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Review article

Demand for biogas: state of the art and future prospective

Abdeen Mustafa Omer*
Energy Research Institute (ERI) Forest Road West, Nottingham NG7 4EU, UK.

*Corresponding author; Energy Research Institute (ERI) Forest Road West, Nottingham NG7 4EU, UK.

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ABSTRACT

Sudan is an agricultural country with fertile land, plenty of water resources, livestock, forestry resources, and agricultural residues. Energy sources are divided into two main types; conventional energy (woody biomass, petroleum products, and electricity); and non-conventional energy (solar, wind, hydro, etc.). Sudan possesses a relatively high abundance of sunshine, solar radiation, moderate wind speeds, hydro, and biomass energy resources. 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. Biogas from biomass appears to have potential as an alternative energy in Sudan, which is potentially rich in biomass resources. This is an overview of some salient points and perspectives of biomass technology in Sudan. This current literature is reviewed regarding the ecological, social, cultural and economic impacts of biomass technology. This chapter provides an overview of biomass energy activities and highlights future plans concerning optimum technical and economical utilisation of biomass energy available in Sudan. It is concluded that renewable environmentally friendly energy must be encouraged, promoted, implemented, and demonstrated by full-scale plan especially for use in remote rural areas.

1. Introduction

Sudan is the largest country in African continent, with a tropical climate, and an area of approximately 10^6 square miles (2.5 x 10^6 km^2). It lies between latitudes 3°N and 23°N; and longitudes 21°45' 'E and 39°E. This large area enjoys a variety of climates, from desert regions in the north, to tropical in the south, and makes it a favourable environment for all activities of integrated agricultural investment from production to processing industries (Ali and Shommo, 1993). Sudan is a relatively sparsely populated country. The total population according to the census 2008 was 39 x 10^6 inhabitants. The annual growth rate is 2.8%, and population density is 14 persons per square kilometre (Duffie and Beckman, 1980). Sudan is rich in land and water resources (Elamin, 1995). Sudan has a predominately continental climate, which roughly divides, into three climatological regions: Region 1 is situated north of latitude 19°N. The summers are invariably hot (mean maximum temperature is 41°C and the mean minimum temperature is 25°C) with large variation; low relative humidity averages (25%). Winters can be quite cool. Sunshine is very prevalent. Dust storms occur in summer. The climate is a typical desert climate where rain is infrequent and annual rainfall of 75-300 mm. The annual variation in temperature is large (maximum and minimum pattern corresponding to winter and summer). The fluctuations are due to the dry and rainy seasons. Region 2 is situated south of latitude 19°N. The climate is a typical tropical continental climate. Region 3 comprises the areas along the Red Sea coast and eastern slopes of the Red Sea hills. The climate is basically as in region 1, but is affected by the maritime influence of the Red Sea. Two main air movements determine the general nature of the climate. Firstly, a very dry air movement from the north that prevails throughout the year, but lacks uniformity; and secondly, a major flow of maritime origin that enters Sudan from the south carrying moisture and bringing rain. The extent of penetration into the country by airflow from the south determines the annual rainfall and its monthly distribution. The average monthly rainfall for Sudan indicates the decreasing trend in the rainfall, as well as in the duration as one moves generally from the south towards the north and from east towards west. The total size of the land of Sudan is 6 x 10^8 Feddans (Feddan = 1.038 acres = 0.42 hectares). The land use in the country is classified into four main categories. There are arable land (8.4 x 10^6 hectares), pasture (29.94 x 10^6 hectares), forest (108.3 x 10^6 hectares), and about 38.22 x 10^6 hectares used for other purposes. Water resources are estimated at 84 x 10^9 cubic meters (m^3); this includes the River Nile and its tributaries. Underground water is estimated at 26 x 10^{10} cubic meters, only 1% of this amount is currently being utilised. The annual average rainfall ranges from about 1 mm in the northern desert to about 1600 mm in the equatorial region. The total annual rainfall is estimated at 1093.2 x 10^9 m^3.

Sudan's economy remains essentially agricultural, with annual agricultural production estimated as 15 x 10^6 tonnes mainly sugar, wheat, sorghum, cotton, millet, groundnut, sesame, tobacco, and fruits (ERI, 1997). Sudan is also viewed as one of the potentially richest nations in livestock (GTZ, 1985), approximately 103 x 10^6 head (70 x 10^6 sheep and goats, 30 x 10^6 cattle, and 3 x 10^6 camels) (Joop et al., 1987). Sudan has a great wealth of the wild life- birds, reptiles, and fishes. Sudan possesses great potentialities for industrialisation since it is rich in agricultural raw materials resources. Since the government realised the importance of industrialisation for economic development, there were many attempts by the State to improve the performance of this sector through different industrial policies. Energy is an essential factor in the development movement, since it stimulates and supports the economic growth, and development. The energy crisis in the mid seventies, and substantial increase in oil prices that followed, has put a heavy financial burden on the less developed countries (LDC's). Sudan is not an exception. The fossil fuels, especially oil and natural gas, are finite in extent, and should be regarded as depleting assets, and since that time the efforts are oriented to search for new sources of energy. Most of the political and economic resources are directed to establish sources of energy, many of which now face serious environmental and other constraints, rather than the biomass sources which are increasingly being regarded as a central part of long solutions to the energy environment dilemma (Appendix 1). However, increasing energy service levels with the same environmental goals would imply stronger exploitation of biomass energy sources and stronger measures for exploiting the potential of energy conservation. In recent years, Sudan has increased efforts to exploit renewable energy sources and reduce its dependence on oil. Wind, solar and biomass offers a variety of renewable options that are well suited to the African climate. A number of renewable energy initiatives are under way in Sudan that can contribute to rural development while also addressing climate mitigation.

2. Energy situation

Energy is one of the key factors for the development of national economies in Sudan. An overview of the energy situation in Sudan is introduced with reference to the end uses and regional distribution. Application of new and renewable sources of energy available in Sudan is now a major issue in the future energy strategic planning for the alternative to the fossil conventional energy to provide part of the local energy demand. Sustainable low-carbon energy scenarios for the new century emphasise the untapped potential of renewable resources. Rural areas of Sudan can benefit from this transition. The increased availability of reliable and efficient energy services stimulates new development alternatives. Like many of the African leaders in renewable energy utilisation, Sudan has a well-defined commitment to continue research, development, and implementation of new technologies. Sudan is enjoyed with abundant solar, wind, hydro, and biomass resources. Sudan is an important case study in the context of renewable energy. It has a long history of meeting its energy needs through renewables. Sudan's renewables portfolio is broad and diverse, due in part to the country's wide range of climates and landscapes. Tables 1 to 7 show energy profile, consumption, and distribution among different sectors in Sudan. Sudan, like most of the oil importing countries, suffered a lot from sharp increase of oil prices in the last decades. The oil bill consumes more than 50% of the income earnings. Sudan meets approximately 87% of its energy needs with biomass, while oil supplies 12%, and the remaining 1% is produced from hydro and thermal power. The household sector consumes 60% of the total electricity supplies [7]. The total annual energy consumed is approximately 11 x 10^9 tonnes of oil, with an estimated 43% lost in the conversion process (Kirtikara, 1983). The heavy dependence on biomass threatens the health and future of domestic forests, and the large quantities of oil purchased abroad causes Sudan to suffer from serious trade imbalances. Poverty and iniquity in the basic services are the major components that hindered rural development. Unless being addressed now, none of the great goals of the international and national community peace, human rights, environment, and sustainable development will be achieved or even progressed. Energy is a vital prime mover to the development whether in urban or rural areas. The rural energy needs are modest compared to urban. A shift to renewables would therefore help to solve some of these problems while also providing the population with higher quality energy, which will in turn, improve living standards and help reduce poverty. For proper rural development the following must be considered:

- Analyse the key potentials and constraints of development of rural energy.
- Assess the socio-technical information needs for decision-makers and planners in rural development.
- Utilise number of techniques and models supporting planning rural energy.
- Design, import and interpret different types of surveys to collect relevant information and analyse them to be an input to planners.

Renewable energy technologies such as solar, wind, etc., become more important since there are local resources, and infinite source of energy. Renewable energy technologies are needed, especially in rural areas and small communities. Renewable sources of energy are regional and site specific. The renewable strategy is well integrated in the National Energy Plan (NEA, 1983), and clearly spelled out in the National Energy Policy, but this is not enough. It has to be integrated in the regional development plans. The role of renewable is big in solving essential life problems especially in rural areas for people and their resource development like the availing of energy for the medical services for people and animal, provision of water, education, communication and rural small industries (NEA, 1985). A new renewable fuels programme in Sudan aims to improve environmental standards while making better use of domestic resources, providing an economic stimulus to the rural economy, and reducing CO_2 emissions. This study discusses Sudan's current energy system, and describes plans for expanding and improving Sudan's emerging portfolio of renewable energy options. The poor situations of conventional energy supplies to the Sudanese people are characterised by high dependence on biomass woody fuels (firewood, and charcoal). More than 70% of the total Sudanese population live in rural and isolated communities characterised by extreme poverty, power social and uneconomical activities [10]. The unavailability and the acute shortages of the conventional energy supply (petroleum and electricity) to rural people forced them to use alternatives available energy sources like biomass (NEA, 1987). This situation caused serious environmental degradation beside the poor unsatisfactory services of some basic needs such as:

- Food security.
- Water supply.
- Health care.
- Communications.

In order to raise rural living standards, the *per capita* energy availability must be increased, through better utilisation of the local available energy resources (Table 8). The rural energy requirements are summarised in Table 9. The suitable energy source, needed for the above rural requirements must be of diffuse low cost types rather than large central installation. Also, those technologies must be appropriate, environmentally, socially and economically acceptable. The urgent problem for rural people development is to increase the energy available per capita; since it is necessary to raise up the present level of extreme poverty and provide better basic need services.

Due to the present limitations, and sharp shortages or unavailability of both electricity and petroleum products to rural people, some renewable energy technologies based on utilising locally available energy materials and skills are alternate energy options to rural development (NEA, 1991). These technologies are not for complete rural electrification (although they can), but they are applied as energies stand alone systems providing energy sources to some rural basic needs. It is necessary that a vigorous programme for renewable energies should be set up immediately (the challenge is to provide a framework enabling markets to evolve along a path that favours environmentally sustainable products and transactions).

Energy is an essential factor in development since it stimulates, and supports economic growth and development. Fossil fuels, especially oil and natural gas, are finite in extent, and should be regarded as depleting assets, and efforts are oriented to search for new sources of energy. The clamour all over the world for the need to conserve energy and the environment has intensified as traditional energy resources continue to dwindle whilst the environment becomes increasingly degraded.

Table 1
Annual energy consumption pattern in Sudan from different energy sources (10^6 MWh) (NEA, 1991).

Sector	Energy	Percent (%)
Residential	4640	77.2%
Transportation	610	10.0%
Industries	340	5.7%
Agricultural	151	2.5%
Others*	277	4.6%
Total	6018	100.0%

* Others are commercial, services, constructions and Quranic schools.

Table 2
Annual biomass energy sources available in Sudan (10^6 tonnes) (NEA, 1991).

Source	Energy
Natural and cultivated forestry	2.9
Agricultural residues	5.2
Animal wastes	1.1
Water hyacinth and aquatic weeds	3.2
Total	13.4

Table 3
Annual biomass energy consumption in Sudan (10^6 tonnes) (Omer, 1990).

Sector	Energy	Percent of total (%)
Residential	4549	92.0%
Industries	169	3.4%
Others*	209	4.6%
Total	4927	100.0%

*Others are commercial, constructions and Quranic schools.

Table 4
Power output of present hydropower plants (10^9 Watts) (Omer, 1993).

Station	Power
Rosaries	275
Sennar	15
Khashm El Girba	13
Total	303

Table 5
Annual electricity consumption in Sudan (10^6 MWh) (Omer, 1993).

