The aim of any modern biomass energy systems must be:

- To maximise yields with minimum inputs.
- Utilisation and selection of adequate plant materials and processes.

Table 1 Annual volume of biomass sources available in Sudan (10^6 tonnes)

Source	Volume of biomass (10^6 tonnes)
Natural and cultivated forestry	2.9
Agricultural residues	5.2
Animal wastes	1.1
Water hyacinth and aquatic weeds	3.2
Total	12.4

Table 2 Annual biomass energy consumption pattern in Sudan (10^3 m^3)

Sector	Firewood	Charcoal	Total	Percent (%)
Residential	6148	6071	12219	88.5%
Industrial	1050	12	1062	7.7%
Commercial	32	284	316	2.3%
Quranic schools	209	0	209	1.5%
Total	7439	6367	13806	
Percent (%)	54%	46%		100.0%

- Optimum use of land, water, and fertiliser.
- Create an adequate infrastructure and strong R & D base.

Direct burning of fuel-wood and crop residues constitute the main usage of Sudan's biomass, as is the case with many developing countries. However, the direct burning of biomass in an inefficient manner causes economic loss and adversely affects human health. In order to address the problem of inefficiency, research centres around the country are investigating the viability of converting the residue to a more useful form, namely solid briquettes and fuel gas. Briquetting is the formation of a char (an energy-dense solid fuel source) from otherwise wasted agricultural and forestry residues. One of the disadvantages of wood fuel is that it is bulky and therefore requires the transportation of large volumes. Briquette formation, on the other hand, allows for a more energy-dense fuel to be delivered, thus reducing the transportation cost and making the resource more competitive. It also adds some uniformity, which makes the fuel more compatible with systems that are sensitive to the specific fuel input (NEA, 1982).

Briquetting of agricultural residues in Sudan started in 1980, with a small briquetting plant using groundnut shells in Khartoum. The second plant was introduced in Kordofan (western Sudan) with a capacity of 2 tonnes per hour with maximum 2000 tonnes per season. Another prototype unit was installed in Nyala with a capacity of 0.5 tonnes per hour (i.e., 600 tonnes per season). In central Sudan, a briquetting plant of cotton stalks was installed at Wad El Shafie with a capacity of 2 tonnes per hour (i.e., 2000 tonnes per season). An ongoing project in New Halfa was also constructed to produce 1200 tonnes per season of bagasse briquettes (NEA, 1993). A number of other factories were built in central Sudan for carbonisation of agricultural residues, namely cotton stalks (Omer, 1996a). The products are now commercialised and more than 2000 families have been trained to produce their cooking charcoal from the cotton stalks.

Gasification is based on the formation of a fuel gas (mostly CO and H_2) by partially oxidising raw solid fuel at high temperatures in the presence of steam. The technology, initially developed for use with charcoal as fuel input, can also make use of wood chips, groundnut shells, sugar cane bagasse, and other similar fuels to generate capacities from 3 to 100 kW for biomass systems. Three gasifier designs have been developed to make use of the diversity of fuel inputs and to meet the requirements of the product gas output (degree of cleanliness, composition, heating value, etc.) (ERI, 1987). Furthermore, Sudan is investigating the potential to make use of more and more of its waste. Household waste, vegetable market waste and waste from the cotton stalks, leather, pulp, and paper industries can be used to produce useful energy by direct incineration, gasification, digestion (biogas production), fermentation, or cogeneration.

The use of biomass through direct combustion has long been, and still is the most common mode of biomass utilisation in the Sudan, as implied in Tables 3, 4, and 5. Examples of dry (thermo-chemical) conversion processes are charcoal making from wood (slow pyrolysis), gasification of forest and agricultural residues (fast pyrolysis), and of course, direct combustion in stoves, furnaces, etc. Wet processes, on the other hand, require substantial amount of water to be mixed with the biomass.

In Sudan, most urban households burn charcoal on traditional square "Canun" stoves that have very low fuel-to-heat conversion efficiencies. The following prototypes were all tried and tested in the Sudan:

- The metal clad Kenyan Jiko
- The vermiculite lined traditional Kenyan Jiko
- The all-ceramic Jiko in square metal box
- The open draft Dugga stoves
- The controlled draft Dugga stoves
- The Umeme Jiko "Canun Al Jadeed"

Another area in which rural energy availability could be secured where woody fuels have become scarce, are the improvements of traditional cookers and ovens to raise the efficiency of fuel saving (NEA, 1991). Also, planting fast growing trees to provide a constant fuel supply should be seriously considered. Note that the energy development is essential and economically important since it will eventually lead to better standards of living, people's settlement, and self-sufficiency in food and water supplies, better services in education and health care and good communication modes (NEA, 1985; Ali and Huff, 1984). Local traditional stoves were also tested, improved, invested, and commercially used in the Sudan (ERI, 1987). These include:

