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Ministry of Energy & Mining

RENEWABLE ENERGY ASSESSMENT FOR THE SUDAN

NATIONAL ENERGY ADMINISTRATION

ME & M/USAID ENERGY POLICY & PLANNING PROJECT
INTERNATIONAL SCIENCE & TECHNOLOGY INSTITUTE, INC
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RENEWABLE ENERGY ASSESSMENT FOR THE SUDAN

NATIONAL ENERGY ADMINISTRATION
MINISTRY OF ENERGY AND MINING
KHARTOUM, SUDAN

September 20, 1982

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ABSTRACT

A review of renewable energy activities in Sudan and an assessment of renewable resources were carried out at the National Energy Administration from February to May, 1982. Biomass, wind and solar energy databases were developed and a number of resource/technology combinations were explored. Of these combinations, the following have been selected as having a high market and utilization potential: (1) ethanol production from molasses; (2) windmills for water pumping; (3) charcoal production from banana stalks; (4) briquetting of agricultural residues for utilization in households and industrial boilers; (5) biogas production for rural cooking and lighting using animal residues and water hyacinths; (6) solar water heating for low-temperature commercial and industrial applications; and (7) improved charcoal kilns. In this report, each of these combinations has been analyzed, including present activities, resource availability, technical and cost characteristics, economic factors and implementation issues. Based on the results of this analysis, it is recommended that a Renewable Energy Demonstration Program be implemented, followed by a full scale National Renewable Energy Program. Suggestions regarding the form and content of each of these programs are presented herein.

1.0 Introduction and Methodology

The main objectives of a renewable energy assessment for the Sudan are to assess the potential of several renewable energy resources (solar, wind and biomass), identify and analyze renewable energy project options which could create a positive impact on the Sudanese energy sector in the short-to-medium term, and develop recommendations for the creation of a national renewable energy program which will encourage the utilization of appropriate renewable energy technologies by addressing technical, economic/financial and institutional issues.

The assessment is primarily concerned with the identification and characterization of renewable energy projects which have the potential to displace imported petroleum products resulting in substantial foreign exchange savings, and which would reduce critical deforestation rates around urban and rural communities by displacing a substantial fraction of the charcoal and firewood consumed in the Northern and Eastern part of the country.

The assessment consists of the following five phases:

Phase 1: Overview of Renewable Energy Activities

In this phase, a summary of renewable energy research, development and demonstration activities is presented. In this context, in-country renewable energy documents and publications were reviewed, experimental renewable energy stations were visited and meetings were conducted with several Sudanese and in-country foreign renewable energy experts.

Phase 2: Renewable Energy Resource Assessment

This phase identifies the magnitude, geographical distribution and temporal variation of available renewable energy resources. In this context, several in-country sources were reviewed (data from meteorological stations, publications, etc) so as to develop three separate renewable energy data bases (solar, wind and biomass).

Phase 3: Preliminary Identification and Analysis of Renewable Energy Combinations

In this phase, all combinations of resources, technologies, and end-uses which can be fully integrated into Sudanese technical, economic, socio-cultural and institutional conditions, are identified. These combinations which were selected after a preliminary review of Sudan's basic energy needs and resources, are grouped on the basis of similar renewable energy resources as follows:

1) Biomass- Combinations

- Improved charcoal kilns for charcoal production
- Improved charcoal and woodstoves for rural and urban household applications (cooking, etc.)
- Fuel briquetting of agricultural residues for utilization in rural and urban households and in industrial boilers
- Ethanol production from sugar molasses
- Charcoal production from banana residues
- Anaerobic digestion of animal residues and water hyacinths for biogas production for rural cooking and lighting
- Biomass plantation for firewood production

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2) Wind Energy Combinations:

- Windmills for water-pumping applications
- Windmills for crop grinding
- Windmills for electricity generation

3) Solar Energy Combinations:

- Solar water heating for low-temperature commercial and industrial applications
- Solar drying of agricultural products
- Solar stills for water desalination
- Solar photovoltaic cells for remote small-scale applications

4) Hydro Combinations:

- Micro and mini-hydro plants for electricity generation

These combinations were compared and screened according to the following parameters:

- Resource availability
- Potential market (number of potential end-users)
- Economic viability (system capital and O&M costs, system life, energy production, cost of competing energy sources)
- Socio-cultural impacts (especially for rural applications)
- Existing infrastructure and technical capability
- Macro-economic impacts (foreign exchange savings, employment generation, etc.)
- Technology appropriateness (availability of local materials and labor)

In order to guarantee the quality of this selection process, several Sudanese and in-country foreign experts from private, academic and governmental institutions involved in the R&D of appropriate renewable energy technologies, participated in the screening process and classified the combinations according to their overall utilization and market potential.