Sector	Energy	Percent of total (%)
Transportation	3.2	4%
Agricultural	22.4	28%
Industries	6.4	8%
Residential	48.0	60%
Total	80.0	100%

Table 6
Annual petroleum product consumption in Sudan (10^6 MWh) (Omer, 1994).

Sector	Energy	Percent of total (%)
Transportation	601	60.0%
Industries	138	13.8%
Agricultural	148	14.8%
Residential	55	5.5%
Others*	60	5.9%
Total	1002	100.0%

*Others are commercial and services.

Table 7
Percentage of the total annual electricity consumption by states (Omer, 1994).

States	Percent (%)
Khartoum, Central and Eastern states	85.8%
Red Sea state	4.5%
Northern states	4.0%
Darfur states	3.1%
Kordofan states	2.3%
Southern states	0.3%

Table 8
Energy sources for rural areas (Omer, 1995a).

Source	Form
Solar energy	Solar thermal and Solar PV
Biomass energy	Woody fuels and Non woody fuels
Wind energy	Mechanical types and Electrical types
Mini and micro hydro	A mass water fall and Current flow of water
Geothermal	Hot water

2.1. Major energy consuming sectors

Sudan is still considered between the 25 least developed African countries. Agriculture is the backbone of economic and social development in Sudan. About 80% of the population depend 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 of farmers. Agriculture determines for the last 30 years the degree of performance growth of the national economy. Petroleum consumption in household sector is mainly consumed in for lightening by using kerosene and gas oil lamps. The LPG is used in household for cooking. The last 5 years reflect increasing consumption of the LPG in household, due to encouragement investment policies in this area. Petroleum consumption in household sector is only 3%. The consumption of the LPG is almost tripled in 2005 compared to 1999. This indicates new trends in energy consumption of this sector. In the short term it requires mechanisms to enable the rapid increase in energy/capita, and in the long term we should be working towards a way of life, which makes use of energy efficiency and without the impairment of the environment or of causing safety problems.

Sudan becomes one of the oil exporting countries since August 1999, producing about 150,000–180,000 barrels/day. A complex refinery was constructed in Khartoum, with capacity of 50,000 tonnes/day. An amount of 500 tonnes/day of the LPG is expected to be produced. The demand was estimated at 100 tons/day. This new situation requires certain activities to be taken. According to pattern of energy consumption in household sector in Sudan the following barriers are concluded: Lack of polices concerned with energy efficiency measures in household sector and lack of public awareness towards important of conservation concept.

2.1.1. Agricultural sector

During the last decades, agriculture contributed by about 41% to the Sudan GNP. This share remained stable till 1984/85 when Sudan was seriously hit by drought and desertification, which led to food shortages, deforestation, and also, by socio-economic effects caused the imposed civil war. The result dropped the agricultural share to about 37%. Recent development due to rehabilitation and improvement in the agricultural sector in 1994 has raised the share 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.

2.1.2. 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 is consuming 5.7% of the total energy consumption, distributed as follows: 13.8% from petroleum products, 3.4% from biomass and 8% from electricity.

2.1.3. Domestic use

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

2.1.4. Transport sector

The transportation sector was not being efficient for the last two decades because of the serious damage that happened to its infrastructure (roads, railways, boats, workshops, etc.). It consumes 10% of the total energy consumption and utilises 60% of the total petroleum products supplied.

2.2. Energy sector

The present position for most people in Sudan for obtaining the needed energy forms (heat, light, etc.) is provided by firewood. Cooking is largely done by wood from forests or its derivative, charcoal. Cattle dung and agriculture waste are being used to lesser extent. Human, animal, and diesel or gasoline engines provide mechanical power. Some cooking and lighting is done by kerosene. The government is encouraging the use of butane gas even in rural areas and the shift in the domestic energy from biomass to butane gas is increasing. It should be recognised that this situation is unlikely to be charged for the next one or two decades. However, because of the need to increase energy availability and also to find alternatives to the rapidly decreasing wood supplies in many rural areas; it is necessary that a vigorous programme reaching into alternative renewable energies should set up immediately. There should be much more realism in formation of such a programme, e.g., it is no use providing a solar powered pump at a price competitive with a diesel for some one who cannot ever afford a diesel engine. The renewable energy technology systems (RETs) are simple, from local materials, clean energy, reliable and sustainable.

Specialist on their applications and demonstrations of renewable energy technologies carried out socio-economic and environmental studies. The output of the studies pointed out that, the RETs are acceptable to the people and have measured remarkable impacts on the social life, economic activities and rural environment (Omer, 1996a; Omer, 1996b). Such a programmes should as far as possible be based on renewable energy resources. The encouragement of greater energy use is an essential component of development.

Table 9
Energy required in Sudan rural areas (Omer, 1995b).

Rural energy	Activity
Domestic	Lighting, heating, cooking and cooling
Agricultural process	Land preparation, weaving, harvesting and sowing
Crop process and storage	Drying, grinding and refrigeration
Small and medium industries	Power machinery
Water pumping	Domestic use
Transport	Schools, clinics, communications, radio, televisions, etc.

2.2.1. 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 contributed to play a significant role in energy supply in Sudan as in all other developing countries. Biomass resources should be divided into residues or dedicated resources, the latter including firewood and charcoal from forest resources as shown in Table 10.

Table 10
Annual biomass energy consumption pattern in Sudan (10^3 m^3) (Omer, 1996b).

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%

Table 11
Biomass residues, current use and general availability (Omer, 1997b).

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

Approximately 13 x 10^6 m^3 of biomass are consumed per year as shown in Table 10. To avoid resource depletion, Sudan is currently undergoing a reforestation programme of 1.05 x 10^6 hectares. Biomass residues are more economically exploitable and more environmentally benign than dedicated biomass resources. There exist a variety of readily available sources in Sudan, including agricultural residues such as sugarcane bagasses, and molasses, cotton stalks, groundnut shells, tree/forest residues, aquatic weeds, and various animal wastes as shown in Table 11. Direct burning of fuel-wood and crop residues constitute the main usage of Sudan 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 have investigated the viability of converting the resource to a more useful form, namely solid briquettes and fuel gas. Briquetting is the formation of a charcoal (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 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 (Omer, 1996c).

Briquetting of agricultural residues in Sudan started since 1980, where small entrepreneur constructed a briquetting plant using groundnut shells in Khartoum. The second plant was introduced in Kordofan (western Sudan), and the plant capacity is 2 tonnes per hour with a maximum of 2000 tonnes per season. Another prototype unit was brought and used in Nyala town (South Darfur) with a capacity of 0.5 tonnes per hour (i.e., 600 tonnes per season). Yet these plants are still producing briquettes. In central Sudan, a briquetting plant of cotton stalks was installed at Wad El Shafie village with a capacity of 2 tonnes per hour (i.e., 2000 tonnes per season). The ongoing project in New Halfa is constructed to produce 1200 tonnes per season of bagasse briquettes (Omer, 1996c). A number of factories have been built for carbonisation of agricultural residues, namely cotton stalks. The products are now commercialised. More than 2000 families have been trained to produce their cooking charcoal from the cotton stalks.

In Sudan, most urban households burn charcoal on traditional square ''Canun'' stove that has very low fuel-to-heat conversion efficiencies. The following prototypes were all tried and tested in 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''.

Local traditional stoves were tested, improved, invested, and commercially used in Sudan (Omer, 1997a):

- Traditional muddy stoves.
- Bucket stoves and tin stoves.

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

Gasification is based on the formation of a fuel gas (mostly CO and H) 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, sugarcane 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.). 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 and also, by planting fast growing trees to provide a constant fuel supply. The rural development is essential and economically important since it will eventually lead to better standards of living, people's settlement, and self sufficient in the following:

- Food and water supplies.
- Better services in education and health care.
- Good communication modes.

Table 12
Effective biomass resource utilisation (Omer, 1998a).

Subject	Tools	Constraints
Utilisation and land clearance for agricultural 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

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, and pulp; and paper industries can be used to produce useful energy either by direct incineration, gasification, digestion (biogas production), fermentation, or cogeneration (Omer, 1998a).

The use of biomass through direct combustion has long been, and still is, the most common mode of biomass utilisation as shown in Tables 11, 12, and 13. Examples for 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 require substantial amount of water to be mixed with the biomass.

Table 13
Agricultural residues routes for development (Omer, 1998a).

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 Energy services
	Fermentation	Biogas	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

The use of biofuels to replace fossil fuels contributes to a reduction in the overall release of carbon dioxide into the atmosphere and hence helps to tackle global warming. The range of waste treatment technologies that are tailored to produce bioenergy is growing. There are a number of key areas of bioenergy from wastes including (but not limited to) biogas, biofuels and bioheat. When considering using bioenergy, it is important to take into account the overall emission of carbon in the process of electricity production.

2.2.2. Hydropower generation

Hydropower plants are classified by their rated capacity into one of four regimes: micro (< 50 kW); mini (50-500 kW); small (500 kW-5 MW); and large (> 5 MW). The numbers of hydropower plants are given in Table 4, accounting for about 1% of total hydropower available in Sudan.

Hydro potential is promising in Sudan. A number of prospective areas have been identified by surveys and studies carried for exploration of mini-hydropower resources in Sudan. Mini and micro hydro can be utilised or being utilised in Sudan in two ways:

- Using the water falls from 1 m to 100 m; energy can be generated, and small power can be generated up to 100 kW.
- Using the current flow of the Nile water i.e., the speed of the Nile water. The water speed can be used to run the river turbines (current river turbines), and then water can be pumped from the Nile to the riverside farms. There are more than 200 suitable sites for utilisation of current river turbines along the Blue Nile and the main Nile (Omer, 1998b).

The total potential of mini-hydro shows 67000 MWh for southern region, 3785 MWh in Jebel Marra area, and 44895 MWh in El Gezira and El Managil canals. Small-scale hydro plants (under 5 MW) are more environmentally benign than the large-scale hydro projects that often involve huge dams and permanent restructuring of the landscape. These smaller plants are perfectly suited for some regions of Sudan where there is plenty of rainfall and mountainous or hilly lands cope such as Jebel Marra. The current distributions of electric power for different states in Sudan are mainly from hydro 55%, and thermal generation 45%.

2.2.3. Solar energy

Sunlight is the driving force behind many of the renewable energy technologies. The worldwide potential for utilising this resource, both directly by means of the solar technologies and indirectly by means of bio-fuels, wind and hydro technologies is vast. The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39 x 10^6 km and, is on average, a distance of 1.5 x 10^{18} km from earth (Omer, 1998c). Energy occurring in the sun comes from the thermonuclear reaction; the reaction causes the reduction in solar mass by approximately 4 x 10^9 kgs^{-1}, and simultaneously releases energy at a rate of 3.85 x 10^{23} kW. However, only 1.79 x 10^4 kW of solar energy is received by the earth (Omer, 1999a). Solar energy is an inexhaustible source of energy. The solar constant is defined as the amount of energy, which received at the outer fringe of the earth's atmosphere 1.35 kWm^{-2} (Omer, 1999b).

Sudan has been considered as one of the best countries for exploiting solar energy. Sunshine duration is ranging from 8.5 to 11 hours per day, with high level of solar radiation regime at an average of 20 to 25 MJm^{-2} day^{-1} on the horizontal surface as shown in Table 14. The annual daily mean global radiation ranges from 3.05 to 7.62 $kWhm^{-2}$ day^{-1}. However, Sudan has an average of 7-9 GJm^{-2} $year^{-1}$, equivalent to 436-639 Wm^{-2} $year^{-1}$ (Omer, 2001). The solar radiation before reaches the earth surface is affected by many factors, e.g., absorption, scattering, and reflection.

Table 14
Correlation of solar radiation with other weather parameters in Sudan (Yearly averages) (Omer, 2000a).