- Traditional muddy stoves
- Bucket stoves
- Tin stoves

4 Sugar Cane Biomass

Residuals from the sugar cane industry represent by far the most important source of current and potential biomass resources in Sudan. The sugar industry in Sudan goes back fifty years. Sugar cane plantations cover one fifth of the arable land in Sudan. In addition, to raw sugar, Sudan enterprises produce and utilize many valuable cane co-products as food for energy and fibre. At present, there are 5 sugar factories. Sugar cane bagasse and sugar cane trash already provide a significant amount of biomass for electricity production, but the potential is much higher with advanced cogeneration technologies. Most sugar factories in Sudan can produce about 15-30 kWh per tonne of cane. If all factories were fitted with biomass gasifier-combined cycle systems, 400-800 kWh of electricity could be produced per tonne of cane, enough to satisfy all Sudan's current electricity demand. This would further be facilitated by the fact that some of the sugar plants are near electric grids (Kenana, El Genaid and Sennar) while others have their own grids.

Table 3 Biomass residues, current use and general availability

Type of residue	Current use / availability
Wood industry waste	No residues available
Vegetable crop residues	Animal feed
Food processing residue	Energy needs
Sorghum, millet, wheat residues	Fodder, and building materials
Groundnut shells	Fodder, brick making, direct fining oil mills
Cotton stalks	Domestic fuel considerable amounts available for short period
Sugar, bagasse, molasses	Fodder, energy need, ethanol production (surplus available)
Manure	Fertilizer, brick making, plastering (*Zibala*)

Table 4 Effective biomass resource utilisation

Subject	Tools	Constraints
Utilisation and land clearance for agriculture expansion	• Stumpage fees • Control • Extension • Conversion • Technology	• Policy • Fuel-wood planning • Lack of extension • Institutional
Utilisation of agricultural residues	• Briquetting • Carbonisation • Carbonisation and briquetting • Fermentation • Gasification	• Capital • Pricing • Policy and legislation • Social acceptability

Table 5 Agricultural residues routes for development

Source	Process	Product	End use
Agricultural residues	Direct	Combustion	Rural poor Urban household Industrial use
	Processing	Briquettes	Industrial use Limited household use
	Processing	Carbonisation (small-scale)	Rural household (self sufficiency)
	Carbonisation	Briquettes Carbonised	Urban fuel
	Fermentation	Biogas	Energy services Household Industry
Agricultural, and animal residues	Direct	Combustion	(Save or less efficiency as wood)
	Briquettes	Direct combustion	(Similar end use devices or improved)
	Carbonisation	Carbonised	Use
	Carbonisation	Briquettes	Briquettes use
	Fermentation	Biogas	Use

Additionally, alcohol could be produced as a by-product of the sugar industry. In Sudan, there have been no alcohol distilleries since 1983. The three factories before then were closed due to the implementation of the Sharia Laws. However, alcohol is used for a variety of applications, mainly for medical purposes and rum production. The current circumstances suggest that Sudan should consider expanding production for its use as transportation fuel, but this option has not yet been pursued.

5 Biogas

At present, Sudan uses a significant amount of kerosene, diesel, firewood, and charcoal for cooking in many rural areas. Biogas technology was introduced to Sudan in the mid seventies when GTZ designed a unit as a side-work of a project for water hyacinth control in central Sudan. Anaerobic digesters producing biogas (methane) offer a sustainable alternative fuel for cooking that is appropriate and economic in rural areas. There are currently over 200 installed biogas units in the Sudan, covering a wide range of scales appropriate to family, community, or industrial uses. The agricultural residues and animal wastes are the main sources of feedstock for larger scale biogas plants.

There are in practice two main types of biogas plant that have been developed in Sudan: the fixed dome digester, which is commonly called the Chinese digester (120 units; each with volumes 7-15 m^3). The other type is with floating gasholder known as Indian digester (80 units; each with volumes 5-10 m^3). The solid waste from biogas plants adds economic value by providing valuable fertiliser as by-products (Ali and Shommo, 1993; GTZ, 1985).

Biogas technology can provide not only fuel, but are also important for comprehensive utilisation of biomass forestry, animal husbandry, fishery, evolution of the agricultural economy, protecting the environment, realizing agricultural recycling, as well as improving the sanitary conditions, in rural areas. The introduction of biogas technology on wide scale has implications for macro planning such as the allocation of government investment and effects on the balance of payments. Factors that determine the rate of acceptance of biogas plants, such as credit facilities and technical backup services, are likely to have to be planned as part of general macro-policy, as do the allocation of research and development funds (Omer, 1994; Omer, 1996b).

6 Bioenergy Potential

For efficient use of Bioenergy resources, it is essential to take account of the intrinsic energy potential. Despite the availability of basic statistics, many differences have been observed between the previous assessments of Bioenergy potential (D'Apote, 1998; World Bank, 2001; FAO, 1999; NFA, 1994). These were probably due to different assumptions or incomplete estimations of the availability, accessibility and use of by-products. However, the biomass sources have been used through:

- Direct combustion of forestry and wood processing residues.
- Direct combustion in the case of main dry crop residues.
- Anaerobic digestion of municipal wastes and sewage.
- Anaerobic digestion of moist residues of agricultural crops and animal wastes.

