The Role of Green Energy Systems and Sustainable Development

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Abstract

People are relying upon oil for primary energy and this will continue for a few more decades. Other conventional sources may be more enduring, but are not without serious disadvantages. The renewable energy resources are particularly suited for the provision of rural power supplies and a major advantage is that equipment such as flat plate solar driers, wind machines, etc., can be constructed using local resources. Without the advantage results from the feasibility of local maintenance and the general encouragement such local manufacture gives to the buildup of small-scale rural based industry. This communication comprises a comprehensive review of energy sources, the environment and sustainable development. It includes the renewable energy technologies, energy efficiency systems, energy conservation scenarios, energy savings in greenhouses environment and other mitigation measures necessary to reduce climate change. This study gives some examples of small-scale energy converters, nevertheless it should be noted that small conventional, i.e., engines are currently the major source of power in rural areas and will continue to be so for a long time to come. There is a need for some further development to suit local conditions, to minimise spares holdings, to maximise the interchangeability of the engine parts, and of the engine applications. Emphasis should be placed on full local manufacture. It is concluded that renewable environmentally friendly energy must be encouraged, promoted, implemented and demonstrated by a full-scale plant (device) especially for use in remote rural areas.

Keywords: Renewable Energy Technologies, Energy Efficiency, Sustainable Development, Emissions, Environment

1. Introduction

Power from natural resources has always had great appeal. Coal is plentiful, though there is concern about despoliation in winning it and pollution in burning it. Nuclear power has been developed with remarkable timeliness, but is not universally welcomed, construction of the plant is energy-intensive and there is concern about the disposal of its long-lived active wastes. Barrels of oil, lumps of coal, even uranium come from nature but the possibilities of almost limitless power from the atmosphere and the oceans seem to have special attraction. The wind machine provided an early way of developing motive power. The massive increases in fuel prices over the last years have however, made any scheme not requiring fuel appear to be more attractive and to be worth reinvestigation (Cheng, 2010). In considering the atmosphere and the oceans as energy sources, the four main contenders are wind power, wave power, tidal and power from ocean thermal gradients. 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 (Kothari, Singal, Rakesh, and Ranjan 2011).

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, while in the long-term it may require the use of energy efficiency without environmental and safety concerns. Such programmes should as far as possible be based on renewable energy resources (Cihan, Dursun, Bora, and Erkan, 2009).

Large-scale, conventional, power plant such as hydropower has an important part to play in development although it does not provide a complete solution. There is however an important complementary role for the greater use of small-scale, rural based power plants. Such plants can be employed to assist development since they can be made locally. Renewable resources are particularly suitable for providing the energy for such equipment and its use is also compatible with the long-term aims.

In compiling energy consumption data one can categorise usage according to a number of different schemes:

- Traditional sector- industrial, transportation, etc.
- End-use- space heating, process steam, etc.
- Final demand- total energy consumption related to automobiles, to food, etc.
- Energy source- oil, coal, etc.
- Energy form at point of use- electric drive, low temperature heat, etc.

2. Methods and Materials

The increased availability of reliable and efficient energy services stimulates new development alternatives. This communication discusses the potential for such integrated systems in the stationary and portable power market in response to the critical need for a cleaner energy technology. Anticipated patterns of future energy use and consequent environmental impacts (acid precipitation, ozone depletion and the greenhouse effect or global warming) are comprehensively discussed in this study. Throughout the theme several issues relating to renewable energies, environment, and sustainable development are examined from both current and future perspectives. It is concluded that green energies like wind, solar, ground-source heat pumps, and biomass must be promoted, implemented, and demonstrated from the economic and/or environmental point view. The key factors to reducing and controlling CO_2, which is the major contributor to global warming, are the use of alternative approaches to energy generation and the exploration of how these alternatives are used today and may be used in the future as green energy sources. Even with modest assumptions about the availability of land, comprehensive fuel-wood farming programmes offer significant energy, economic and environmental benefits. These benefits would be dispersed in rural areas where they are greatly needed and can serve as linkages for further rural economic development. There is strong scientific evidence that the average temperature of the earth's surface is rising. This was a result of the increased concentration of carbon dioxide (CO_2), and other greenhouse gases (GHGs) in the atmosphere as released by burning fossil fuels. This global warming will eventually lead to substantial changes in the world's climate, which will, in turn, have a major impact on human life and the environment. Energy use reductions can be achieved by minimising the energy demand, by rational energy use, by recovering heat and the use of more green energies. This study was a step towards achieving this goal. The adoption of green or sustainable approaches to the way in which society is run is seen as an important strategy in finding a solution to the energy problem.

3. Renewable Energy Potential

The increased availability of reliable and efficient energy services stimulates new development alternatives (Omer, 1995a). This communication discusses the potential for such integrated systems in the stationary and portable power market in response to the critical need for a cleaner energy technology. Anticipated patterns of future energy use and consequent environmental impacts (acid precipitation, ozone depletion and the greenhouse effect or global warming) are comprehensively discussed in this approach. Throughout the theme several issues relating to renewable energies, environment and sustainable development are examined from both current and future perspectives. It is concluded that renewable environmentally friendly energy must be encouraged, promoted, implemented and demonstrated by full-scale plants (devices) especially for use in remote rural areas. Globally, buildings are responsible for approximately 40% of the total world annual energy consumption. Most of this energy is for the provision of lighting, heating, cooling, and air conditioning. Increasing awareness of the environmental impact of CO_2, NO_x and CFCs emissions triggered a renewed interest in environmentally friendly cooling, and heating technologies. Under the 1997 Montreal Protocol, governments agreed to phase out chemicals used as refrigerants that have the potential to destroy stratospheric ozone. It was therefore considered desirable to reduce energy consumption and decrease the rate of depletion of world energy reserves and pollution of the environment. One way of reducing building energy consumption is to design buildings, which are more economical in their use of energy for heating, lighting, cooling, ventilation and hot water supply.

Passive measures, particularly natural or hybrid ventilation rather than air-conditioning, can dramatically reduce primary energy consumption. However, exploitation of renewable energy in buildings and agricultural greenhouses can, also, significantly contribute towards reducing dependency on fossil fuels. Therefore, promoting innovative renewable applications and reinforcing the renewable energy technologies market will contribute to preservation of the ecosystem by reducing emissions at local and global levels. This will also contribute to the amelioration of environmental conditions by replacing conventional fuels with renewable energies that produce no air pollution or greenhouse gases.