Station	Mean temp. (ºC)	Sunshine duration (h)	Solar radiation (MJm^{-2} day^{-1})	Wind velocity (ms^{-1})	Relative humidity (%)
Port Sudan	28.4	9.0	20.87	5.1	65
Shambat	29.7	9.9	22.82	4.5	31
Wad Medani	28.4	9.8	22.84	4.5	40
El Fasher	25.8	9.6	22.80	3.4	33
Abu Na'ama	28.2	8.8	21.90	3.1	46
Ghazala Gawazat	27.2	9.3	21.72	3.0	43
Malakal	27.9	7.8	19.90	2.8	54
Juba	27.6	7.8	19.59	1.5	66
Dongola	27.2	10.5	24.06	4.6	27
Toker	28.8	7.3	17.60	4.1	53
Hudeiba	29.3	10.0	22.37	4.0	25
Aroma	29.1	9.6	21.40	4.2	37
El Showak	26.3	9.7	22.90	4.1	39
Zalingei	24.5	8.8	22.98	2.7	39
Babanusa	28.2	8.9	21.73	2.8	48
Kadugli	27.5	8.5	21.30	2.7	48

The country strives hard to make use of technologies related to renewable sources in rural areas where it is appropriate and applicable. Sudan already has well-established solar thermal applications. The most promising solar energy technologies are related to thermal systems; industrial solar water heaters in the residential sector and in larger social institutions, such as nurseries, hospitals, and schools. Solar cookers, solar dryers for peanut crops, solar stills, solar driven cold stores to store fruits and vegetables, solar collectors, solar water desalination, solar ovens and solar commercial bakers. Solar photovoltaic system (PV): solar PV for lighting, solar refrigeration to store vaccines for human and animal use, solar PV for water pumping, solar PV for battery chargers, solar PV for communication network, microwave receiver stations, radio systems in airports, VHF and beacon radio systems in airports, and educational solar TV posts in some villages (Omer, 2000b).

2.2.4. Wind energy potential

The use of wind as a source of power has a long history. Wind power has been used in the past for water pumping, corn grinding, and provision for power for small industries. In areas of low population density where implementation of a central power system would be uneconomical, the decentralised utilisation of wind energy can provide a substantial contribution to development (Omer, 2001; Omer, 2003a). The use of the wind machine is divided into two; one is the use of small-scale wind machines for water pumping or electricity generation, and the other is the use of large-scale wind machines for generating electricity (big wind machines or wind farms). However, the wind machine can be used for pumping water, electricity generation or any other task. A programme of wind power for generating electricity as well as for pumping water appears to be attractive for rural development, e.g., lights, radios, and televisions. Wind electric generators can be utilised to meet the power requirements of isolated settlements. Wind energy is found to match well with the demand pattern of the loads, high load during the day for illumination. Wind energy has considerable resources in Sudan where the annual average wind speeds exceeds 5 ms^{-1} in the most parts north latitude 12^{o} 'N (at the coastal area along the Red Sea), and along the Nile valley (from Wadi Halfa to Khartoum, and south of Khartoum covering the El Gezira area). The southern regions have the poorest potential because of the prevailing low wind speeds. Many designs of wind machines have been suggested and built in Sudan as shown in Table 15.

Table 15
Number of wind pumps installed for irrigation purpose in Sudan (Omer and Yemen, 2003b).

Location	No. of pumps
Tuti island (Khartoum state)	2
Jebel Aulia (Khartoum state)	1
Soba (Khartoum state)	4
Shambat (Khartoum state)	4 (one was locally manufactured)
Toker (eastern Sudan)	2 (both locally manufactured)
Karima (northern Sudan)	2 (both locally manufactured)
Total	15

In Sudan, wind energy is today mainly used for water pumping. Wind has not yet been significantly exploited for power generation. Experience in wind energy in Sudan was started since the 1950's, where 250 wind pumps from the Australian government, had been installed in El Gezira Agricultural Scheme (Southern Cross Wind Pumps). But, these pumps were gradually disappeared due to the lack of spare parts and maintenance skills combined with stiff competition from relatively cheep diesel pumps. However, the Sudanese government has recently begun to recognise the need to reintroduce wind pump technology to reduce the country's dependence on oil. This increases economic security, given high and/or fluctuating oil prices, and it helps to reduce the trade deficit. Using wind power also allows for pumping in rural areas where transportation of oil might be difficult.

In the last 15 years the Energy Research Institute (ERI) installed 15 Consultancy Services Wind Energy Developing Countries (CWD 5000 mm diameter) wind pumps around Khartoum area, Northern state, and Eastern state. Now the ERI with the cooperation of the Sudanese Agricultural Bank (SAB) has introduced 60 wind pumps to be used for water pumping in agricultural schemes, but only 5 were manufactured and installed. The other 55 are in the process of locally manufacturing. The maximum extractable monthly mean wind power per unit cross sectional area, P, is given by (Omer and Yemen, 2003b):

$$P = 0.3409\ V^3 \quad (1)$$

Where:
P is the wind power Wm^{-2}; and V is the average wind speed ms^{-1}.

The amount of power extracted from the wind depends generally on the design of the wind rotor. In practice the wind machine power will be lost by the aerodynamic affects of the rotor. An important problem with wind pump system is matching between the power of the rotor, and that of the pump. In general the wind pump systems consist of the following items:

- The wind rotor.
- Transmission.
- The pump.

The overall efficiency of the system is given by the multiplication of the rotor efficiency, transmission efficiency, and the pump efficiency (Omer, 2005).

$$\eta_{Overall} = \eta_{rotor} \times \eta_{transmission} \times \eta_{pump} \qquad (2)$$

For wind pumps though efficiency is important, a more suitable definition is the number of gallons of water pumped per day per dollar. A sizing of wind pump for drinking and irrigation purposes usually requires an estimation of hourly, daily, weekly, and monthly average output. The method for making such estimation is combining data on the wind pump at various hourly average wind speeds with data from a wind velocity distribution histogram (or numerical information on the number of hours in the month that wind blows within predefined speed). The result is given in Table 16, which gives the expected output of wind pump in various wind speeds, and the statistical average number of hours that the wind blows within each speed range.

Generally, it is concluded that wind pump systems have a potential to fulfil water lifting needs, both in Khartoum area and even in remote rural areas, both for irrigated agriculture and water supply for man and livestock. This conclusion is based on:

- Studies of several agencies dealing with the feasibility of wind pumps.
- The history of water pumping in the Gezira region for drinking purposes.
- The national policy of Sudan vis a vis wind energy.

Table 16
Wind speeds versus wind pump discharges (Omer, 2007a).

Wind speeds (ms^{-1})	Annual duration (h)	Output rate (m^3h^{-1})
3.0	600	0.3
3.5	500	1.4
4.0	500	2.3
4.5	400	3.0
5.0	500	3.7
5.5	450	4.3
6.0	450	4.7
6.5	300	5.2
7.0	300	5.7

Sudan is rich in wind; mean wind speed of 4.5 ms^{-1} are available over 50% of Sudan, which is well suited for water lifting and intermittent power requirements, while there is one region in the eastern part of Sudan that has a wind speed of 6 ms^{-1} which is suitable for power production. In areas where there is wind energy potential but no connection to the electric grid the challenge is simplicity of design, and higher efficiency (Omer, 2006). Because of this potential for fulfilment of rural water pumping needs, it is recommended to continue the development of wind pumping in Sudan. The most obvious region to start with seems to be the northern regions because of a combination of:

- Favourable wind regime.
- Shallow ground water level 5-10 meters depth.
- Existing institutional infrastructures.

The research and development in the field of wind machines should be directed towards utilising local skills and local available materials. Local production of wind machines should be encouraged in both public and private organisations.

2.2.5. Sugarcane biomass

Residuals from the sugarcane 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 and Sudan has been one of the world's leading sugar producers. Sugarcane plantations cover one-fifth of the arable land in Sudan. In addition to raw sugar, Sudan enterprises produce and utilise many valuable cane co-products for feed, food, energy and fibre. At present, there are 5 sugar factories as illustrated in Table 17.

Sugarcane bagasse and sugarcane 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, as elsewhere in the developing world, 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 of Sudan's current electricity demand.

In Sudan there are no alcohol distilleries since 1983. The three factories have disappeared with Islamic Laws. The current circumstances suggest that Sudan should consider expanding production for use as transportation fuel, but this option has not yet been pursued. The alcohol is used for a variety of applications, mainly for medical purposes and rum production. Blending with gasoline would also have direct environmental advantages by substituting for lead as an octane enhancer. Kenana Sugar Factory has recently established a factory for the production of ethanol.

2.2.6. Geothermal energy

In Sudan (Omer, 2008) geothermal resources have been identified, and the following sites are expected to have a significant potential:

- Volcanic Jebel Marra area.
- The Red Sea littoral (Suwakin area).
- Volcanic territories.
- Some other remote areas.

Table 17
Annual sugarcane bagasse available in Sudan (10^3 tonnes) (Omer and Siddig, 2007b).

Factory	Design capacity	Yearly bagasse
Kenana	300	266
El Genaid	60	53
New Halfa	75	65
Sennar	100	58
Asalaia	100	60
Total	635	502

Scientific studies are needed on the above sites for the geothermal energy availability, and then the economic and social feasibility studies can be done.

3. Biomass potential

Combined heat and power (CHP) installations are quite common in greenhouses, which grow high-energy, input crops (e.g., salad vegetables, pot plants, etc.). Scientific assumptions for a short-term energy strategy suggest that the most economically efficient way to replace the thermal plants is to modernise existing power plants to increase their energy efficiency and to improve their environmental performance. However, utilisation of wind power and the conversion of gas-fired CHP plants to biomass would significantly reduce Sudan's dependence on imported fossil fuels. Although a lack of generating capacity is forecast in the long-term, utilisation of the existing renewable energy potential and the huge possibilities for increasing energy efficiency are sufficient to meet future energy demands in Sudan in the short-term.

A total shift towards a sustainable energy system is a complex and long process, but is one that can be achieved within a period of about 20 years. Implementation will require initial investment, long-term national strategies and action plans. However, the changes will have a number of benefits including: a more stable energy supply than at present and major improvement in the environmental performance of the energy sector, and certain social benefits. A vision used a methodology and calculations based on computer modelling that utilised:

- Data from existing governmental programmes.
- Potential renewable energy sources and energy efficiency improvements.
- Assumptions for future economy growth.
- Information from studies and surveys on the recent situation in the energy sector.

In addition to realising the economic potential identified by the National Energy Savings Programme, a long-term effort leading to a 3% reduction in specific electricity demand per year after 2020 is proposed. This will require: further improvements in building codes, and continued information on energy efficiency. The environmental NGOs in Sudan are urging the government to adopt sustainable development of the energy sector by:

- Diversifying of primary energy sources to increase the contribution of renewable and local energy resources in the total energy balance.
- Implementing measures for energy efficiency increase at the demand side and in the energy transformation sector.

The price of natural gas is set by a number of market and regulatory factors that include:

Supply and demand balance and market fundamentals, weather, pipeline availability and deliverability, storage inventory, new supply sources, prices of other energy alternatives and regulatory issues and uncertainty.

Classic management approaches to risk are well documented and used in many industries. This includes the following four broad approaches to risk:

Avoidance includes not performing an activity that could carry risk. Avoidance may seem the answer to all risks, but avoiding risks also means losing out on potential gain.

Mitigation/reduction involves methods that reduce the severity of potential loss.

Retention/acceptance involves accepting the loss when it occurs. Risk retention is a viable strategy for small risks. All risks that are not avoided or transferred are retained by default.

Transfer means causing another party to accept the risk, typically by contract.