Phase 4: Renewable Energy Project Identification:

This phase provides a detailed analysis of several renewable energy projects which have been selected in Phase 3 as having the best potential for utilization in Sudan.

For each project, the following issues were addressed:

1) Introduction, including project description, resource assessment, etc.
2) Project technical and performance characteristics
3) Project estimated cost characteristics
4) Economic analysis of the project (micro-analysis-IRR-macro-analysis - charcoal, firewood and petroleum products displaced -)
5) Implementation issues (technical, economic/financial and institutional), and market penetration estimates.

Phase 5: Recommendations for a National Renewable Energy Program

A set of recommendations related to the creation of a national renewable energy program was developed. This program will encourage the utilization of renewable energy by addressing technical, economic/financial and institutional issues which will help to overcome the obstacles limiting the introduction of appropriate, low-cost, simply-designed renewable energy technologies.

The information used in this report (resource assessment data, technical, performance and cost data, etc.) was derived from a review of several technical and economic feasibility studies, renewable energy reports, and meetings with Sudanese and in-country foreign energy officials. For the purpose of the report, a simplified micro-economic analysis was carried out for each renewable energy project identified. The project internal rate of return was a simplified discount cash flow analysis which did not include depreciation and debt services.

2.0 Overview of Renewable Energy Activities:

This section summarizes past, present and future renewable energy activities and projects in Sudan. The information was collected from various publications (see Appendix 1: list of references) and meetings with several Sudanese officials involved in the research and development of renewable energy sources and technologies (see Appendix 2: list of people contacted).

Research in renewable energy sources in Sudan started in 1955 at the Physics Department of the University of Khartoum where work on power generation and solar energy measurements was underway. At the same time, some 250 Australian windmills were installed on boreholes in the Gezira Province for pumping drinking water for dispersed small communities in the area. In 1958, the Department of Mechanical Engineering at the University of Khartoum began conducting research on solar water heating, desalination and drying. Solar energy started receiving government support since 1970 with the establishment of the Institute of Solar Energy, currently Institute of Energy Research, as part of the Sudanese Council for Scientific and Technological Research.

Table 2.1 summarizes the research and development activities in various renewable energy sources (solar, wind and biomass) which are currently underway (or would be in the near future) at several academic, and governmental institutions in Sudan.

2.1 Solar Energy:

Several solar energy projects are underway at the Institute of Energy Research, most of them in collaboration with the Mechanical Engineering Department (University of Khartoum).

a) Solar Water Heating: Several flat plate collectors using galvanized steel tubes and absorber plates are being tested at the Mechanical Engineering Department (University of Khartoum).

b) Solar Desalination: Several solar stills (4-6m^2) are operating in locations such as Shambat (Food Research Center), University of Khartoum (Institute of Energy Research), and Wad Medani (Agricultural Research Corporation) producing an average of 1 gal/m^2/day distilled water. A pilot plant (40m^2) had been operating since 1975 at the Institute of Energy Research testing center in Soba (20 km south of Khartoum). The plant area is going to be extended to 100m^2.

c) Solar Drying: Several solar air dryers using flat plate collectors have been developed for processing agricultural products: an indirect solar dryer is operating successfully at Shambat (Food Research Center) and an experimental direct solar dryer is being tested at Um Dome.

d) Solar Refrigeration: A
designed by the Technical
granted to the Institute
The unit, based on a soli
$CaCl_2$/ammonia and produci
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e) Solar Water Pumping: A
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2) The German GTZ renewa
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plant in a wood processi

d) Solar Refrigeration: A solar refrigeration unit, designed by the Technical University of Denmark, was granted to the Institute of Energy Reserach in 1975. The unit, based on a solid absorption system using $CaCl_2$/ammonia and producing 40 Kg of ice/day, is being tested at the Mechanical Engineering Department (University of Khartoum).