There is strong scientific evidence that the average temperature of the earth's surface is rising. This is a result of the increased concentration of carbon dioxide and other GHGs in the atmosphere as released by burning fossil fuels. This global warming will eventually lead to substantial changes in the world's climate, which will, in turn, have a major impact on human life and the built environment. Therefore, effort has to be made to reduce fossil energy use and to promote green energies, particularly in the building sector. Energy use reductions can be achieved by minimising the energy demand, by rational energy use, by recovering heat and the use of more green energies. This study was a step towards achieving that goal. The adoption of green or sustainable approaches to the way in which society is run is seen as an important strategy in finding a solution to the energy problem. The key factors to reducing and controlling CO_2, which is the major contributor to global warming, are the use of alternative approaches to energy generation and the exploration of how these alternatives are used today and may be used in the future as green energy sources (Omer, 1998a). Even with modest assumptions about the availability of land, comprehensive fuel-wood farming programmes offer significant energy, economic and environmental benefits. These benefits would be dispersed in rural areas where they are greatly needed and can serve as linkages for further rural economic development. The nations as a whole would benefit from savings in foreign exchange, improved energy security, and socio-economic improvements. With a nine-fold increase in forest – plantation cover, a nation's resource base would be greatly improved. The international community would benefit from pollution reduction, climate mitigation, and the increased trading opportunities that arise from new income sources. The non-technical issues, which have recently gained attention, include: (1) Environmental and ecological factors, e.g., carbon sequestration, reforestation and revegetation. (2) Renewables as a CO_2 neutral replacement for fossil fuels. (3) Greater recognition of the importance of renewable energy, particularly modern biomass energy carriers, at the policy and planning levels. (4) Greater recognition of the difficulties of gathering good and reliable renewable energy data, and efforts to improve it. (5) Studies on the detrimental health efforts of biomass energy particularly from traditional energy users. The renewable energy resources are particularly suited for the provision of rural power supplies and a major advantage is that equipment such as flat plate solar driers, wind machines, etc., can be constructed using local resources and with the advantage resulting from the feasibility of local maintenance and the positive influence such local manufacturing has on small-scale rural based industry. This study gives some examples of small-scale energy converters, nevertheless it should be noted that small conventional, i.e., engines are currently the major source of power in rural areas and will continue to be so for a long time to come. There is a need for some further development to suit local conditions, to minimise spares holdings, to maximise the interchangeability of the engine parts and of the engine applications. Emphasis should be placed on full local manufacture.

The renewable energy resources are particularly suited for the provision of rural power supplies and a major advantage is that equipment such as flat plate solar driers, wind machines, etc., can be constructed using local resources and without the high capital cost of more conventional equipment. Further advantage results from the feasibility of local maintenance and flourishing benefits such local manufacturing has on small-scale rural based industry. Table 1 lists the energy sources available.

Table 1. Sources of energy (Omer, 1998a)

Energy source	Energy carrier	Energy end-use
Vegetation	Fuel-wood	Cooking Water heating Building materials Animal fodder preparation
Oil	Kerosene	Lighting Ignition fires
Dry cells	Dry cell batteries	Lighting Small appliances
Muscle power	Animal power	Transport Land preparation for farming Food preparation (threshing)
Muscle power	Human power	Transport Land preparation for farming Food preparation (threshing)

Table 2. Renewable applications

Systems	Applications
Water supply system	Rain collection, purification, storage and recycling
Wastes disposal system	Anaerobic digestion (CH_4)
Biogas cooking system	Methane
Food production	Cultivation of 1-hectare plot and greenhouse for four people
	Wind generator
Electrical demands	Solar collectors
Space heating system	Solar collectors and excess wind energy
Water heating system	Ultimately hardware
Control system	Integration of subsystems to cut costs
Building fabric	

Currently the 'non-commercial' fuels wood, crop residues and animal dung are used in large amounts in the rural areas of developing countries, principally for heating and cooking; the method of use is highly inefficient. Table 2 presented some renewable applications.

Table 3 lists the most important of energy needs.

Table 3. Energy needs in rural areas

Transport, e.g., small vehicles and boats
Agricultural machinery, e.g., two-wheeled tractors
Crop processing, e.g., milling
Water pumping
Small industries, e.g., workshop equipment
Electricity generation, e.g., hospitals and schools
Domestic, e.g., cooking, heating, and lighting
Water supply, e.g., rain collection, purification, and storage and recycling
Building fabric, e.g., integration of subsystems to cut costs
Wastes disposal, e.g., anaerobic digestion (CH_4)

Considerations when selecting power plant include the following:

- Power level- whether continuous or discontinuous.
- Cost- initial cost, total running cost including fuel, maintenance and capital amortised over life.
- Complexity of operation.
- Maintenance and availability of spares.
- Life span of the plant.
- Suitability for local manufacture.

Table 4 listed methods of energy conversion.

Table 4. Methods of energy conversion

Muscle power	Man, animals
Internal combustion engines	
Reciprocating	Petrol- spark ignition
	Diesel- compression ignition
	Humphrey water piston
Rotating	Gas turbines
Heat engines	
Vapour (Rankine)	

Reciprocating	Steam engine
Rotating	Steam turbine
Gas Stirling (Reciprocating)	Steam engine
Gas Brayton (Rotating)	Steam turbine
Electron gas	Thermionic, thermoelectric
Electromagnetic radiation	Photo devices
Hydraulic engines	Wheels, screws, buckets, turbines
Wind engines (wind machines)	Vertical axis, horizontal axis
Electrical/mechanical	Dynamo/alternator, motor

The household wastes for family of four persons, could provide (280 kWh/yr) of methane, but with the addition of vegetable wastes from 0.2 hectare (ha) or wastes from 1 ha cultivated under a complete diet, about 1500 kWh/yr may be obtained by anaerobic digestion (Omer, 1999a). The sludge from the digester may be returned to the land. In hotter climates, this could be used to set up productive biomass utilisation energy cycle (Figure 1).

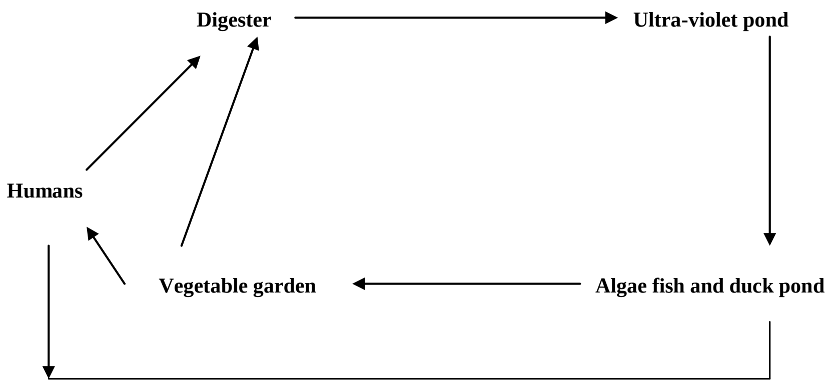


Figure 1. Biomass energy utilisation cycle.

There is a need for greater attention to be devoted to this field in the development of new designs, the dissemination of information and the encouragement of its use. International and government bodies and independent organisations all have a role to play in renewable energy technologies.

4. Energy Consumption

Over the last decades, natural energy resources such as petroleum and coal have been consumed at high rates. The heavy reliances of the modern economy on these fuels are bound to end, due to their environmental impact, and the fact that conventional sources might eventually run out. The increasing price of oil and instabilities in the oil market has led to search for energy substitutes.

Society and industry in Europe and elsewhere are increasingly dependent on the availability of electricity supply and on the efficient operation of electricity systems. In the European Union (EU), the average rate of growth of electricity demand has been about 1.8% per year since 1990 and is projected to be at least 1.5% yearly up to 2030 (ERI, 1987). Currently, distribution networks generally differ greatly from transmission networks, mainly in terms of role, structure (radial against meshed) and consequent planning and operation philosophies.

In addition to the drain on resources, such an increase in consumption consequences, together with the increased hazards of pollution and the safety problems associated with a large nuclear fission programmes makes this type of energy environment unfriendly. This is a disturbing prospect. It would be equally unacceptable to suggest that the difference in energy between the developed and developing countries. The developed countries to move towards a way of life which, whilst maintaining or even increasing quality of life. This reduces significantly the energy consumption per capita. Such savings can be achieved in a number of ways:

- Improved efficiency of energy use, for example better thermal insulation, energy recovery, and total energy.
- Conservation of energy resources by design for long life and recycling rather than the short life throwaway product.
- Systematic replanning of our way of life, for example in the field of transport.