3.1. Risk management

Financial hedges (such as futures and options) are contractual vehicles that convey rights and obligations to buy or sell a commodity at a specified price. Possible purchasing strategies using hedges are summarised in Table 18. These financial derivations are a method of reducing price risk with a relatively modest transaction price. Over the past 10 years the use of financial hedges has grown dramatically. Figure 1 illustrates various hypothetical reduction strategies and the resulting average fuel price. The basic concept is to utilise existing financial tools to guard against conditions that will negatively affect the operating budget. Basic hedges include:

- Swap contract- a bilateral agreement with a party that agree to guarantee a ‘fixed’ price.
- Future contract- a financial tool that limits upside price exposure.
- Options contract- a financial tool that can limit upside and downside price exposure (‘puts’ are a hedge against falling prices, and ‘calls’ are a hedge against rising prices).

Politicians at the local and national level have evaluated sustainability as an important issue facing the communities. The future will have leaders who develop sustainable solid waste programmes that further improve the community to achieve the following:

- Reduce the generation of solid waste by establishing policies that encourage manufacturers to reduce packaging material volumes.

- Reuse/recycle/recover the pre-collection waste.
- Promote the development of 'green' local secondary material manufacturing facilities through implementation of tax credits and incentives.
- Thermally treat the remaining waste by either incineration or gasification and produce renewable 'green power' or 'green energy'.
- Landfill the discarded/unusable material.

The demand for energy continues to outstrip supply and necessitates the development of renewable energy option. Effective low-carbon and renewable energy policies need to encourage millions of building owners, developers, and construction companies to invest. To do this, incentives need to be reliable, predictable and sufficiently valuable and long-term in nature to encourage sustained investment. An effective strategy needs to be developed that would address these characteristics and provide the support needed to stimulate the market to create a level playing field electricity producing projects:

- First, polices should be based on a long-term meaningful price for carbon. Currently there is no carbon price for heating or cooling, as existing mechanisms do not apply to this market.
- Secondly, policies should support innovation. A heating and cooling strategy could encourage innovation in technologies, building design and urban planning, controls and metering. It should also drive innovation in financing and commercial structures.
- Thirdly, it should encourage behaviour change. A strategy that encourages low-carbon and renewables could through small-scale technologies give the public a clear opportunity to become directly involved a solution to climate change and change consumers' view surrounding these technologies.

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.

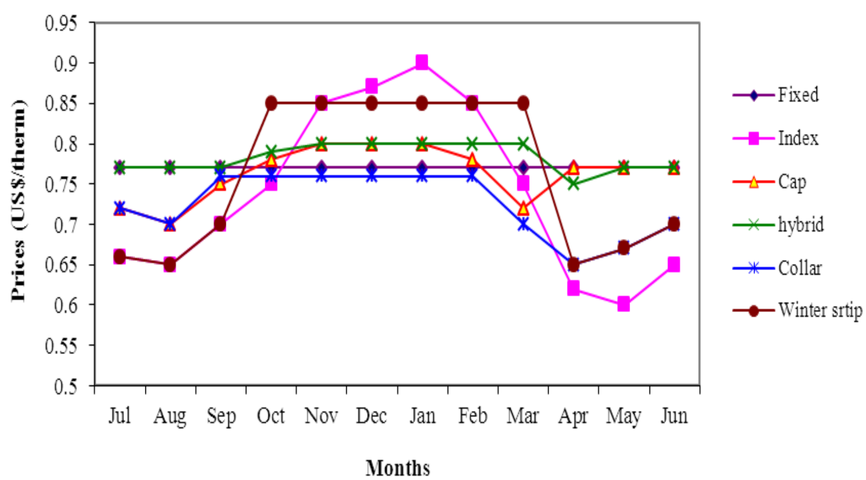

Fig. 1. Purchasing strategies using hedges.

Table 18
Purchasing strategies using hedges.

Strategy	Description
Index	Fuel is purchased month-by-month at a first of the month index price
Forward physical purchase	Monthly fuel is purchased in advance for an averaged fixed price
Cap	A fixed price for fuel is set, but 'put' contracts are purchased to guarantee that when future market prices for fuel settle below the fixed cost, the monthly price is adjusted downward towards the tower index price
Collar	A series of 'put' and 'call' contracts are purchased to guarantee that monthly prices for fossil fuel will be contained within a defined price range regardless of market conditions
Hybrid	Where a percentage of each month's fuel needs are purchased at a fixed price, and the reminder purchased at an index price
Winter strip	Fuel purchased at a fixed price from November through March, and at an index price all other months

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 (Omer, 2009). Biogas from biomass appears to have potential as an alternative energy in Sudan, which is potentially rich in biomass resources.

4. Biogas technology

Biogas is a generic term for gases generated from the decomposition of organic material. As the material breaks down, methane (CH_4) is produced as shown in Figure 2. Sources that generate biogas are numerous and varied. These include landfill sites, wastewater treatment plants and anaerobic digesters.

Presently, Sudan uses a significant amount of kerosene, diesel, firewood, and charcoal for cooking in many rural areas. Biogas technology was introduced to Sudan in mid seventies when the 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. In Sudan, there are currently over 200 installed biogas units, 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.

Biogas technology is not only for the provision of fuel, but it is also important for comprehensive utilisation of biomass forestry, animal husbandry, fishery, evolutions the agricultural economy, protecting the environment, and realising 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 (Wesselink et al., 2002).

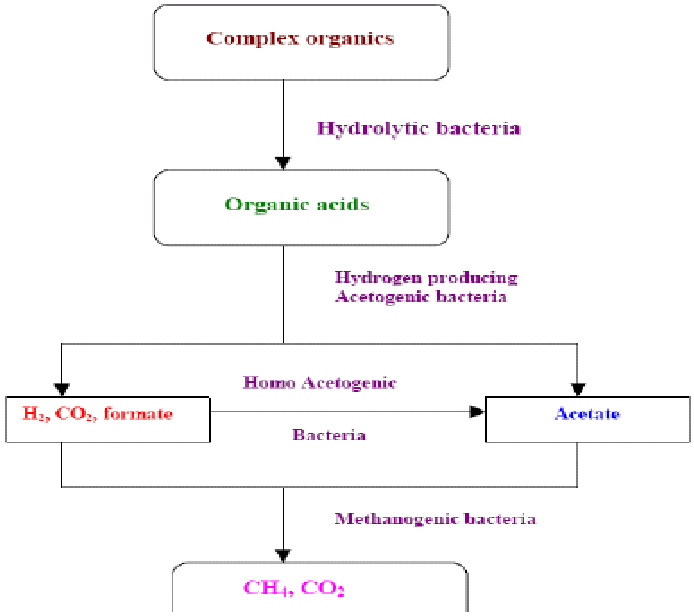

Fig. 2. Biogas production processes (Wesselink et al., 2002).

Biogas typically comprises of 50%-75% methane and carbon dioxide along with other minor gases. It is the methane that is used for the generation of electricity or use as a fuel for transportation. Biogas is produced by anaerobic digestion where complex carbon molecules in organic material are broken down into simpler structures including CH_4 and CO_2. Biogas can be produced from a variety of biodegradable waste feedstocks including sewage sludge, biodegradable waste and mixed municipal waste or as a natural process of decomposition in landfills. Typically different variants of anaerobic digesters need to be used to treat each different feedstock optimally. The absorption potential of agricultural soils could contribute significantly to fulfilling the goal to reduce carbon dioxide emissions. Compost as a soil improver is primarily intended to give organic matter to soils, thereby resulting in many benefits of improving levels of organic matter in soil such as: improved structure and workability, improved water retention and locking up carbon in soils, which will be retained in a comparatively long time frame.

Many possible side effect of compost application can also be considered including:

- A reduction in the use of pesticides (might imply avoiding emissions for their production).
- Improved workability (might lead to less consumption of fuels).
- The displacement of chemical fertilisers (implies avoidance of greenhouse gases and energy uptake related to their production).

Bacteria form biogas during anaerobic fermentation of organic matters. The degradation is very complex process and requires certain environmental conditions as well as different bacteria population. The complete anaerobic fermentation process is briefly described below as shown in Table 19.

Table 19
Anaerobic degradation of organic matter (Wesselink et al., 2002).

Level	Substance	Molecule	Bacteria
Initial	Manure, vegetable, wastes	Cellulose, proteins	Cellulolytic, proteolytic
Intermediate	Acids, gases, oxidised, inorganic salts	CH_3COOH, $CHOOH$, SO_4, CO_2, H_2, NO_3	Acidogenic, hydrogenic, sulphate reducing
Final	Biogas, reduced inorganic compounds	CH_4, CO_2, H_2S, NH_3, NH_4	Methane formers

4.1. Biogas utilisation

The importance and role of biogases in energy production is growing. Nowadays, a lot of countries in Europe promote utilisation of renewable energies by guaranteed refund prices or emission trading systems. A general schematic of an agricultural biogas plant, with the anaerobic digester at the 'heart' of it as shown in Figure 3. Pre-treatment steps (e.g., chopping, grinding, mixing or hygienisation) depend on the origination of the raw materials.

In the past two decades the world has become increasingly aware of the depletion of fossil fuel reserves and the indications of climatic changes based on carbon dioxide emissions. Therefore extending the use of renewable resources, efficient energy production and the reduction of energy consumption are the main goals to reach a sustainable energy supply. Renewable energy sources include water and wind power, solar and geothermal energy, as well as energy from biomass. The technical achievability and the actual usage of these energy sources are different around Europe, but biomass is seen to have a great potential in many of them. An efficient method for the conversion of biomass to energy, is the production of biogas by microbial degradation of organic matter under the absence of oxygen (anaerobic digestion). It is now possible to produce biogas at rural installation, upgrade it to bio-methane, feed it into the gas grid, use it in a heat demand-controlled CHP and to receive revenues.

Biogas is a mixture containing predominantly methane (50-65% by volume) and carbon dioxide and in a natural setting it is formed in swamps and anaerobic sediments, etc., due to its high methane concentration, biogas is a valuable fuel. Wet (40-95%) organic materials with low lignin and cellulose content are generally suitable for anaerobic digestion (Figure 4). A key concern is that treatment of sludge tends to concentrate heavy metals, poorly biodegradable trace organic compounds and potentially pathogenic organisms (viruses, bacteria and the like) present in wastewaters. These materials can pose a serious threat to the environment. When deposited in soils, heavy metals are passed through the food chain, first entering crops, and then animals that feed on the crops and eventually human beings, to whom they appear to be highly toxic. In addition they also leach from soils, getting into groundwater and further spreading contamination in an uncontrolled manner. European and American markets aiming to transform various organic wastes (animal farm wastes, industrial and municipal wastes) into two main by-products:

- A solution of humic substances (a liquid oxidate).
- A solid residue.

4.2. Ecological advantages of biogas technology

An easier situation can be found when looking at the ecological effects of different biogas utilisation pathways. The key assumptions for the comparison of different biogas utilisation processes are:

- Biogas utilisation in heat demand controlled gas engine supplied out of the natural gas grid with 500 kWe - electrical efficiency of 37.5%, thermal efficiency of 42.5%, and a methane loss of 0.01.
- Biogas utilisation in a local gas engine, installed at the biogas plant with 500 kWe - electrical efficiency of 37.5%, thermal efficiency of 42.5%, and a methane loss of 0.5.
- Biogas production based on maize silage using a biogas plant with covered storage tank - methane losses were 1% of the biogas produced.
- Biogas upgrading with a power consumption 0.3 kWhe/m^3 biogas - methane losses of 0.5.