e) Solar Water Pumping: An agreement was signed with CNRS of Finance for four years in 1974 and extended in 1978 for another four years. Under this agreement two Sudanese students are working on their Ph.Ds in the field of solar energy in France and two SOFRETES solar thermal pumps of 1 KW capacity each, were installed at Soba (IER testing center) and at Hillat-Hamad (90 km from Khartoum) in 1977. Both systems (thermal-hydraulic press type) stopped operating in 1979 due to a number of technical problems (safety valves, leakage in the boiler, gaskets) partly because of the high temperature and high salinity of the pumped water.

As part of the "Small-Scale Solar Powered Irrigation Pumping Systems" project, funded by the UNDP and executed by the World Bank with techncial consulting services from Sir W. Halcrow& Partners and the Intermediate Technology Group, three Photovoltaic (PV) pumps were installed at Butri(30 km south of Khartoum) and one thermal pump was installed at Soba (IER Testing Center). The Institute of Energy Research is coordinating all field trials in Sudan. Technical and performance characteristics for the four pumps are shown in Table 2.2. Lectures, training courses and reserach work in solar energy is also taking place at the physics department (passive solar cooling, solar cooking, lectures on solar energy, etc) and at the Mechanical Engineering Department (solar heating, desalination, drying and refrigeration, etc.) of the University of Khartoum.

Two additional solar energy projects are still under study:

1) The UNIDO Solar Community Development Center at Um Safari (North Kordofan Province) proposed by the National Research Council. This project includes the installation of solar photovaltaic systems and wind energy systems for pumping highly saline (salinity greater than 10%) brackish underground water (estimated total installed capacity of 16KW). Salt and distilled water will be produced by solar desalination plants, and electric energy storage batteries will operate television sets, refrigerators, radios and lighting facilities. The project is supposed to start in late 1982.

2) The German GTZ renewable energy program (proposed in 1980) which includes the installation of a solar PV system (7.5 KW of rated capacity) and a solar water heating system (55m^2 of flat plate collectors) at the Maridi Hospital. The program proposes to use solar TV sets (powered by PV cells) in the Gezira educational television project, and the installation of two wood gasification plants in the south of Sudan (a 180 KW plant for the Kagelu forestry college, and a 50 KW plant in a wood processing firm in Juba).

Location	Water Source	Total Head (M)	Supplier	Type	Cost ($)	Peak Flow L/S	Array Area (m^2)	Peak Array Power (w)	Remarks
Soba	Borehole	38	SOFRETES	Thermal	50,000	1.4 at 38m head	100	1000	Installed 1979 Stopped operation 1979
Hillat Hamad	"	38	"	"	50,000	"	100	1000	"
Soba	Borehole	20	Solar Pump Corporation	Thermal	12,000	0.8 at 15m head	5.1	N.A.	Installed in 1981
Butri	Open Well	9.5-18	Arco Solar	PV	4,800	1 at 15m head	5.92	530	Installed in 1980
Butri	" "	4.9-11	Inter Technology Solar Corporation	PV	21,500	1 at 8m head	5.92	530	Installed in 1980
Butri	Open Well	9.5-11	Soterem	PV Tracking	31,500	1 at 8m head	N.A.	480	Installed in 1981

Table 2.2 Technical and Performance Characteristics Of Solar Water Pumping Systems

Wind Energy:

Wind mills were first introd
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2.3 Biomass

a) Water Hyacinth Utili

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- Trials with primitive b
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Table 2.2 Technical and Performance Characteristics Of Solar Water Pumping Systems

Butri	Open Well	9.5-11	Soterem	PV Tracking	31,500	at 8m head	5.92	530	Installed in 1980
						at 8m head	N.A.	480	Installed in 1981

Wind Energy:

Wind mills were first introduced in Sudan in the early 1950's, with about 250 systems installed throughout the Gezira province. These "American" type wind mills pumped drinking water for dispersed small communities in the area. They were progressively replaced by diesel and electrical-driven engines, and by 1965 the last windmill had been dismantled primarily because of inadequate windmill design for Sudanese conditions, lack of spare parts and the very high operating and maintenance costs of the systems.