Energy ratio is defined as the ratio of energy content of the food product/energy input to produce the food.

$$Er = Ec/Ei \quad (1)$$

Where Er is the energy ratio, Ec is the energy content of the food product, and Ei is the energy input to produce the food.

Currently the non-commercial fuelwood, crop residues and animal dung are used in large amounts in the rural areas of developing countries, principally for heating and cooking, the method of use is highly inefficient. As in the developed countries, the fossil fuels are currently of great importance in the developing countries. Geothermal and tidal energy are less important though, of course, will have local significance where conditions are suitable. Nuclear energy sources are included for completeness, but are not likely to make any effective contribution in the rural areas. Economic importance of environmental issue is increasing, and new technologies are expected to reduce pollution derived both from productive processes and products, with costs that are still unknown.

4.1. Agriculture Sector

During the last decades, agriculture contributed about 41% to the Sudan’s GNP. This share remained stable till 1984/1985 when Sudan was seriously hit by drought and desertification, which led to food shortages, deforestation, and also, socio-economic effects caused by the imposed civil war. The result dropped the agriculture share to about 37%. Recent development due to rehabilitation and improvement in 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.

4.2. Industrial Sector

The industrial sector is mainly suffering from power shortages, which is the prime mover to the large, medium and small industries. The industrial sector was consuming 5.7% of the total energy consumption, distributed as: 13.8% from petroleum products, 3.4% from biomass and 8% from electricity.

4.3. Domestic Use

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

4.4. Transport Sector

The transportation sector was not being efficient for the last two decades because of serious damage that affected its infrastructure. It consumed 10% of the total energy consumption and utilised 60% of the total petroleum products supplied.

4.5. 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 being used to lesser extent. Human, animal, and diesel or gasoline engines provide mechanical power. Some cooking and lighting are done by kerosene. 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, other energy alternatives are being sought.

5. Energy Situation

Sudan is the largest country in African continent, with a tropical climate, and an area of approximately 10^6 square miles (2.5×10^6 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 (Omer, 1997a). Sudan is a relatively sparsely populated country. The total population according to the census 2009 was 39×10^6 inhabitants. The annual growth rate is 2.8%, and population density is 12 persons per square kilometre (Omer, 1997a). Sudan is rich in land and water resources (Omer, 1997a). 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 41°C and mean minimum 25°C) with large variation; low relative humidity averages. Winters are 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 6×10^8 Feddans (Feddan = 1.038 acres = 0.42 hectares). The land use in the country is classified into four main categories. There is arable land (8.4×10^6 hectares), pasture (29.94×10^6 hectares), forest (108.3×10^6 hectares), and about 38.22×10^6 hectares used for other purposes. Water resources are estimated at 84×10^9 cubic meters (m^3), this including the river Nile and its tributaries. Underground water is estimated at 26×10^{10} cubic meters, and 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 estimated at (1093.2×10^9) m^3/annum.

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 (Omer, 1997a). Sudan is also viewed as one of the potentially richest nations in livestock (Omer, 1997a), approximately 103 x 10^6 heads (70 x 10^6 sheep and goats, 30 x 10^6 cattle, and 3 x 10^6 camels) (NEA, 1985). 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 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 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. 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.

Tables 5 to 10 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 consumed 60% of the total electricity supplies (Omer, 1994). The total annual energy consumed is approximately 11 x 10^9 tonnes of oil, with an estimated 43% lost in the conversion process (Omer, 1996a). 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.

Table 5. Annual energy consumption pattern in Sudan from different energy sources (10^6 MWh)

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 6. Annual biomass energy sources available in Sudan (10^6 m^3)

Source	Volume of biomass (10^6 m^3)
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 7. Annual biomass energy consumption in Sudan (10^6 tonnes)

Sector	Volume of biomass (10^6 m^3)	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 8. Power output of present hydropower plants (GW)

Station	Energy delivered per pear
Rosaries	275
Sennar	15
Khashm El Girba	13
Total	303

Table 9. Annual electricity consumption in Sudan (10^6 MWh)

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 10. Annual petroleum product consumption in Sudan (10^6 MWh)

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.

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 nation 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 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 (Omer, 1996b), 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 animals, provision of water, education, communication and rural small industries (Omer, 1995b). 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 approach 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 populations live in rural and isolated communities characterised by extreme poverty, hunger, and economical activity (NEA, 1983a). 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, 1983a). 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 11). The rural energy requirements are summarised in Table 12. 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 rise up the present level of extreme poverty and 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 (Duffie, and Beckman, 1980).

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 program 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).

Table 11. Percentage of the total annual electricity consumption by states

States	Percent (%)
Khartoum, Central and East 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 12. Energy sources for rural area

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 & micro hydro	A mass water fall, and current flow of water
Geothermal	Hot water

5.1. Major Energy Consuming Sectors

Sudan is still considered between the 25 most developing African countries. Agriculture is the backbone of economic and social development in Sudan. About 80% of the populations 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. Agriculture determines for the last 30 years the degree of performance growth of the national economy.

It is necessary that a vigorous programme reaching into alternative renewable energies should be 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 offer a diesel engine. The renewable energy technology systems (RETs) are simple, from local materials, clean energy; reliable and sustainable (Table 13). Specialist on their applications carried out socio-economic and environmental studies. The output of the studies pointed out that, they are acceptable to the people and have measured remarkable impacts on the social life, economical activities and rural environment (Kirtikara, 1983; and Omer, 1990).

Table 13. Energy required in Sudan rural area

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.

5.2.1. 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 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 14.

Table 14. Annual biomass energy consumption pattern in Sudan (10^3 m^3)

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

Approximately 13 x 10^6 m^3 of biomass are consumed per year as shown in Table 14. 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 bagasse, and molasse, cotton stalks, groundnut shells, tree/forest residues, aquatic weeds, and various animal wastes shown in Table 15.

Table 15. Biomass residues, current use and general availability

Type of residue	Current use / availability
Wood industry waste	No residues available
Vegetable crop residues	Animal feed
Food processing residue	Energy needs
Sorghum, millet, 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*)

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 of 2 tonnes per hour with maximum 2000 tonnes per season. Another, prototype unit was brought forth, and worked in Nyala with capacity of 0.5 tonnes per hour (i.e., 600 tonnes per season). In central Sudan, a briquetting plant of cotton stalks was installed at Wad El Shafie with 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, 1997b; Omer, 1998a; Omer, 1993; Joop, Paul, and Omer, 1987). 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 have burnt charcoal on traditional square ‘’Canun’’ stoves that have 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 (NEA, 1991): 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 (R & D) base.

Gasification is based on the formation of a fuel gas (mostly CO and H_2) by partially oxidising raw solid fuel at high temperatures in the presence of steam (Elamin, 1995). 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 (Omer, 1999a). 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 (in terms of degree of cleanliness, composition, heating value, etc.) (Omer, 1998c).

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.

Furthermore, Sudan is investigating the potential to make use of more and more of its wastes. Household wastes, vegetable market wastes, and wastes 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.