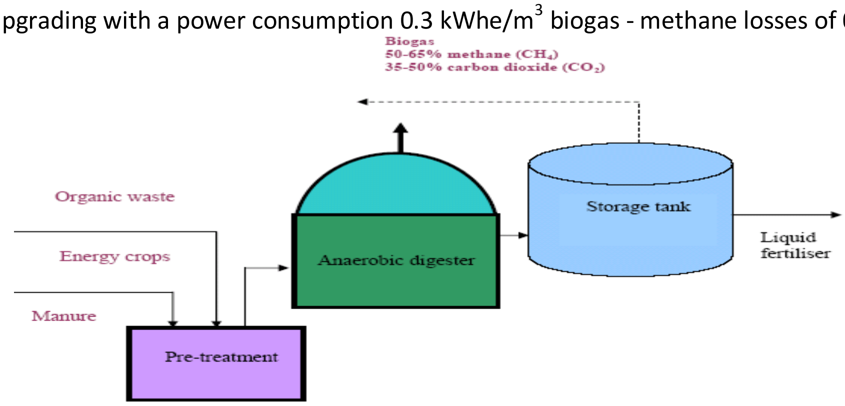

Fig. 3. General schematic of an agricultural biogas plant.

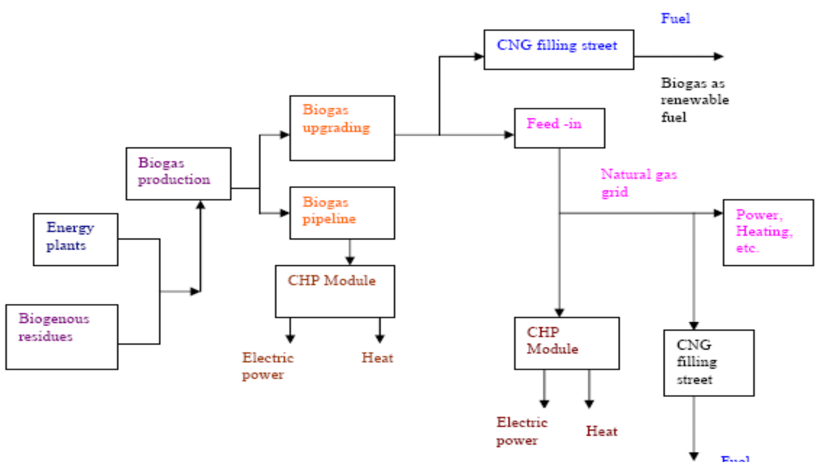

Fig. 4. Overview of biogas utilisation pathways.

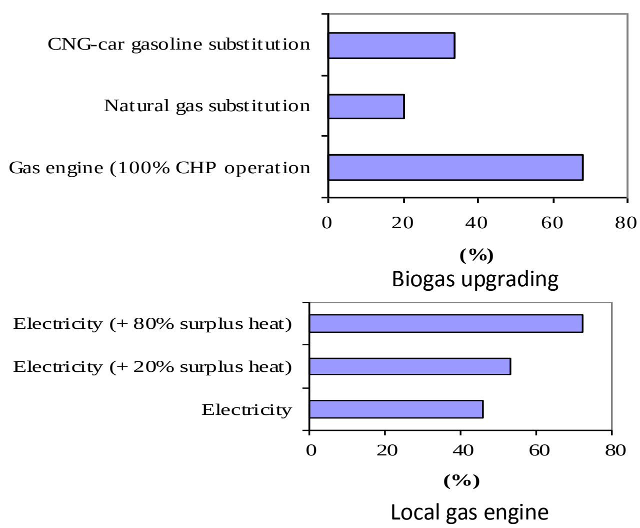

Fig. 5. Greenhouse gas emissions savings for different biogas utilisation pathways in comparison to fossil energy production.

Figure 5 presents the results of the greenhouse gas (GHG) savings from the different biogas utilisation options, in comparison to the fossil fuel-based standard energy production processes. The organic matter was biodegradable to produce biogas and the variation show a normal methanogene bacteria activity and good working biological process. Biogas can be converted to energy in several ways. The predominant utilisation is combined heat and power (CHP) generation in a gas engine installed at the place of biogas production. There are mainly two reasons for this. First, biogas production is an almost continuous process; it is rather difficult or, in the short-term, even impossible, to control the operation of anaerobic digesters according to any given demand profile. Secondly, promotion of renewable energies is focused on electricity production. Because of that, biogas plant operators receive the predominant fraction of revenues from the guaranteed feed-in tariffs for electricity. Summarising the results of the eco-balances it becomes obvious that - not only by using fossil fuels but also by using renewable fuels like biogas – combined heat and power cogeneration is the optimal way for fighting climate change (Table 20). From a technical point of view it can be concluded that biogas production, i.e., the conversion of renewable resources and biowaste to energy, can be seen as state-of-the-art technology.

Table 20
Comparison of various fuels (Wesselink et al., 2002).

Fuel	Calorific value (kcal)	Burning mode	Thermal efficiency (%)
Electricity, kWh	880	Hot plate	70
Coal gas, kg	4004	Standard burner	60
Biogas, m^3	5373	Standard burner	60
Kerosene, l	9122	Pressure stove	50
Charcoal, kg	6930	Open stove	28
Soft coke, kg	6292	Open stove	28
Firewood, kg	3821	Open stove	17
Cow dung, kg	2092	Open stove	11

Agricultural wastes are abundantly available globally and can be converted to energy and useful chemicals by a number of microorganisms. The organic matter was biodegradable to produce biogas and the variation show a normal methanogene bacteria activity and good working biological process as shown in Figures 6-7. The success of promoting any technology depends on careful planning, management, implementation, training and monitoring.

Main features of gasification project are:

- Networking and institutional development/strengthening.
- Promotion and extension.
- Construction of demonstration projects.
- Research and development, and training and monitoring.

Biomass is a raw material that has been utilised for a wide variety of tasks since the dawn of civilisation. Important as a supply of fuel in the third world, biomass was also the first raw material in the production of textiles. The gasification of the carbon char with steam can make a large difference to the surface area of the carbon. The corresponding stream gasification reactions are endothermic and demonstrate how the steam reacts with the carbon charcoal (Wesselink et al., 2002).

$$H_2O\ (g) + C_x\ (s) \rightarrow H_2\ (g) + CO\ (g) + C_{x-1}\ (s) \quad (3)$$
$$CO\ (g) + H_2O\ (g) \rightarrow CO_2\ (g) + H_2\ (g) \quad (4)$$
$$CO_2\ (g) + C_x\ (s) \rightarrow 2\ CO\ (g) + C_{x-1}\ (s) \quad (5)$$

The sources to alleviate the energy situation in the world are sufficient to supply all foreseeable needs. Conservation of energy and rationing in some form will however have to be practised by most countries, to reduce oil imports and redress balance of payments positions. Meanwhile development and application of nuclear power and some of the traditional solar, wind and water energy alternatives must be set in hand to supplement what remains of the fossil fuels.

The encouragement of greater energy use is an essential component of development. In the short-term it requires mechanisms to enable the rapid increase in energy/capita, and in the long-term we should be working towards a way of life, which makes use of energy efficiency and without the impairment of the environment or of causing safety problems. Such a programme should as far as possible be based on renewable energy resources.

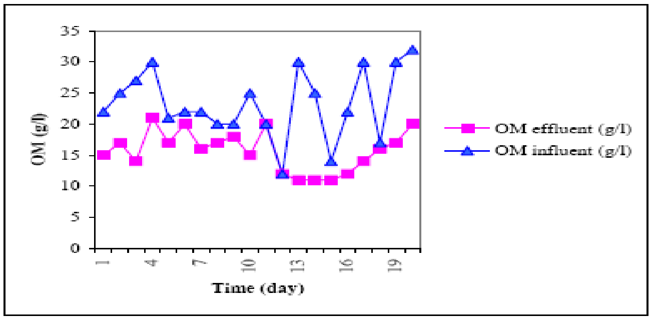

Fig. 6. Organic matters before and after treatment in digester (Wesselink et al., 2002).

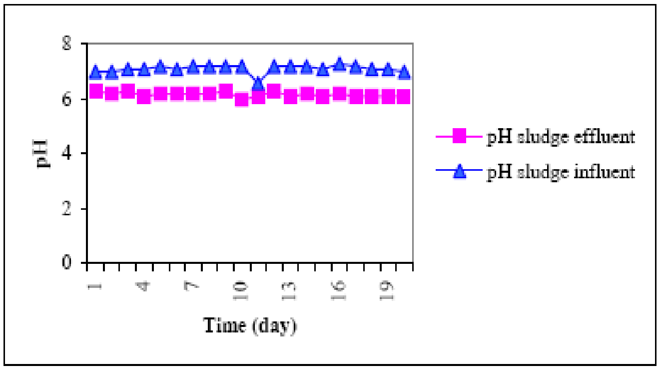

Fig. 7. Potential of hydrogen (pH) sludge before and after treatment in the digester (Wesselink et al., 2002).

4.3. Factors to be considered in economic analysis

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. In some rural communities, cultural beliefs regarding handling animal dung are prevalent and will influence the acceptability of biogas technology. Co-ordination of production and use of biogas, fertiliser and pollution control can optimise the promotion and development of agricultural and animal husbandry in rural areas.

4.3.1. Economic factors

- Interest on loan
- Current/future cost of alternative fuels
- Current/future cost of chemical fertiliser
- Current/future cost of construction materials
- Saving of foreign currency
- Current/ future labour cost
- Inflation rate
- Costs of transport of feeding materials and effluents

4.3.2. Social factors

- Employment created
- Better lighting: more educational/cultural activities
- Less time consumed for fetching firewood and for cooking
- Improved facilities in villages; thus less migration to cities
- Less expense for buying alternative fuels
- More time for additional income earning activities

4.3.3. Technical factors

- Construction, maintenance and repairs of biogas plants
- Availability of materials and land required
- Suitability of local materials

4.3.4. Ecological/health factors

- Improved health
- Forest conservation (positive or negative)
- Environment pollution abatement
- Improvement in yields of agricultural products

Growth, modernisation and urbanisation in many states of Sudan have created both energy supply shortages and a growing source of free fuel: biogas. The use of biogas has been proven and is ready to be deployed in Sudan. The technology is available, it is economically feasible and it is reliable. An additional benefit of using these gases as a fuel source is minimisation of the environmental impacts that result from gas venting or flaring. The burning of such gases release air-borne pollutants, which can also enter groundwater sources and pollute farmlands. The optimum range in Table 21 is for ambient temperatures during hot seasons of Sudan tropical climates. The potential gas volumes produced from wastes vary depending on many factors, and can be expressed based in head count.

Biogas from biomass appears to have potential as an alternative energy source, which is potentially rich in biomass resources. This is an overview of some salient points and perspectives of biogas technology. The current literature is reviewed regarding the ecological, social, cultural and economic impacts of biogas technology. This communication gives an overview of present and future use of biomass as an industrial feedstock for production of fuels, chemicals and other materials. However, to be truly competitive in an open market situation, higher value products are required. Results suggest that biogas technology must be encouraged, promoted, invested, implemented, and demonstrated, but especially in remote rural areas.

Table 21
Optimum conditions for biogas production (WRI, 1994).

Parameter	Optimum value
Temperature ºC	30-35
pH	6.8-7.5
Carbon/Nitrogen ratio	20-30
Solid content (%)	7-9
Retention time (days)	20-40

4.4. Improved sanitation, water and indoor air quality

Health problems associated with leakage of human wastes into the wider environment can occur due to pit toilets becoming overfull due to inadequate pit depths and toilets being cited too close to water sources. Human wastes can also leach into ground water from a functioning pit toilet if cited on a highly permeable soil type. Contamination of groundwater and reservoirs by running storm water and flash floods can result in significant sporadic pollution events

The type of contamination includes enterobacteria, enteroviruses and a range of fungal spores. Some key human/animal pathogens that may be spread in this way include *Salmonella typhi, Staphylococus spp, E. coli, Campylobacter coli, Listeria monocytogenes, Yersinia enterocolitica, Hepatitis* B and C viruses*, Rotavirus, Aspergillus spp, Candida spp, Trichophyton spp., Cryptosporidium,* mycobacteria*, Toxoplasma and Clostridium botulinum.* Many of these can be passed between animal and human populations. Cattle slurry introduces a range of pathogens including *Clostridium chavoie* (black leg disease); *Ascaris* ova, *E. coli* and *Salmonella spp*. as reported in cow dung slurries in Bauchi state, Nigeria (Yongabi et al., 2009); Salmonella spp, E. coli, yeasts and aerobic mesophilic bacteria in poultry wastes in Cameroon (Yongabi et al., 2003). Pathogen prevalence in the environment is affected by local climate, soil type, animal host prevalence, topography, land cover and management, organic waste applications and hydrology.