Wood is very important raw material used by a number of industries. Its excessive utilisation as a fuel results in soil erosion, degradation of the land, reduced agricultural productivity and potentially serious ecological damage. Hence, minimisation of fuelwood demand at a national level and the incremental increase in the efficiency of fuelwood use seem to be essential. Utilisation of more efficient stoves and improvement of insulation using locally available materials in buildings are also effective measures to increase efficiency. Biogas or commercial fuels may be thought of as possible substitutes for fuelwood. Table 6 suggests that liquefied petroleum gases (LPG), such as kerosene, are strong candidate to replace firewood in rural areas of Sudan. Indeed, increased, LPG utilisation over the last decade has been one of the main reasons that led to the deceleration of the diffusion of biogas technology into rural areas.

On the other hand, biomass gasification is a technology that transforms solid biomass into syngas (hydrogen and carbon monoxide mixtures produced from carbonaceous fuel). Current use of biomass (gas or solid), which stands at about 87% of the total energy supply in Sudan, is primarily used in combustion for immediate use. Biomass fuels are characterised by high and variable moisture content, low ash content, low density, and fibrous structure. In comparison with other fuels, they are regarded as of low quality despite low ash content and very low Sulphur content (Haripriye, 2000; Hall and Scrase, 1998. However, small-scale gasification for combined heat and power (CHP), also called embedded generation, is feasible. Many villages and mini-grids can be served by biomass power generation in the size range from 1 kWe to 5 MWe.

6.1 Environmental advantages

Potential mitigation measures to decrease greenhouse gas (GHG) emissions from the oil industry and decelerate the threat of global climate change may include the following:

- Controlling GHGs emissions by improving the efficiency of energy use, changing equipment and operating procedures.

Table 6 Energy carrier and energy services in rural Sudan

Energy carrier	Energy end-use	Typical annual household consumption
Fuel-wood	Cooking Water heating Building materials Animal fodder preparation	10 tonnes
Kerosene	Lighting Ignition fires	100 litres
Dry cell batteries	Lighting Small appliances	50 pairs
Animal power	Transport Land preparation for farming Food preparation (threshing)	
Human power	Transport Land preparation for farming Food preparation (threshing)	

- Controlling GHGs emission detection techniques in oil production, transportation and refining processes in Sudan and more efficient use of energy-intensive materials and changes in consumption patterns.
- A shift to low carbon fuels, especially in designing new refineries. The development of alternative energy sources (e.g., biomass, solar, wind, hydro-electrical and cogeneration).
- The development of effective environment standards, policies, laws and regulations particularly in the field of oil industry.
- Activating and supporting environmental and pollution control activities within the Ministry of Energy and Mining (MEM) to effectively cope with the evolving oil industry in the Sudan.

This list shows that biomass and renewable energy sources in general, have an important role to play in protecting the environment, a potential that need to be taken seriously.

6.2 Barriers to implementation

The afforestation programme appears an attractive option for the country to pursue in order to reduce the level of atmospheric carbon by enhancing carbon sequestration in the nation's forests, which would consequently mitigate climate change. However, it is acknowledged that certain barriers need to be overcome if the objectives were to be fully achieved. These include the followings.

- Low level of public awareness of the economic and environmental benefits of forestry. The generally low levels of individual income and pressures from population growth.
- The land tenural system, which makes it difficult (if at all possible) for individuals to own or establish forest plantations.
- Poor pricing of forest products especially in the local market.
- Inadequate financial support on the part of governments.
- Weak institutional capabilities of the various Forestry Departments as regards technical manpower to effectively manage tree plantations.

7 Conclusions

Despite the recent increase in refinery capacity, Sudan is still an energy importing country and the energy requirements have been supplied through imports that have caused financial problems. Because of the economical problems in the Sudan today, the Sudanese energy policy should concentrate on assurance of energy supply, reliability, domestic sufficiency and renewability. Therefore, biomass, as a renewable energy source, seems interesting (especially fuelwood) because its share of the total energy production at 87% is high and the techniques for converting it to useful energy are easy. Additionally, biomass may, also, see greatly expanded use in response to the environmental problems caused by fossil fuel use in the country. Hence, bioenergy in general, and biomass particularly, is proposed in this paper to have a central role to play in future, more sustainable energy scenarios.

However, for this to become a reality, several real problems need to be overcome. For example, in the Sudan, as in other developing countries, modernisation of biomass energy provision is an urgent necessity for the sake of human health, protection of the environment, and climate change abatement. Given sufficient recognition, resources and research, bioenergy could become the environmentally friendly fuel of the future.

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