The use of biomass through direct combustion has long been, and still is the most common mode of biomass utilisation as shown in Tables 16, and 17. 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 16. Effective biomass resource utilisation

Subject	**Tools**	**Constraints**
Utilisation and land clearance for	• Stumpage fees	• Policy

agriculture expansion	• Control • Extension • Conversion • Technology	• Fuel-wood planning • Lack of extension • Institutional
Utilisation of agricultural residues	• Briquetting • Carbonisation • Carbonisation and briquetting • Fermentation • Gasification	• Capital • Pricing • Policy and legislation • Social acceptability

Table 17. Agricultural residues routes for development

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

5.2.2. Biogas Production

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 (Omer, 1998d). Landfills and wastewater treatment plants emit biogas from decaying waste. To date, the waste industry has focused on controlling these emissions to our environment and in some cases, tapping this potential source of fuel to power gas turbines, thus generating electricity (Omer, 1998d). The primary components of landfill gas are methane (CH_4), carbon dioxide (CO_2), and nitrogen (N_2). The average concentration of methane is ~45%, CO_2 is ~36% and nitrogen is ~18% (Omer, 1998d). Other components in the gas are oxygen (O_2), water vapour and trace amounts of a wide range of non-methane organic compounds (NMOCs). Landfill gas-to-cogeneration projects present a win-win situation. Emissions of particularly damaging pollutant are avoided; electricity is generated from a free fuel and heat is available for use locally.

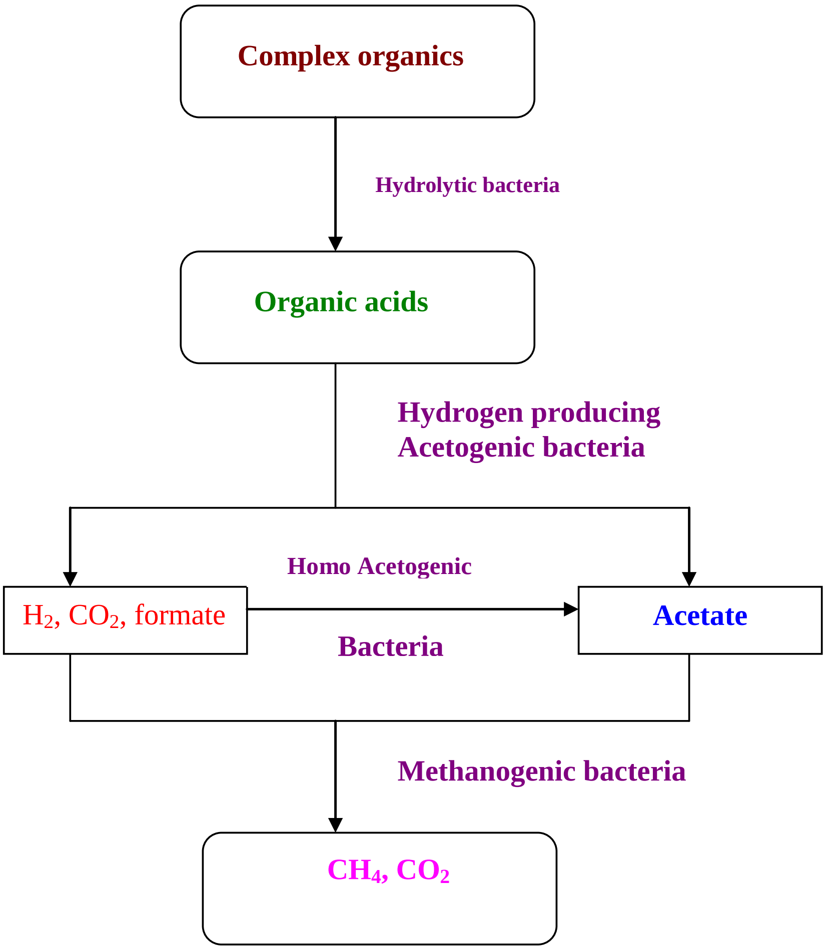


Figure 2. Biogas production process.

Heat tariffs may include a number of components such as: a connection charge, a fixed charge and a variable energy charge. Also, consumers be incentivised to lower the return temperature. Hence, it is difficult to generalise but the heat practice for any domestic heat (DH) company no matter what the ownership structure can be highlighted as follows:

- To develop and maintain a development plan for the connection of new consumers.
- To evaluate the options for least cost production of heat.
- To implement the most competitive solutions by signing agreements with other companies or by implementing own investment projects.

- To monitor all internal costs and with the help of benchmarking, and improve the efficiency of the company.
- To maintain a good relationship with the consumer and deliver heat supply services at a sufficient quality.

Installing DH should be pursued to meet the objectives for improving the environment through the improvement of energy efficiency in the heating sector. At the same time DH can serve the consumer with a reasonable quality of heat at the lowest possible cost. The variety of possible solutions combined with the collaboration between individual companies, the district heating association, the suppliers and consultants can, as it has been in Denmark, be the way forward for developing DH in the United Kingdom. Three scales of combined heat and power (CHP) which were largely implemented in the following chronological order: (1) Large-scale CHP in cities (>50 MWe), industrial and small-scale CHP. (2) Small (5 kWe – 5 MWe) and medium-scale (5-50 MWe). A review of the potential range of recyclables is presented in Table 18.

Table 18. Summary of material recycling practices in the construction sector

Construction and demolition material	Recycling technology options	Recycling product
Asphalt	Cold recycling: heat generation; Minnesota process; parallel drum process; elongated drum; microwave asphalt recycling system; finfalt; surface regeneration	Recycling asphalt; asphalt aggregate
Brick	Burn to ash, crush into aggregate	Slime burn ash; filling material; hardcore
Concrete	Crush into aggregate	Recycling aggregate; cement replacement; protection of levee; backfilling; filter
		Recycled steel scrap
Ferrous metal	Melt; reuse directly	Recycled window unit; glass fibre; filling material; tile; paving block; asphalt; recycled aggregate; cement replacement; manmade soil
Glass	Reuse directly; grind to powder; polishing; crush into aggregate; burn to ash	
		Thermal insulating concrete; traditional clay
		Recycled metal
Masonry	Crush into aggregate; heat to 900°C to ash	Recycled paper
	Melt	Panel; recycled plastic; plastic

Non-ferrous metal Paper and cardboard Plastic	Purification Convert to powder by cryogenic milling; clopping; crush into aggregate; burn to ash	lumber; recycled aggregate; landfill drainage; asphalt; manmade soil
Timber	Reuse directly; cut into aggregate; blast furnace deoxidisation; gasification or pyrolysis; chipping; moulding by pressurising timber chip under steam and water	Whole timber; furniture and kitchen utensils; lightweight recycled aggregate; source of energy; chemical production; wood-based panel; plastic lumber; geofibre; insulation board

5.2.3. Hydropower

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 8, 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 (WRI, 1994).

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 (< 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. Table 11 lists the current distribution of electric power for different states in Sudan (mainly from hydro 55%, and thermal generation 45%).

5.2.4. Solar Energy

The harsh climate in the Red Sea area, for example the Sudan, presents unique challenges in meeting growing demands for water and power. The availability of data on solar radiation is a critical problem. Even in developed countries, very few weather stations have been recording detailed solar radiation data for a period of time long enough to have statistical significance and the Sudan is not an exception.

The country strives hard to make use of technologies related to renewable sources in rural areas where it is appropriate and applicable. 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 19. The annual daily mean global radiation ranges from 3.05 to 7.62 $kWhm^{-2}$ day^{-1} (Abdeen, 2008a). However, Sudan has an average of 7-9 GJm^{-2} $year^{-1}$, equivalent to 436-639 Wm^{-2} $year^{-1}$ (Abdeen, 2008b; Abdeen, 2008c; and Abdeen, 2008d).

Table 19. Correlation of solar radiation with other weather parameters in Sudan (Yearly averages: 2000-2013)

Station	Mean temp. (°C)	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
Wadi 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 installed for communication network, microwave receiver stations, radio systems in airports, VHF and beacon radio systems in airports, and educational solar TV posts installed in some villages (Abdeen, 2008e).