Research work in wind mill design, construction and testing had been underway at the Mechanical Engineering Department (U. of K.) in collaboration with Reading University. The Australian Government has agreed to supply the National Administration for Domestic Water Supply in Khartoum with five wind mills, as a result of the positive conclusions made by a team from the Australian Development Assistance Bureau on the feasibility of wind mill utilization for water pumping applications. These systems will be installed shortly in the Khartoum, Kordofan, and Darfur areas.

A wind energy program in the Sudan initiated with the support from the Deutsh Steering Committee Wind Energy Developing Countries (SWD) in collaboration with the Institute of Energy Research, is currently under study. This two phase, five-year program will establish a wind energy department (within the Institute of Energy Research) which can develop and introduce appropriate wind energy technology in the Sudan. The objective of the first phase (2 years) is to design, develop and test water pumping wind mills that are suitable for local manufacture in the Sudan, and to prepare and initiate pilot projects. The program includes the creation of a wind energy center that will train engineering students and others in topics such as wind data analysis, site selection, rotor, pump and tower design, wind mill construction and analysis. In the next phase, wind energy conversion systems (for water pumping applications and electricity generation) will be erected in well-exposed sites throughout Sudan, and problems limiting the wide-spread utilization of these systems will be identified, analyzed and solved.

2.3 Biomass

a) Water Hyacinth Utilization

The spread of water hyacinth throughout the White Nile and its tributaries (in the late 1950's) threatening a number of national interests (navigation, transportation, fishing, irrigation and public health), had called for the creation of a National Council for Water Hyacinth Control chaired by the Ministry of Agriculture, Food and Natural Resources. Its function is to help the Water Hyacinth Control Section of the Plant Protection Administration (annual budget of 1 million Sudanese pounds) find alternative ways to utilize the aquatic weed.

In this context, a joint Sudanese-German Water Hyacinth Control Project, initiated in 1972, dealt with the chemical and mechanical control of the weed. As part of this project, work on water hyacinth utilization started in Kosti (on White Nile) in 1976 and included the following activities:

- Trials with primitive biogas digesters (200 liter drums, producing 450 liters of biogas/kg of dry matter after a retention time of 4 months).

- Development and construction of a floating and a stationary cropping device.

- Laboratory trials with regard to the pyrolysis potential of water hyacinth (one kilogram of dry matter gave 0.976m^3 of gas, 0.537 kg of charcoal and 0.045 kg of heavy oils).

- Investigation of the weed's nutrient content with regard to its utilization potential as animal feed and soil fertilizer (fertilizer trials showed a 31.8% increase in agricultural yield by distributing 7.5 tons of water hyacinth ash/ha on light sandy soils.

In 1968-70 several biogas digesters were installed as a result of the experimental work completed on primitive units.

Table 2.3 Technical and Performance Characteristics of Biogas Digesters Operating in Tawila

Biogas Digester	Tube-Type Butyl-Rubber (England)	Bell-Type (India)	Dome-Type (China)
Number of Units	2	1	2
Total Volume	2.5	8	12-18
(Fermentation Space) (m^3)	(2.5)	(3.8)	(8.1-12)
Gas Production (m^3/day)	1.5-1.8	2.3-2.8	4.9-5.8
Amount of Wet Water Hyacinth Needed (Kg/Day)	60	95	200
Cost of Unit (Sudanese Pounds/m^3)	224	210	265

For all these units, the gas produced was pumped to adjoining households where it was utilized to operate modified gas refrigerators, gas ovens and lamps. The technical and performance characteristics of the different types of biogas digesters currently operating in Tawila (Kosti) are shown in Table 2.3 (above)

One proposal from the Institute of Environmental Studies (University of Khartoum) suggests harvesting the weeds using booms to deflect the material to the shore, and compressing the sun-dried water hyacinth into fuel briquettes for direct utilization as an energy source in rural households and small-scale industries. Laboratory trials are currently underway at the College of Agriculture (University of Khartoum), determining the optimal conditions for biogas production from water hyacinth (particle size, stirring, temperature, PH, and solid content of mixture). A total biogas volume of 0.75m^3 (60-80% methane content)/KG of dry matter was obtained using a 5% solid content mixture kept at a temperature of 37°C and at a PH of about 7.