Interest in the use of small scale biogas digesters for household energy generation and treatment and utilisation of organic wastes in rural areas of Sub-Saharan Africa (SSA) has been increasing with numerous organisations promoting their adoption for both socioeconomic and environmental benefits. In this study, we review energy production using small-scale biogas digesters in the SSA, a technology that is already improving the lives of poor people in many parts of the developing world, but has to-date had only limited uptake in Africa. Small-scale biogas digesters have great potential to contribute to sustainable development by providing a wide variety of socioeconomic benefits, including diversification of energy (cooking fuel) supply, enhanced regional and rural development opportunities, and creation of a domestic industry and employment opportunities. Potential environmental benefits include reduction of local pollutants, reduced deforestation due to logging for fuel, and increased sequestration of carbon in soils amended with the digested organic waste. Ecosystem services that are potentially delivered through implementation of biogas digesters include carbon sequestration, improved water quality and increased food production. Carbon can be directly sequestered in the soil through application of soil organic matter originating from the digested material. Indirect carbon sequestration can also be achieved through reduced carbon losses due to logging as household fuel is replaced by methane produced by the digester. Replacement of household fuel by biogas has added benefits to household air quality. Water quality can be improved through reduced runoff of waste material and reduced erosion of sandy soils due to stabilisation of the soil through increased input of organic matter. Food production can be improved by application to the soil of digested material containing readily available nutrients. The productivity of the soil can also be improved through improved soil structure and water holding capacity achieved by the organic amendments of digested material to the soil.

In most developing countries, for example, Bangladesh, Burundi, Bolivia, Ivory Coast, Tanzania and Thailand, biogas is produced through anaerobic digestion of human and animal excreta using the Chinese fixed-dome digester and the Indian floating cover biogas digester (WRI, 1994). These plants were built for schools and small-scale farmers, in most cases by non-governmental organisations (NGOs). Most of the plants have only operated for a short period due to poor technical quality. There is thus a need to introduce more efficient reactors to improve both the biogas yields and the reputation of the technology. Factors that control crop production include uptake of nutrients, water and oxygen, light interception, and temperature. The environmental constraints that directly impact these factors include availability of nutrients, organic matter content of the soil, water availability and climate. The widespread introduction of biogas digesters is likely to have an impact on all of these environmental constraints.

Access to an improved water source is not prevalent in Africa and contaminated or polluted water sources present a major health risk. Access to water is a precondition for sedentary agriculture and livestock husbandry, improved sanitation and the proper operation of a biogas plant. Occurrence of diarrhea is closely related to polluted water sources and poor sanitation practices. For African children, diarrhea is a very serious health threat. All countries in the central east-west band of Africa suffer major health and sanitation problems. Many of these countries have the potential to improve their sanitation through use of domestic biogas digesters, and improvements in the technology may further increase the potential for use of biogas digesters. Biogas digesters have the potential to reduce the risks of encountering these pathogens if properly operated. However, risks could be increased due to the person handling the materials undergoing increased direct contact with these pathogens, the digester amplifying the growth of certain pathogens, or the processed material from the digester being used as a fertiliser for agricultural crops where it would not otherwise have been used. The risks from these pathogens can be mitigated by developing a toolkit that includes safe operating instructions. Microbiological data should be generated for the pathogens or indicator organisms to determine the extent to which the levels change during the anaerobic digestion process. Advice on the use of the processed materials in agricultural production should also be provided.

The organic carbon content of soils in Sub-Saharan Africa tends to be low due to the high temperatures, low clay contents (or cation exchange capacity) and low organic inputs due to poor crop nutrition. However, increasing the organic inputs, increases the steady state carbon content, and so sequesters soil carbon. If organic inputs were increased, for instance by adding material from a biogas digester to the soil, the carbon content of the soil would increase until it reached a new steady state level; after that no more carbon would be sequestered unless the organic inputs were further increased. The sequestered carbon is not a permanent store; it will only remain in the soil while the balance between the organic inputs and the rate of decomposition remains the same. If the organic inputs were reduced to their original level, for instance because the material from the biogas digester was no longer available, the amount of carbon held in the soil would return to its original level. Furthermore, if the rate of decomposition increased, for instance due to increased temperatures associated with climate change, the amount of carbon held in the soil would also decrease. The rate of decomposition of material added to the soil also depends on the quality of the organic matter. If sufficient nutrients are available to allow decomposition, fresh material tends to decompose more quickly than material that has been composted or digested. Composted and digested material decomposes more quickly than material that has been converted to charcoal, which is highly recalcitrant.

4.5. Potential of small0-scale biogas in improving soil quality and reducing deforestation

Developing alternative energy source to replace non-renewable sources has recently become more and more attractive due to the high energy demand, the limited resource of fossil fuel, and environmental concerns around the globe. Biogas has become more attractive as an alternative to non-renewable fuels because it is an integrated system with multi-benefits such as diversification of energy (cooking fuel) supply, reduction of local pollutants, reduced deforestation due to logging for fuel; air quality, sanitation and crop yield improvement through sequestration of carbon in soils amended with the digested organic waste. The challenge does not lie in the development of the small-scale biogas digesters; the processes of digestion are already well understood and different designs for low-cost digesters are operational. What is needed is the translational research to make it possible for these digesters to become available to people in the SSA who have little or no disposable income and access to only limited material resources. Development is needed of effective, safe and affordable methods for using small-scale biogas digesters to provide household energy and improve sanitation in the range of special conditions found in the SSA, while obtaining the maximum economic and environmental benefits from the digested products, which are an important source of scarce nutrients. Issues that must be considered further to increase accessibility of biogas technology to the rural poor are: a) Can the poor afford the initial investment and maintenance costs? b) Do the poor have access to finance/credit? c) Is there commitment from national governments in disseminating the technology? d) Are the non-government organisations initiated biogas schemes sustainable? e) What is the economic efficiency? f) Is there potential for reducing costs by working at a larger scale? g) What potential is there for improving cost-effectiveness?

There is a need for further research into behavioural studies (choices and preferences) including experimental economics, quantification issues (capturing various costs and benefits components), socio-economic design mechanisms, and barriers to uptake, knowledge transfer (awareness, training, and participation).

4.6. Environmental aspects

A great challenge facing the global community today is to make the industrial economy more like the biosphere, that is, to make it a more closed system. This would save energy, reduce waste and pollution, and reduce costs. In short, it would enhance sustainability. Often, it is technically feasible to recycle waste in one of several different ways. For some wastes there are powerful arguments for incineration with energy recovery, rather than material recycling. Cleaner production approach and pollution control measures are needed in the recycling sector. The industrial sector world widely is responsible for about one third of anthropogenic emissions of carbon dioxide, the most important greenhouse gas (Galal, 1997). Industry is also an important emitter of several other greenhouse gases. And many of industry's products emit greenhouse gases as well, either during use or after they become waste. Opportunities exist for substantial reducing industrial emissions through more efficient production and use of energy. Fuel substitutions, the use of alternative energy technologies, process modification, and by revising materials strategies are to make use of less energy and greenhouse gas intensive materials. Industry has an additional role to play through the design of products that use less energy and materials and produce lower greenhouse gas emissions.

Environmental pollution is a major problem facing all nations of the world. People have caused air pollution since they learned to use fire, but man-made air pollution (anthropogenic air pollution) has rapidly increased since industrialisation began. Many volatile organic compounds and trace metals are emitted into the atmosphere by human activities. The pollutants emitted into the atmosphere do not remain confined to the area near the source of emission or to the local environment, and can be transported over long distances, and create regional and global environmental problems.

From Tables 22 and 23, it is noticed that most of the CO_2 emissions in Sudan are from land-use change, representing 92% of emissions. On the other hand, the emissions of CO_2 from industries represent only 8%, which is mainly from burning liquid and gas petroleum products. The *per capita* CO_2 emission in Sudan was estimated at 0.15×10^3 tonnes in 2005, which is considered very low compared to the average of Africa which is 1.03×10^3 tonnes *per capita* CO_2 (world *per capita* is 4.21×10^3 tonnes) (Omer, 2006). Gas flaring is the practice of burning off gas released in the process of petroleum extraction and processing, and the CO_2 emission from it all is negligible. Nevertheless, and due to increasing momentum in oil industry and oil products, and the future increase in petroleum products consumption in Sudan; it is expected in the coming decades that the emissions of greenhouse gases from oil industry and use will certainly exceed by large this figure if certain measures of mitigation are not undertaken.

Yet, due to lack of good information and advice on energy saving, along with the capital to finance energy efficiency improvements, this huge potential for reducing energy demand is not being realised. Traditionally, energy utilities have been essentially fuel providers and the industry has pursued profits from increased volume of sales. Institutional and market arrangements have favoured energy consumption rather than conservation. However, energy is at the centre of the sustainable development paradigm as few activities affect the environment as much as the continually increasing use of energy.

Table 22
Annual amount of emissions from industrial processes in Sudan (10^6 tonnes) (GTZ, 1985).

Emissions	10^6 tonnes
Liquid	3320
Gas	N.A
Gas flaring	N.A
Cement manufacturing	84
Total	3404
Per capita CO_2 emissions	0.15

Table 23
Annual greenhouse gas emissions from different sources in Sudan (10^6 tonnes) (GTZ, 1985).

CO_2 emission from land use change	CH_4 from anthropogenic sources				Chlorofluorocarbons
	Solid waste	Oil and gas production	Agriculture	Livestock	
3800	47	N.A.	1	1100	N.A.

4.7. Environmental policies and industrial competitives

The industrial development strategy in Sudan gives priority to the rehabilitation of the major industrial areas with respect to improvement of infrastructure such as roads, water supply, power supply, sewer systems and other factors. This strategy also takes into consideration the importance of incorporating the environmental dimension into economic development plans. However, the relationship between environmental policies and industrial competitiveness has not been adequately examined. For the near future, the real issue concerns the effectiveness of environmental expenditures in terms of reduction of pollution emissions per unit of output. A number of issues relevant to this central concern are presented as follows:

4.7.1. Implementing ecologically sustainable industrial development strategies

Agenda 21 for achieving sustainable development in the 21st century calls on governments to adopt National Strategies (NS) for sustainable development that “build on and harmonise the various sectoral, social and environmental policies that are operating in the country” (Omer, 2008). The NS Sudan focuses almost exclusively on development issues and does not integrate industrial and environmental concerns. It does not consider industrial specific environmental objectives or time frames for achieving them. Moreover, it does not specify how specific industrial sub-sectors and plants will meet environmental objectives. Finally, it is formulated with minimal involvement of industrial institutions and private sector associations. To bring together industrial development and environmental objectives it is necessary to:

- Establish environmental goals and action plans for the industrial sector.
- Develop an appropriate mix of policy instruments that support the goals of those plans.
- Design appropriate monitoring and enforcement measurements to realise those goals.

4.7.2. Applying cleaner production processes and techniques

Traditional approaches to pollution reduction have been based on the application of end of pipe technologies in order to meet discharge standards. However, the growing recognition that reduction at source is a potentially more cost effective method of abatement is resulting in replacing end of pipe technologies with cleaner production processes. Major constraints in adopting cleaner production methods relate to:

- Lack of awareness about the environmental and financial benefits of cleaner production activities.
- Lack of information about techniques and technologies.
- Inadequate financial resources to purchase imported technologies.