5.2.5. 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 [30-33]. 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, 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°'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 20.

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 started since 1950's, where 250 wind pumps from Australian government, had been installed in El Gezira Agricultural Scheme (Southern Cross Wind Pumps). But these were gradually disappeared due to a lack of spare parts and maintenance skills combined with stiff competition from relatively cheep diesel pumps. However, the government has recently begun to recognise the need to reintroduce wind pump technology to reduce the country's dependence on foreign 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) each 5000 mm diameter, wind pumps around Khartoum area, Northern state, and Eastern state. Now ERI with cooperation of the Sudanese Agricultural Bank (SAB) introduced 60 wind pumps to be use for water pumping in agricultural schemes, but not yet manufactured due to lack of financial support.

The maximum extractable monthly mean wind power per unit cross sectional area, P, is given by:

$$P = 0.3409 V^3 \quad (2)$$

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.

$$\eta_{Overall} = \eta_{rotor} \times \eta_{transmission} \times \eta_{pump} \quad (3)$$

Table 20. Number of wind pumps installed for irrigation purpose in Sudan

Location	Number of pumps
Tuti island	2
Jebel Aulia	1
Soba	4
Shambat	4 (one was locally manufactured)
Toker (eastern Sudan)	2 (both locally manufactured)
Karima (northern Sudan)	2 (both locally manufactured)
Total	15

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 21, 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.

Sudan is rich in wind; mean wind speed of 4.5 ms^{-1} is 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 (Abdeen, 2009a). 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 (Abdeen, 2009b).

Table 21. Wind speeds versus wind pump discharges

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

5.2.6. Sugarcane Biomass

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 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 (Abdeen, 2009c).

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 (Abdeen, 2009d).

Biogas technology cannot only provide fuel, but 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.

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 22.

Table 22. Annual sugarcane bagasse available in Sudan (10^3 tonnes)

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

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 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.

5.2.7. Geothermal Energy

In Sudan (Omer, 2008a) 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.

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

6. Results and Discussions

6.1. Achievements

In 1991, Sudan created the Ministry of Higher Education and Scientific Research (MHESR) to take responsibility for all matters relating to non-conventional/renewable energy. It undertakes the role of renewable energy policymaking, planning, promotion, and coordination. In recent years Energy Research Institute (ERI)-National Centre for Research (NCR)-MHESR has overseen the development of a broad base of technologies including biogas plants, solar thermal and PV systems, wind turbines, small and micro hydropower units, energy from urban and industrial wastes, and even improved cooking stoves. Table 23 summarises the potential and the current status of renewable energy development in Sudan.

Table 23. Renewable energy achievements in Sudan

	Status (units as of July 2010)
Industrial solar heaters (16 m^2-80 m^2)	150
Solar cookers	2000
Solar stills (1 m^2-10 m^2)	100
Solar dryers	10
PV solar refrigerators (120 W-250 W)	200
PV communication systems	30
PV solar water pumps (1.5 kW-5.5 kW)	120
PV solar lighting systems (40 W-1.5 kW)	1000
Wind pumps (diameters 2.4 m-7.4 m)	25
Wind generators (research facilities)	4

Table 23. (Continued)

Source/system	**Status (units as of July 2010)**
Biomass gasifiers	3
Improved stoves	25000
Briquetting plants (600-2000 tonnes per season)	5
Biogas plants	200
Current driven turbines	10

Under the present federal system, Sudan is divided into 26 federal states. This made regional development planning a more important tool for the utilisation of natural resources particularly planning for the utilisation of renewable energy sources. The role of renewable energy is big in solving essential live 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. Consequently, the energy plan includes:

- Installation of 200 solar pumps in the rural areas every year to achieve self-satisfaction of drinking water in areas suitable for solar applications.
- Utilisation of solar energy in the telecommunications to cover by the end of the plan all existing airports, and the railway stations, the remote hospitals and microwave stations through the installation of 300 units.
- Lighting of rural areas at a level of 2 MW every year starting with 50 kW (8 MW for 10 years of the program).
- Popularise the use of solar refrigerators by the installation of 300 units per year for vaccines and medicines preservation for human beings and animals.
- Supply distilled water by producing 1000 m^3 of distilled water every year.
- Solar water heating in hotels, hospitals, and relevant industries through the installation of 500 units every year.
- Disseminate the use of solar cookers in the northern states for household use through the production of 1000 units every year.
- Production of 60 wind pumps for Sudan rural areas.
- Production of 200 current driven pumps per year.
- Installation of 50 biogas units per year.
- Support research and development for:
    1. Biomass gasifiers (stand-alone)
    2. Biomass combustion/gasifier
    3. Bagasse based cogeneration
    4. Ethanol production from sugar cane
    5. Floating pumps
    6. Wind generators
    7. Solar collectors
    8. Solar dryers

6.2. Privatisation and Price Liberalisation in Energy Source Supplies

The strategy of price liberalisation and privatisation in some products of agriculture, industry, and energy sectors implemented over the last two years, and has some extent (a positive result) on government deficit and restriction of imports. The investment law approved recently has a cleaner statement and rules on the above strategy in particular to agriculture and industry areas. In case of the agriculture the strategy was encouraging and area wise was increased (irrigated or rained), and hence the agricultural increased.

The privatisation and price liberalisation in energy fields has been secured to some extent (but not fully). Availability and adequate energy supplies to the major productive sectors. The result is that, the present situation of energy supplies is for better than ten years ago. The investment law has also encouraged the participation of the investors from the national level as well as from the international friendly and sisters' countries to invest in energy sources supply such as:

- Petroleum products (import in particular) in the northern states.
- Electricity generation (in some states) through providing large diesel engine units.

The readily implementation of electricity price liberalisation has some extent relieved the National Electricity Corporation (NEC) from the heavy dependency of government subsidies, and a noticeable improved of the NEC management, and electricity supplies are achieved.

6.3. Environment Aspects

Environmental pollution is a major problem facing all nations of the world. People have caused air pollution since they learned how 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 (Omer, 2008b).

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 as much as in others. The industrial sector worldwide is responsible for about one third of anthropogenic emissions of carbon dioxide, the most important greenhouse gas (Omer, 2008c). 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 reduction of industrial emissions through more efficient production and use of energy. Fuel substitutions, the use of alternative energy technologies, process modification, and revising materials strategies 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.

From the Tables 24 and 25 it is noticed that most of CO_2 emissions in Sudan were from land-use change, representing 92% of emissions. On the other hand, the emissions of CO_2 from industrial 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 x 10^3 tonnes / (capita*year), which is considered very low compared to average of Africa which is 1.03 x 10^3 tonnes *per capita* CO_2 (world *per capita* is 4.21 x 10^3 tonnes / (capita*year)) [37-38]. Average European figure is in order of magnitude of 9 tonnes / (capita*year) (Omer, 2009a). Gas flaring is the practice of burning off gas released in the process of petroleum extraction and processing, and the CO_2 emissions from it all negligible. Nevertheless, and due to increasing momentum in oil industry and oil products, and the future increase in petroleum products consumption in Sudan will increase CO_2 emissions. It is expected in the coming decades that the emissions of greenhouse gases from oil industry and use will certainly exceed by large figure if certain measures of mitigation are not undertaken.

Table 24. Annual amount of emissions from industrial processes in Sudan (10^6 tonnes)

Emissions	**10^6 tonnes**
Liquid	3320
Gas	0
Gas flaring	0
Emissions	**10^6 tonnes**
Cement manufacturing	84
Total	3404

Per capita CO_2 emissions	0.15

Table 25. Annual greenhouse gas emissions from different sources in Sudan (10^6 tonnes)

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

6.4. 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:

(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, 2009b). The NS 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 subsectors 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.