b) Sugar Residues Utiliza

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b) Sugar Residues Utilization:

Sugar residues are currently exported or used locally to extract liquors or as an animal feed (in the case of molasses). Others are used as fuel and burned in the boilers of sugar factories (in the case of bagasse). Sudan Development Corporation is considering a sch[illegible] produce gasohol motor fuel: a mixture of gasoli[illegible] (80%) and alcohol distilled from molasses (20%). United Molasses of the United Kingdom (wholly-owned subsidary of Tate and Lyle) has prepared a feasibility study, commissioned by the European Development Fund, for a plant to produce 15,000-20,000 tons of alcohol a year (estimated cost of $20 million).

Aba International, Inc. (of Hawaii) has also prepared a similar study for the extraction of ethanol (alcohol from molasses from Kenana molasses using a continuous fermentation system. The proposal calls for the construction of a molasses fermentation factory (rated capacity: 105,000-157,000 tons of molasses/year) which will produce ethanol(32.55-48.83 million liters/year), yeast (1102.5-1653.8 tons/year) and methane (44.1×10^9 - 66.2×10^9 KCal/year) at a capital cost of $20.5 - $25.9 million with a total annual operating and maintenance costs of $6 to $9 million. Another company with a $5.8 million capital has been established to produce yeast from Guneid factory molasses. The Mechanical Engineering Department at Khartoum University is coordinating a National Alcohol Program evaluating the performance of gasohol-fired engines and studying the possibility of building an alcohol distillery. As part of this program, the performance of two popular cars in the Sudan (Peugeot 504 and Land Rover) was investigated using an alcohol mixture of 45% tops, 45% plat formate and 10% alcohol. Road tests were conducted for a distance of 1800Km for each car. Results showed an improved fuel consumption (6-8%) easier and smoother driveability than with regular gasoline. No overheating and no starting problems were noticed. However, carbon deposits were found on the valves and piston crowns due to either incomplete combustion or to the quality of the blend used.

c) Agricultural and Animal Residues Utilization:

Animal residues such as cow dung are mixed with water (typically 1:1) and digested anaerobically in biogas units producing a medium quality gas (60-80% methane content) which can be utilized in rural households for cooking, lighting and operating modified gas-refrigerators. Such a unit has been operating in Torit (Southern Region) since 1979, as part of Norwegian Church Aid-Sudan project in the Eastern Equatorial Province. This simply designed system made of three sealed drums has a total volume of $0.6m^3$, and a fermentation space of $0.45m^3$. Another similar system is being tested at Juba University providing biogas to its science laboratory burners.

A "Methanization of Agricultural and Animal Wastes" project is currently underway at the Institute of Energy Research (CSTR) with two objectives, namely, the assessment of available agricultural and animal waste materials and the identification of suitable locations for methane production. The project will

also include experimental work so as to determine the most suitable conditions and designs of biogas plants for Sudan.

The Cellulose, Chemistry and Technology Unit (CSTR) was established in 1971 so as to act as a coordinator for all the parties involved in the utilization of crop residues (pulp and paper production, energy utilization, animal feed production, fertilizer production and building equipment).

A UN project involved in the energy gasification and fuel briquetting of cotton stalks and bagasse has been approved very recently (February 1982). The project calls for the establishment of a research center within the cellulose unit, training of Sudanese officials in the various technologies and processes, and the provision of Foreign expertise to help coordinate the entire project.

d) Charcoal Production and Utilization

Very little work was done in improving charcoal production and utilization methods in Sudan. The Forestry Department is planning to introduce modern charcoal kilns increasing charcoal production yields. Already, several French metalic kilns have been introduced in rural areas: they had a little market potential mostly because of their small production capacity and the difficulty of transporting them from one location to another according to the availability of fuelwood.

An improved charcoal stove was designed and constructed as part of a project at the Ahfad University College for Women. The stove, built at the Mechanical Engineering Department (University of Khartoum), has an estimated combustion efficiency of 25%, significantly higher than that of conventional charcoal stoves (15%). Several models are supposed to be disseminated in rural areas of Sudan.