A coordinated effect by industry, government and international organisations can go a long way in overcoming these constraints. In this context key questions that need to be addressed are as follows:

(a) Need for local capacity building, information dissemination, training and education.
(b) Need for sub-sectoral demonstration projects.
(c) Need for increased cooperation with environmental market sectors in developed countries.
(d) Need for life cycle analysis and research on environmentally compatible products.

4.7.3. Implementing environmental management systems

Environmental management systems (EMSs) are necessary to enable plant to achieve and demonstrate sound environmental performance by controlling the environmental impact of their activities, products and services. The basic tools to ensure compliance with national and/or international requirements and continually improve its environmental performance include:

- Environmental auditing.
- Environmental reporting, and
- Environmental impact assessments.

In addition, the adoption of the EMS may require extensive training of corporate staff. A practical and effective means of doing this is through the design and support of joint capacity strengthening programmes by industry association and bilateral and multilateral agencies.

4.7.4. Managing and conserving water resources

It is estimated that by the year 2025, there will be a global crisis in water resources. Accelerated growth of industry will lead to increase in industrial water use. Moreover, major industrial water pollutant load is expected to increase considerably in the near future. Therefore, to better manage water resources by industry, there is a real need for integrating demand trend and use patterns. The main elements of an industrial management strategy can be identified as follows:

- Analytical services.
- Promotional services.
- Services for the development of industry and water supply infrastructure.

4.7.5. Using Market Based Instruments (MBIs) to internalise environmental costs

As this complements are to command and control measures for resource conservation and pollution prevention in industry. The MBIs represent a useful and efficient cost effective policy measures that internalise environmental costs. A plant's decision to invest in clean production depends primarily on the following factors:

(a) Relative costs of pollution control in overall production costs.
(b) Price elasticities of supply and demand for intermediary and final goods, and
(c) Competitive position of plant in a particular industrial sector.
(d) Counteracting threats from eco-labelling requirements:

The increasing export orientation of production makes it necessary to maintain competitive position in world markets. The emergence of a wide variety of eco-labelling requirements and lack of timely information on multitude of scheme may adversely affect certain export sectors. Needed initiatives to counteracting perceived threats could be presented as follows:

- Information dissemination.
- Life cycle analysis.
- Establishing certification centres.
- Infrastructure support.

4.7.6. Implementing the United Nations (UN) framework convention on climate change

The UN climate change convention entered into force on the 21st of March 1994. The convention objective is the stabilisation of greenhouse gas concentration in the atmosphere at safe levels. For industry, responding to this convention will undoubtedly be a major challenge. Industry will be directly affected. Sudan as party to this convention is obliged to take a number of actions and cooperates effectively in order to meet this challenge. Sudan has to contribute to the common goal of reducing greenhouse gases emissions by taking precautionary measures to mitigate causes and anticipate impacts of climate change. However, there may not be adequate means to do so, and Sudan will therefore require international assistance. The main requirements are:

- Access to best energy-efficient technologies available on the world market, where such technologies are relevant to our natural resources endowments, our industrial requirements and are cost effective.
- Building an energy-efficient capital stock by accelerating the development of low energy intensity processes and equipment.
- Strengthening national capabilities for energy-efficient design and manufacturing.

Areas where technical expertise to implement the convention is necessary include:

- Preparing national communications on greenhouse gas emissions. The communications are supported to contain an assessment of the magnitudes and sources of greenhouse gases as well as identification of reduction methods.
- Supporting technology transfer for improvement in the efficiency of fuel based power generation.
- Promotion technology transfer for the use of renewable sources of energy such as biomass, wind, solar, hydro, etc.
- Developing and implementing technology transfer for energy efficiency programmes in industry, in complementarities with cleaner production/pollution prevention measures.
- Analysing the impact of climate change response measures on the economic and industrial development of the country, with the view to identifying economically viable technology options for reducing greenhouse gas emissions from the production and consumption of energy.

4.7.7. Addressing Concerns of Small and Medium Scale Industry (SMI)

Small and medium scale enterprises not only contribute to productivity growth and employment but are also important as collective sources of localised pollution loading such as organic wastes in water effluent, as well as hazardous wastes, heavy metal sludge, solvents, waste oils, acidic and alkaline wastes, photo wastes, etc. Often, these wastes are disposed of in unsafe manure and are extremely difficult to monitor. The cost of control in relation to output is too high, so even a modest increase in the costs (of environmental regulations) may threaten prevention and control may be well known and easily available, there is no guarantee that they will be adopted. Moreover, even when policy measures are in place, their enforcement and monitoring is a real problem for the SMI sector on account of their large numbers and diversity. It is clear that environment problems of the SMIs require special attention and special measures to address their particular problems.

4.8. Petroleum industry pollution and greenhouse gases emissions

The activities of oil exploration in Sudan began in late 1950s in the coastal areas of the Red Sea. The results of exploration indicated that there is considerable amount of natural and liquefied gases in Suwakin and Bashair, and the quantities were estimated 45-326 x 10^9 cubic meters. According to the increasing oil industry activities in

Sudan such as production, refining and export/consumption, and if we consider the entire fuel cycle, namely: exploration, extraction, preparation, transformation, transportation, storage, pollution, including the increase in greenhouse gases, as result of petroleum industry will be very significant in the forthcoming future. In the year 1997 about 2 x 10^9 tonnes of petroleum products were burnt in Sudan. This amount will be doubled in the year 2010. More information and data are available in the First National Communication 2003 and the Second National Communication under preparation by the Higher Council of Environment and Natural Resources concerning the area of greenhouse gases recording in Sudan.

5. Climate change, global warming and the enhanced greenhouse effect

Industry's use of fossil fuels has been blamed for our warming climate, when coal, gas and oil are burned, they released harmful gases, which trap heat into atmosphere and cause global warming. However, there has been ongoing debate on this subject, as scientists have struggled to distinguish between changes, which are human induced, and those, which could be put down to natural climate variability. Industrialised countries have the highest emission levels, and must shoulder the greatest responsibility for global warming. But action must also be taken by developing countries to avoid future increases in emission level as their economics develop and population grows. Rising concentrations of greenhouse gases (GHGs) enhance atmospheric absorption of infrared radiation (IR) with the potential to cause global warming and associated climate change. Human activities that emit carbon dioxide (CO_2), the most significant contributor to potential climate change, occur primarily from fossil fuels to produce energy that sustain economics, and powers socio-economic development. Consequently, efforts to control CO_2 emissions could have serious, negative consequences for economic growth, employment, investment, trade and the standard living for individuals everywhere. Scientifically it is difficult to predict the relation between global temperature and greenhouse gas concentrations. The climate system contains many processes that will change if warming occurs. Critical processes include heat transfer by winds and currents, the hydrological cycle involving evaporation, precipitation, runoff and groundwater, and the formation of clouds, snow, and ice, all of which display enormous natural variability. The equipment and infrastructure for energy supply and use are designed with long lifetimes, and the premature turnover of capital stock involves significant costs. Economic benefits occur if capital stock is replaced with more efficient equipment in step with its normal replacement cycle, and if opportunities to reduce future emissions are taken wherever in the world they are least costly, such flexible approaches would also allows society to take account of evolving scientific and technological knowledge, and to gain experience in designing policies to address climate change.

5.1. Cost comparison of diesel and wind pumps

Two systems are compared:

(1) A borehole of 35-40 m depth with a 18 HP = 13.3 kW diesel engine powered pump.
(2) A borehole of 25-30 m depth with a modified CWD 5000 wind pump.

A tentative cost comparison is shown in Table 24, using the formulaes (Cihan et al., 2009):

$$CT = (A + FP + M)/V \quad (6)$$

Where CT is the total annual cost, and

$$A = [C \times I \times (I+1)]^{T}/[I+1]^{T-1} \quad (7)$$

Where A is the annual cost of capital; C is the initial capital cost; I is the interest rate or discount rate; and T is the lifetime. F is the total annual fuel consumption; P is the fuel cost per unit volume; M is the annual maintenance cost; and V is the volume of water pumped.

The comparison indicates that the necessary fuel and maintenance needed to run the diesel pump unit long-term are the main lifetime costs, and not the capital cost of the diesel pump itself. In Sudan, where the fuel is expensive, the supply is uncertain, the infrastructure is poor, and where there are many populated remote areas, the following is concluded:

(1) The initial investment cost of wind pumps is too high; this may be a manufacturing scale problem.
(2) Maintenance costs in some areas are too high for the user.

(3) The lifetime pumping costs are similar for pumping water by wind pump and by diesel pump.
(4) Parallel and integrated projects could reduce costs.
(5) Local production is favoured (Figure 8).
(6) Utilities and water authorities should have responsibilities for technology and investment.
(7) There are substantial power production fluctuations due to variation in wind speed, and so using water storage is beneficial.

Fig. 8. Locally-manufactured wind pump installed at kilo 8 site.

Table 24
Cost comparison of diesel and wind pumps in Sudanese Pound (S.P.) (Bhutto et al., 2011).

Specification	Diesel pump	Wind pump
Cost of borehole deep well	182,400	114,000
Cost of the system (purchased or fabricated in Sudan)	93,600	440,000
Cost of storage tank	-	420,000
Cost of annual fuel consumption	343,700	-
Cost of maintenance and repair	120,000	110,000
Total annual cost	1,582,100	1,084,000
Specific water pumping cost/S.P.	79 per m^3	54 per m^3

1 US $ = S.P. 400 (Sudanese Pound), in January 2008. Annual output 15,000-20,000 m^3 of water. Annual fuel consumption: 490 gallons (1 imperial gallon = 4.55 litre) at price S.P. 475 per gallon. A cost comparative evaluation of a solar photovoltaic driven pump versus a diesel driven pump is presented by (Sims, 2007) for drinking water and irrigation. The economic dimension of biogas technology is reviewed and documented by (Sims, 2007; CEC, 2000). Solar still technology is primarily aimed at small-scale household water provision and is as such not suitable for bulk water supply, e.g., for sanitation and/or gardening/agriculture.

Ideally, the water produced by solar stills should only be used for human intake, i.e., drinking and cooking purposes and where the rest of the household water can be provided by means of a dual water supply system (e.g., where water of higher salinity can be used). In Sudan, people are requested to constructed solar stills plants by themselves in order to reduce costs. In remote areas, the costs for materials increase by about 15-20% due to transportation. In an economic analysis, many factors have to be considered as outlined in Table 24. Due to the lack of knowledge and awareness, villagers cannot be expected to understand the benefits of solar stills, nutrient conservation, or health improvement (Omer, 2008). A poor rural peasant is very hesitant to enter a new venture. The negative attitude towards the use of stills water varies from place to place, but when it occurs, it is a major obstacle to the implementation of solar still technology. In designing the solar still, the following points were considered: the unit has to cost as little as possible and materials should be readily available in rural areas. Technology should be simple, within the reach of a common village man. The unit should be usable in situations of emergency, e.g., during floods and after cyclones, etc.

5.2. Sudan's experience in renewable energy technologies

In Sudan, great attention is given to the utilisation of the renewable, and the overall renewable energy potential of the country. Three distinct groups contribute to research, development and utilisation of the resources. These are:

1. Research institutes.
2. Universities, and
3. Private-sector.

Participation and roles in technology diffuse:

1. Government

- Improved economic competitiveness of technology.
- Support information flow technical financial viability, and resource assessment.
- Support training.
- Undertake R&D.

2. NGOs

- Training.
- Extension.
- Assessment of local needs.
- Demonstration.
- Promotion of small-scale production.

3. Private-Sector

- Production.
- Assembly, maintenance and spare-parts supply.
- Marketing.