(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 subsectoral 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.

(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) Managing and conserving water resources:

It is estimated that by year 2025, there will be a global crisis in water resources (Omer, 2010a). 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.

(5) Using market-based instruments (MBIs) to internalise environmental costs:

The MBIs as complements to command and control measures for resource conservation and pollution prevention in industry are important. The MBIs represent a useful and efficient cost-effective policy measures that internalise environmental costs. Decision on investing in plants for 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 the plant in a particular industrial sector.

(d) Counteracting threats from eco-labelling requirements:

(6) 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.

(7) Implementing the United Nations (UN) framework convention on climate change:

The UN climate change convention became effective on 21st 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 resource's 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.

(8) 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.

6.5. Petroleum Industry Pollution and Greenhouse Gases Emissions in Sudan

The activities of oil exploration in Sudan began in late 1950s in the coastal areas of 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 between (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. There is a shortage of information concerning the area of greenhouse gases recording in Sudan (Omer, 2010a).

6.6. 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 the 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 economies 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 allow society to take account of evolving scientific and technological knowledge, and to gain experience in designing policies to address climate change. The most advanced market is the USA and also the worst per capita CO_2 emitter (Omer, 2010b).

6.7. Mitigation Measures

Mitigation measures that could be undertaken 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.

6.8. 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.

7. Petroleum Projects

Like most African countries, Sudan is vulnerable to climate variability and change. Drought is one of the most important challenges (Figure 3). 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 the 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.

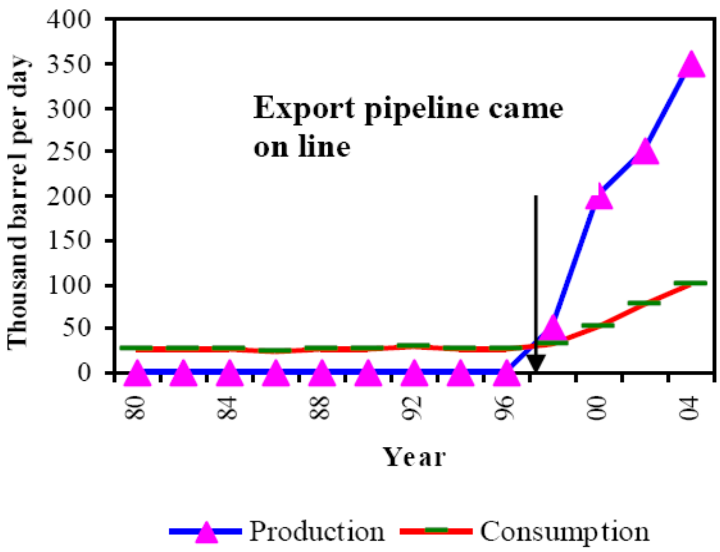


Figure 3. Sudan's oil production and consumption 1980-2005.

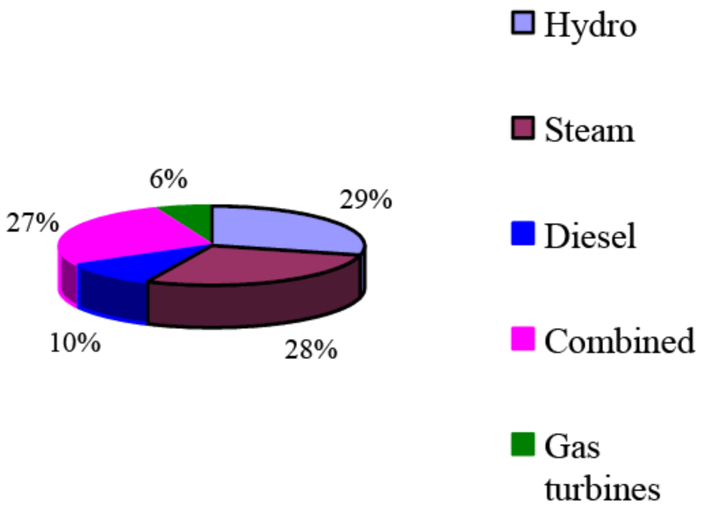


Figure 4. Electricity generated in 2005 (GWh).

Table 26. Electricity output of present power plants in Sudan (GWh)

Plants	**Power (GWh)**
Hydro power stations	1095.12
Steam power stations	1037.93
Diesel power stations	359.9
Gas turbine power stations	235.35
Combined power stations	1020.62
Total	3748.9

Peak load for national grid (MW)	534
Total number of consumers (head)	745418
Total number of employees (head)	7097

The NEC handled wide variety of electricity generation technologies (Table 26), including:

- Thermal (fossil, combined cycle, and combustion turbines).
- Storage (pumped hydro, batteries, and compressed air).
- Non-dispatchable technologies (solar, wind, cogeneration, and load management).

Electricity is transmitted through two interconnected electrical grids, the Blue Nile grid and the Western grid, which cover only a small portion of the country. Some regions are not covered by the grid, and rely on small diesel-fired generators for power, although blackouts and brownouts are common (Figure 4). Only 30% of the population currently has access to electricity, although the government hopes to increase that figure up to 90% in coming years.

In the past, Sudan was badly affected by rapidly rising fuel costs, although the country is now in a position to export oil. The country intends to implement new hydro projects to meet increasing demand and to avoid power shortages. Small-scale, decentralised hydropower can provide valuable reserve power and potentially make major contributions to local energy needs, especially the southern region along the White Nile from Malakal to the border with Uganda. There are plans to develop other sources of renewable energy in the next five to ten years, including solar energy: photovoltaic and thermal, wind energy, biomass, geothermal energy and mini hydro.

The China National Petroleum Company (CNPC) is wholly owned by the Chinese government and owns a 40% stake in the Greater Nile Oil Project (GNOP). The GNOP was set up by the Sudanese government and includes, among other investors, Sudapet, the national oil company. The CNPC operates interests in the Sudanese oil industry with SINOPEC, Petronas, ONGC, and other investors, and is not only active in the GNOP, but also has stakes in Petrodar and other oil blocks in Sudan. When CNPC attempted to go public on the New York Stock Exchange in 1999, public criticism over its holdings in Sudan forced it to create a subsidiary, PetroChina, which went public instead. At the time of its creation, PetroChina was 90% owned by the CNPC and was comprised of the CNPC's domestic holdings. When PetroChina was created, it inherited $15 billion in debt from the CNPC, some of which was incurred in respect to its Sudan activities. There is a large overlap between the management and the board of PetroChina and the CNPC. This creates doubt that there exists a firewall between the two companies. The ACIR perceives that the separation between these two companies is largely cosmetic. Companies should not be rewarded for creating lists of subsidiaries that purposefully do not directly own controversial assets owned by the parent company.

The Zhongyuan Petroleum Exploration Bureau (ZPEB), a powerful subsidiary of China's second largest national petroleum consortium, the China Petrochemical Corporation (SINOPEC), appears to be the principal oil firm operating in Gambella at present, under subcontract to Malaysia's national oil company PETRONAS. The base camp for the ZPEB equipment and petroleum explorations is located approximately 1.5 kilometres from the centre of Gambella town on the Abobo-Gambella road. The base camp is under tight security and heavily guarded by the EPRDF troops. PETRONAS and the China National Petroleum Corporation currently operate in Sudan. A recent report by Human Rights Watch raises charges that the Asian oil giants have provided cover for their respective governments to ship arms and military equipment to Sudan in exchange for oil concessions granted by Khartoum.