Two major studies (Omer, 2008; Abdeen, 2008) for the utilisation of renewable and biomass residues for energy in Sudan have been conducted through joint foreign projects such as:

1. Groundnut shells briquetting (UNDP/UNSO/NEA).
2. Biogas and briquettes from water hyacinth (GTZ/PPD/German).
3. Cotton stalks gasification (UNDP/ERI/NEA/France).
4. Direct combustion (SIDA).
5. Carbonisation (GTZ/ERI).
6. Carbonisation and briquetting (DIGS/UNIDO/USAID/BTG/ERI).
7. Solar energy (USAID, GTZ, GEF/UNDP, UNFCCC).
8. Wind energy (CWD, GTZ).

5.3. Sustainable development

Like most African countries, Sudan is vulnerable to climate variability and change. Drought is one of the most important challenges. The most vulnerable people are the farmers in the traditional rain-fed sector of western, central and eastern Sudan, where the severity of drought depends on the variability in amount, distribution and frequency of rainfall. Three case studies were conducted in Sudan as part of the project. They examined the condition of available livelihood assets (natural, physical, financial, human and social) before and after the application of specific sustainable livelihood environmental management strategies, in order to assess the capacity of communities to adapt creased resilience through access to markets and income generating opportunities.

5.4. Oil production

Oil was discovered in Sudan in the mid-1970s, but production did not start until 1999. The pioneer companies Chevron and Shell were forced to bow out in 1984, after the outbreak of civil war. They eventually sold their rights in 1990, booking a $1 billion loss. Oil in Sudan accounts for 92.6% of the country's export revenues and with most of its producing oilfields located in the South of the country, the management of the oil industry is a key factor that will determine the future of the country. The oil industry is poorly supervised and highly politicised, and as such, rather than contributing to an enabling environment for peace and equitable development, a source of strife and division (Figure 9). The focus for 2007 is on both exploration and development. The operators of the producing blocks are implementing aggressive exploration programmes (Table 25). With the companies wanting to achieve payback as quickly as possible, development of discoveries is likely to be prompt. Refineries:

- Khartoum (50/50 joint venture between the Sudanese government and the CNPC, capacity of (100,000 bbl/d).
- Port Sudan Refinery (21,700 bbl/d).
- Petronas has agreed to joint venture with the Sudanese government to build a new refinery in Port Sudan with capacity of (100,000 bbl/d) to treat Dar Blend crude; to be operational in 2010.
- The small top-up refinery in Abu Gabra is planned for closure 2010. There are plans to build a refinery in Kosti Sudan's oil production will probably in 2010, but revenues may be maintained for another ten years at current levels, depending on the development of oil prices and whether the Dar Blend refinery will indeed be a price booster.

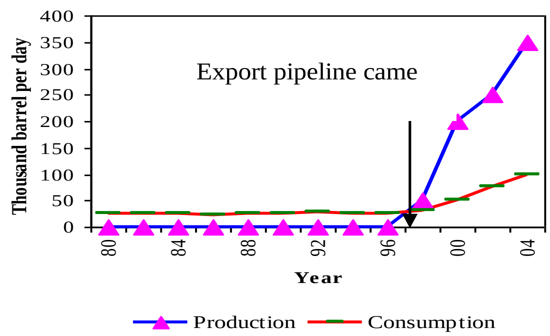

Fig. 9. Sudan's oil production and consumption 1980-2005.

Table 25
Sudan's oil reserves.

Year	Proven reserves (bln bbl)	Oil production (10^3 bbl/d)
1981	0.2	0.0
1991	0.3	0.0
2001	0.7	211
2005	6.4	355
2006	6.4	397

Oil is a principal factor in Sudanese politics. It is the government's main source of income and the oil sector is driving economic growth. Meanwhile, the oil industry is poorly managed and highly politicised. Rather than contributing to an environment of peace and equitable development, it remains a source of strife and division (Abdeen, 2008). The Sudanese oil industry is exceptionally profitable because oil companies are exempted from paying taxes in Sudan. These conditions may have been quite reasonable in 1997. The main Sudanese oil contracts were negotiated in the 1990s, when oil was being traded for less than $20 per barrel and the Sudanese governments had to offer lucrative conditions to attract investments. It makes a big difference, however, whether the companies' share of 20% to 40% of the Profit Oil is sold at $20 or $60 per barrel. Oil is now traded at $90 per barrel and more, boosting profits for the companies and leaving the government of the Sudan with too small a share.

5.5. Mitigation measures

Mitigation measures that could be under taken to influence the effect of oil industry and use that may contribute in decreasing greenhouse gases (GHGs) emissions 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.
- Controlling GHGs emission detection techniques in oil production, transportation and refining processes in Sudan.
- 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 Sudan.

5.6. Policy development

The non-technical issues, which have recently gained attention, include:

- Environmental and ecological factors, e.g., carbon sequestration, reforestation and revegetation.
- Biomass as CO_2 neutral replacement for fossil fuels.
- Greater recognition of the importance of renewable energy, particularly modern biomass energy carriers, at the policy and planning levels.
- Greater recognition of the difficulties of gathering good and reliable renewable energy data, and efforts to improve it.
- Studies on the detrimental health efforts of renewable energy particularly from traditional energy users.
- Greater awareness of the need to internalise the externality cost of conventional energy carriers to place them on more equal terms with alternative energy sources.

5.7. The future

(1) In the most of the developing countries, the governments acknowledge that, renewable energy can resolve many pressing problems. Yet, the matter stops at this level ‘’Acknowledgement’’. Much more is needed, like laws regulating and encouraging business, tax concessions, both to investors and customers, and most of all, a sustained, coordinated and well-planned official publicity campaign to enlight, inform and educate the public at a large.

(2) To avoid the problems of fuel altogether (uncertain availability and skyrocketing prices), and minimise spare-parts, solar and wind pumps are proposed to replace diesel engines in the predominant irrigation areas.

(3) Local manufacture, whenever possible, is to be emphasised to avail renewable energy devices since limited funds are the main constraints in commercialisation and dissemination of the technology. Low cost devices as well as reliable devices have to be provided.

(4) Embarking on conservation energy and reduction of pollution of environment to be undertaken without delay:

- To save on fossil fuel for premium users/export.
- To accelerate development of new and/or remote lands otherwise deprived of conventional energy sources.
- As a preventive measure against shortage of future energy supply against prospective national energy demand.

(5) Launching of public awareness campaigns among investor’s particularly small-scale entrepreneurs and end users of renewable energy technologies to highlight the importance and benefits of renewables.

(6) To direct Sudan resources away from feeding wars and the arms industry towards real development, this will serve the noble ends of peace and progress.

(7) The energy crisis is a national issue and not only a concern of the energy sector, and the country has to learn to live with the crisis for a long period, and develop policies, institutions and manpower for longer term, more effective solutions.
(8) To invest in research and development through the existing specialised bodies, e.g., Energy Research Institute (ERI).
(9) To encourage co-operation between nations, a fact this will be much easier in this era of information and the communications revolution.
(10) Government should give incentives to encourage the household sector to use renewable energy technologies instead of conventional energy.
(11) Promotion research and development, demonstration and adaptation of renewable energy resources (solar, wind, biomass, and mini-hydro, etc.) amongst national, regional, and international organisations which seek clean, safe, and abundant energy sources.
(12) Execute joint investments between the private-sector and the financing entities to disseminate the renewables with technical support from the research and development entities.
(13) Promotion the general acceptance of renewable energy strategies by supporting comprehensive economic energy analysis taking account of environmental benefit.
(14) Availing of training opportunities to personnel at different levels in donor countries and other developing countries to make use of their wide experience in application and commercialisation of renewable energy technologies.
(15) To encourage the private-sector to assemble, install, repair and manufacture renewable energy devices via investment encouragement, more flexible licensing procedures.

Recommendations may be classified into three broad categories: policy, institutional and enterprise levels.

(1) Policy level action

At the policy level, the following aspects may be considered:

- Giving priority to pollution prevention rather than pollution control.
- Using market based instrument complements to command and control measures.
- Recognising small and medium scale industry (SMI) as a special case in environmental legislation.
- Adopting proper industrial sitting and relocation policies.

(2) Institutional level actions

- Setting up environmental extension services for small and medium scale industry (SMI).
- Creating information dissemination cells.
- Facilitating common waste treatment facilities.
- Promoting outreach from large plants to small and medium scale industry (SMI).

(3) Enterprise level actions

- Supporting demonstrations of the financial environmental benefits of pollution prevention measures.
- Promoting self-initiated demonstrations at enterprises through the provision of grants to enterprises.

6. Conclusion

Sudan as an agricultural country has a good rational of energy from agricultural residues, forestry resources, and animal wastes. Sudan has an excellent annual mean solar radiation of 5.44 kW h m^{-2} day^{-1} which could be of strategic important in substituting for oil, electricity, wood and charcoal; in assisting in rural development, and in improving the quality of life in rural areas. Sudan is rich in wind; about 50% of Sudan's area is suitable for generating electricity (annual average wind speed more than 5 ms^{-1}), and 75% of Sudan's area is suitable for pumping water (annual average wind speed 3-5 ms^{-1}). Production of bio-fuels such as ethanol from sugarcane, takes advantages of year-round cultivation potential in a tropical country like Sudan. Benefits extend from local to regional to national to global. Local rural economies benefit through new economic opportunities and employment in the agricultural sector. Urban regions benefit through cleaner air and health improvements. The nation benefits through substituting domestic resources for costly imported gasoline. The world benefits from reduced CO_2 emissions.

In a country with a population dense, there are extreme pressures on energy and waste systems, which can stunt the country's economic growth. However, Sudan has recognised the potential to alleviate some of these problems by promoting renewable energy and utilising its vast and diverse climate, landscape, and resources, and by coupling its solutions for waste disposal with its solutions for energy production. Thus, Sudan may stand at the forefront of the global renewable energy community, and presents an example of how non-conventional energy strategies may be implemented. Sudan's energy system is in the midst of a transition away from fossil fuels towards a more sustainable energy system based on biomass and other renewable options. Biogas plants offer renewable options that are relatively inexpensive and well suited to rural areas. Hydropower will continue to play a role in smaller-scale energy supply. There is also potential for expanding wind and solar applications in Sudan, particularly in rural areas.

Energy efficiency brings health, productivity, safety, comfort and savings to the homeowner, as well as local and global environmental benefits. The use of renewable energy resources could play an important role in this context, especially with regard to responsible and sustainable development. It represents an excellent opportunity to offer a higher standard of living to the local people, and will save local and regional resources. Implementation of renewable energy technologies offers a chance for economic improvement by creating a market for producing companies, maintenance and repair services.

Appendix 1. Facts about Sudan

Full country name	Republic of the Sudan.
Total area	One million square miles (2.5 x 10^6 square kilometres). Land 2.376 x 10^6 square kilometres.
Population	39 x 10^6 inhabitants (2008 est.).
Capital city	Khartoum (population 5 million).
Language	Arabic (official), English, Nubian, Ta Bedawie, diverse dialects of Nilotic, Nilo – Hamitic, Sudanic languages.
Religions	Sunni Muslim 70% (in north), indigenous beliefs 25%, Christian 5% (mostly in south and Khartoum).
GDP per head	US $ 533.
Annual growth	4% (1997 est.).
Inflation	23% (1998 est.).
Ethnic groups	Black 52%, Arab 39%, Beja 6%, Foreigners 2%, others 1%.
Agricultures	Agriculture is the backbone of economic and social development. 62% of the populations are employed in agriculture. Agriculture contributes 33% of the gross national products (GNP), and 95% of all earnings.
Animal wealthy	35 x 10^6 head of cattle. 35 x 10^6 head of sheep. 35 x 10^6 head of goats. 3 x 10^6 head of camels. 0.6 x 10^6 head of horses and donkeys. Fish wealth 0.2 x 10^6 tonnes of food annually. Wildlife, birds and reptiles.
Environment	Inadequate supplies of potable water, wildlife populations threatened by excessive hunting, soil erosion, and desertification.
International agreements	Party to: biodiversity, climate change, desertification, endangered species, law of the sea, nuclear test ban, ozone layer protection.

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