China Petroleum and Chemical Corporation (SINOPEC) were set up in 2000 as a publicly traded company by the state-owned China Petrochemical Corporation (Sinopec Group). 67.2% of Sinopec Corp. is owned by Sinopec Group. Sinopec Group is the unlisted parent company of Sinopec Corp. This situation is similar to the CNPC's relationship to PetroChina. It is one of the largest oil companies in China today. SINOPEC's involvement in the Sudan is three-fold. First, through its subsidiary, ZPEB International, it is one of the largest oil engineering service providers in Sudan. Second, through its subsidiary Sinopec International Petroleum Service Corp. (SIPSC), this is SINOPEC Group's international overseas and engineering and service arm. Third, it is through a direct 6% ownership share in Petrodar.

On this parched and dusty African plain, China's largest energy company is pumping crude oil, sending it 1,760 kilometres upcountry through a Chinese-made pipeline to the Red Sea, where tankers wait to ferry it to China's industrial cities. Chinese labourers based in a camp of prefabricated sheds work the wells and lay highways across the flats to make way for heavy machinery. This is the first public analysis of Sudan's oil figures. It documents how the oil figures published by the Government of National Unity in Khartoum are smaller than the equivalent figures published by the China National Petroleum Corporation (CNPC), the operator of the oil blocks. While the respective figures for the only block located entirely in the north, and therefore not subject to revenue sharing, approximately match, those for blocks which are subject to revenue sharing. There were discrepancies of:

- 9% for the Greater Nile Petroleum Operating Company's blocks in 2007.
- 4% for the Petrodar Operating Company's blocks in 2007.
- 26% for the Greater Nile Petroleum Operating Company and Petro Energy's blocks in 2005.

These findings cover six of the seven productive oil blocks in Sudan. A comparison of the government and company figures was not possible for the White Nile Petroleum Operating Company's block as no company figures were available. Mismatches of this magnitude represent potentially massive sums of money. If it were found that the oil figures published by the Government of National Unity had been under-reported by, for example, 10%, the southern government would be owed more than $600 million (on the basis that the Government of Southern Sudan has received more than $6 billion in oil revenues since the signing of the peace agreement). This is more than three times the south's combined annual budgets for health and education.

The consortium's Heglig and Unity oil fields now produce 350,000 barrels per day, according to the USA Energy Department. Separately, CNPC owns most of the field in southern Darfur, which began trial production this year, and 41 percent of the field in the Melut Basin, which is expected to produce as much as 300,000 barrels per day by the end of 2006. Another Chinese firm, Sinopec Corp., is erecting a pipeline from that complex to Port Sudan on the Red Sea, where China's Petroleum Engineering Construction Group is building a tanker terminal.

Sudan Khartoum refinery is one of the three major petroleum projects that China National Petroleum and Gas Corporation (CNPC) invested in and constructed in Sudan. It was designed and constructed with Chinese standards and equipment. With total investment reported to be US$ 64 million, the refinery was built on a 50% share basis by the CNPC and Ministry of Energy and Mining (MEM). The processing capacity of the refinery is 50,000 b/d. It consists of four major units: 2.5 million m/yr CDU, 1.8 million m/yr RFCC, 150,000 m/yr REF, 500,000 m/yr HDT, as well as its own power station (8-8.5 million kWh), air separation and air compression units, water supply and drainage, central laboratory, and other auxiliary units. The annual output of gasoline, jet fuel, gasoline and LPG are 2.2 million tonnes.

The agreement establishing the joint venture refinery project was signed on March 1st 1997. Construction commenced on May 26th 1998 and was completed on January 23rd 2000. Products are supplied to the domestic market of Sudan, and diesel, gasoline and liquefied petroleum gas have also been exported to neighbouring countries. Some electricity is also supplied to the local area. The refinery at Port Sudan is now closed. Several studies have been made to reopen the Port Sudan refinery since the crude export terminal was built near the refinery. A study by Petronas in 2001 concluded that to process the new Sudanese crude, the refinery needed significant expenditure including the building of a delayed coker. As it is unlikely that such large amounts of finance can be raised for a refinery that will export 90% of the products, the Port Sudan refinery will probably remain closed for the foreseeable future. The El Obeid refinery is a small topping refinery in Southern Sudan fed by crude from the Sudanese oil fields.

7.1. The Future

(1) In 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 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, in fact 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 of 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 of 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, and more flexible licensing procedures.

7.2. Recommendations

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 the demonstrations of measures that are of financial and environmental benefits, for pollution prevention, by enterprises.
- Promoting self-initiated demonstrations by enterprises through the provision of grants to them.

7.3. Southern Sudan

Recently, the Southern Sudan had been separated from Sudan in July 2011. Northern Sudan is now called ''The Republic of Sudan''. To find and analyse accurate data for those newborn countries are so big task (Kothari, Singal, Rakesh, and Ranjan, 2011). ''Energy-resources assessment in Sudan is not an easy task because of uncertainty of parameters, numerous factors that affect the variables, lack of information and inaccurate measurements''. So, I have tried my best to use the available data in the past and present ''To ensure a better quality of life for all people, now and in the future, through the implementation of sustainable development initiatives that promote: (1) Food and water security (2) Economic efficient that helps to eliminate inequalities

(3) Social equity for all, regardless of gender, race, religion, disability or creed, age, class, culture, education, ethnicity, sexuality and spirituality (4) Effective education for environmentally and socially responsible citizenship (5) Environment integrity, and environmental justice (6) Democracy, and mutual understanding between people''. Southern Sudan is rich country with fertile land, plenty of water resources, livestock, forestry resources, and agricultural residues. It is also, a rich in fossil fuels, and natural gas.

CONCLUSION

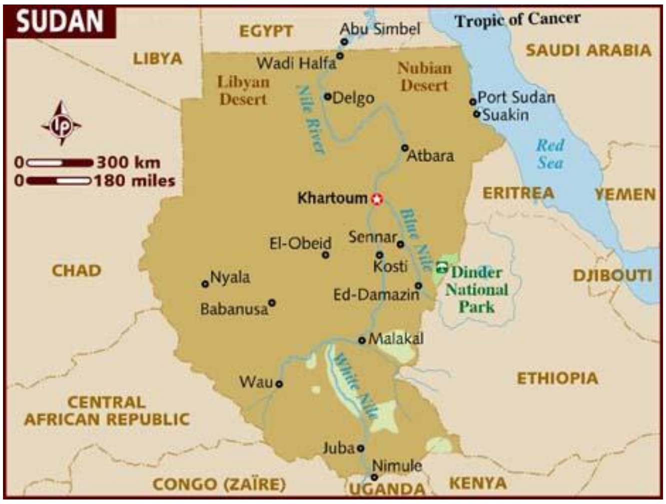
Sudan as an agricultural country has a good rational of energy from agricultural residues, forestry resources, and animal wastes. Sudan has an excellent annual mean solar radiation of (5.44 kW h m^{-2} day^{-1}) which could be of strategic importance in substituting for energy from oil, electricity, 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 is 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. MAP OF SUDAN BEFORE SPLIT



Appendix 2. Map of Sudan before Separation

APPENDIX 3. SOUTHERN SUDAN MAP

Conflicts of Interest

There is no relevant interest of conflict

Funding Statement

There are no funds for this article.

REFERENCES

1. Abdeen, M. O. (2008a). Renewable building energy systems and passive human comfort solutions. *Renewable and Sustainable Energy Reviews*, *12*(6), 1562-1587.
2. Abdeen, M. O. (2008b). People, power and pollution. *Renewable and Sustainable Energy Reviews*, *12*(7), 1864-1889.
3. Abdeen, M. O. (2008c). Energy, environment and sustainable development. *Renewable and Sustainable Energy Reviews*, *12*(9), 2265-2300.
4. Abdeen, M. O. (2008d). Focus on low carbon technologies: The positive solution. *Renewable, and Sustainable Energy Reviews*, *12*(9), 2331-2357.
5. Abdeen, M. O. (2008e). Chapter 10: Development of integrated bioenergy for improvement of quality of life of poor people in developing countries. In F. L. Magnusson & O. W. Bengtsson (Eds.), *Energy in Europe: Economics, policy and strategy* (pp. 341-373). New York, NY: NOVA Science Publishers.
6. Abdeen, M. O. (2009a). Environmental and socio-economic aspect of possible development in renewable energy use. In *Proceedings of the 4th International Symposium on Environment*, Athens, Greece, 21-24 May 2009.
7. Abdeen, M. O. (2009b). Energy use, environment and sustainable development. In *Proceedings of the 3rd International Conference on Sustainable Energy and Environmental Protection* (SEEP 2009), Paper No.1011, Dublin, Republic of Ireland, 12-15 August 2009.
8. Abdeen, M. O. (2009c). Energy use and environmental: Impacts: A general review. *Journal of Renewable and Sustainable Energy*, *1*(5), 1-29.
9. Abdeen, M. O. (2009d). Chapter 3: Energy use, environment and sustainable development. In R. T. Mancuso (Ed.), Environmental cost management, (pp. 129-166). New York, NY: NOVA Science Publishers.

10. Cheng, R. (2010). Advanced biofuel technologies: status and barriers. World Bank Report, WPS5411.
11. Cihan, G., Dursun, B., Bora, A. &Erkan, S. (2009). Importance of biomass energy as alternative to other sources in Turkey. *Energy Policy*, *37* (2), 424-431.
12. Duffie, J. A. & Beckman, W. A. (1980). *Solar Engineering of Thermal Process.* New York: Wiley Interscience.
13. Elamin, S. M. E. (1995). Towards Participative Approach for the Design of Appropriate Energy Technology in Sudan Rural Settings. MSc. Thesis. University of Khartoum (UOK). Khartoum: Sudan.
14. Energy Research Institute (ERI). (1987). *Renewable Energy Resources Potential in Sudan.* Khartoum: Sudan.
15. Joop, V. M., Paul, H. & Omer, A. M. (1987). Evaluation of Sudan Wind Energy Project. The Netherlands: CWD-ERC.
16. Kirtikara, K. (1983). Solar radiation and measurement. In *Proceedings of Seminar on Solar Energy and Applications*. Bangkok: Thailand.
17. Kothari, D. P., Singal, K. C. &Rakesh, Ranjan (2011). *Renewable energy sources and emerging technologies,* 2nd Edition, Private Ltd, New Delhi, 2011.
18. National Energy Administration (NEA). (1983a). Renewable Energy Assessment for the Sudan. Khartoum: Sudan.
19. National Energy Administration (NEA). (1983b). A Pre-investment Study for Fuel Production from Agricultural Wastes for Power Generation and Household Consumption. Khartoum: Sudan.
20. National Energy Administration (NEA). (1985). The National Energy Plan 1985-2000. Khartoum: Sudan.
21. National Energy Administration (NEA). (1991). *Energy Handbook*. Khartoum: Sudan.
22. Omer, A. M. (1990). Solar Atlas for Sudan. P. G. Thesis. University of Khartoum (UOK). Khartoum: Sudan.
23. Omer, A. M. (1993). Wind speeds and wind power potential in Sudan. In *Proceedings of the 4th Arab International Solar Energy Conference. Amman*, Jordan, 20-25 November. Amman: Renewable Energy Research Centre.
24. Omer, A. M. (1994). Renewable energy technology applications in the Sudan. In *Proceedings of the 3rd World Renewable Energy Congress*. Reading, UK, 11-16 September. Oxford: Elsevier Science Ltd.
25. Omer, A. M. (1995a). Rainfall patterns in Sudan. *NETWAS News*, *2* (7), 4-7.
26. Omer, A. M. (1995b). Solar energy technology applications in the Sudan. In *Proceedings of the 1st Jordanian Mechanical Engineering Conference*. Amman, Jordan, 25-28 June. Amman: Jordanian Mechanical Engineering Association.
27. Omer, A. M. (1996a). Renewable energy potential and future prospect in Sudan. *Agriculture and Development in Arab World*, *3* (1), 4-13.
28. Omer, A. M. (1996b). Biogas technology and environment. *Regional Energy News*, *2*(4), 2-5.
29. Omer, A. M. (1996c). Solar energy potential and future prospect in Sudan. In *Proceedings of the 4th World Renewable Energy Congress. Denver*, USA, 15-21 June. Oxford: Elsevier Science Ltd.
30. Omer, A. M. (1997a). *Review of Hydropower in Sudan*. Khartoum: Sudan.
31. Omer, A. M. (1997b). Compilation and evaluation of solar and wind energy resources in Sudan. *Renewable Energy*, *12* (1), 39-69.
32. Omer, A. M. (1998a). Sudan energy background; an overview. *Renewable Energy*, *14* (1-4), 467-472.
33. Omer, A. M. (1998b). Horizons of using wind energy and establishing wind stations in Sudan. *Dirasat*, *25* (3), 545-552.

34. Omer, A. M. (1998c). *Renewable Energy Potential and Environmentally Appropriate Technologies in Sudan*. Khartoum: Sudan.

35. Omer, A.M. (1998d). Renewable energy resources in Sudan. In *Proceedings of the 5th World Renewable Energy Congress*. Florence, Italy, 19-25 September. Oxford: Elsevier Science Ltd.

36. Omer, A. M. (1999a). *Sudan Experience in Biomass Energy*. Khartoum: Sudan.

37. Omer, A. M. (1999b). *Biomass Energy Potential and Future Prospect in Sudan*. Khartoum: Sudan.

38. Omer, A. M. (2008a). Green energies and the environment. *Renewable and Sustainable Energy Reviews*, *12*, 1789-1821.

39. Omer, A. M. (2008b). On the wind energy resources of Sudan. *Renewable and Sustainable Energy Reviews*, *12*(8), 2117-2139.

40. Omer, A. M. (2008c). Energy demand for heating and cooling equipment systems and technology advancements. In J. R. White & W. H. Robinson (Eds.), *Natural resources: Economics, management and policy*, (pp. 131-165).

41. Omer, A. M. (2009a). Energy use and environmental impacts: A general review. *Renewable and Sustainable Energy*, *1*, 1-29.

42. Omer, A. M. (2009b, October-November). Principle of low energy building design: Heating, ventilation and air conditioning. *Cooling India: India's Premier Magazine on the Cooling Industry*, *5*(4), 26-46. Mumbai, India.

43. Omer, A. M. (2010a). Chapter 9: Development of sustainable energy research and applications. In W. H. Lee and V. G. Cho (Eds.), *Handbook of sustainable energy*, (pp. 385-418). New York, NY: NOVA Science Publishers, Inc.

44. Omer, A. M. (2010b). *The crux of matter: Water in the Republic of the Sudan*, (pp. 1-50). New York, NY: NOVA Science Publishers, Inc.

45. World Resource Institute (WRI). (1994). World Resources: A Guide to the Global Environment, People and the Environment.