3.0 Renewable Energy Resource Assessment

3.1 Solar Energy Data Base

Sudan has been recording solar radiation in many locations since 1957. Hourly total (diffuse and direct) solar radiation on a horizontal surface is currently being recorded at 15 meteorological stations throughout Sudan (Table 3.1).

According to Mr. Jalal El Din Awad (Head of the Solar Radiation collection section at the Meteorological Department), most of the recording stations use 10-junction Epply pyranometers for solar insolation measurement, G-type Speedomax recorders for recording solar radiation data and Linke-Feussner actinometers for calibration of the pyranometer-recorder.

For each station, hourly total solar radiation is calibrated

and used to determine monthly mean daily solar radiation which is tabulated for every month of the year and for every year of the recording period. Table 3.1 lists monthly mean daily solar radiation ($MJ/m^2/year$) and total annual solar radiation ($GJ/m^2/year$) on a horizontal surface for each of the 15 meteorological stations. The solar radiation data in Table 3.1 were averaged over the entire recording period of the station (up to 23 years). Direct solar radiation (useful data in the case of solar systems using concentrating collectors) can only be obtained from Shambat and Wad Medani meteorological stations.

The variation of annual mean hourly solar radiation (total and diffuse) for Khartoum (Shambat station, 1979) is shown in Figure 3.1. This figure indicates that diffuse solar radiation is typically 20%-40% of the total solar radiation: cloudiness, sand rising and sand storms (haboobs) are the major causes of the diffusion of direct solar radiation. The solar concentrating collector systems can utilize only the direct portion of the solar radiation, resulting in a reduction of the performance of such solar systems. The figure also indicates that annual mean daily sunshine duration is about 12 hours (4380 hours/year), and that annual mean peak solar power density is $1070 W/m^2$.

Even with a relatively high fraction of diffuse solar radiation, Sudan enjoys a considerable solar energy resource base with annual total solar radiation ranging between 6.88 to 10.1 $GJ/m^2/year$ on a horizontal surface (it should be noted that the amount of solar energy received on a surface tilted by nine-tenths of the latitude and facing the equator will be, in average, 10% higher than the energy received on a horizontal surface). The annual total solar radiation is low in the Southern region of Sudan (Juba) and increases as we move to the north. It reaches very high values in the Northern region (Dongola), Darfur region (El Fasher, Zalinge), Khartoum region (Shambat) and Gezira region (Wad Medani).

The values for annual solar radiation obtained from the recording stations are similar to those obtained from the Relative Global Radiation Map for the World developed by the Meteorological Organization: this map derived for the United Nation's Renewable Energy Conference in Nairobi (August 1981), shows the distribution of monthly and annual global radiation expressed as a percentage of the astronomically possible global radiation.

Station	Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total Solar Radiation (GJ/m^2/year)
Abu Naama	1963-1980	23.6	26.1	27.6	28.3	27.6	25.9	24.1	24.4	25.4	24.3	23.8	22.4	9.23
Aroma	1973-1980	22.2	23.4	25.7	26.6	25.8	25.2	25.6	28.4	27.3	24.3	21.4	19.4	8.98
Babanusa	1974-1980	23.5	26.1	27.7	28.3	27.4	26.2	23.7	23.8	25.0	23.6	22.8	22.3	9.14
Dongola	1973-1980	23.1	26.2	29.4	31.3	31.7	31.6	30.0	29.0	27.7	26.3	23.9	21.8	10.1
El Fasher	1957-1980	23.4	26.3	28.4	29.3	28.8	27.5	25.9	26.1	26.6	26.0	24.7	23.2	9.61
El Showak	1971-1980	23.9	26.9	29.4	30.3	29.2	31.2	25.6	25.8	26.5	25.3	24.0	22.4	9.76
Ghazala Gawazat	1964-1980	23.8	25.9	27.1	27.2	26.0	25.0	23.7	23.6	24.7	24.8	24.6	23.5	9.12
Hudeiba	1974-1980	22.5	24.8	28.1	29.3	28.4	26.4	26.0	26.8	26.2	24.9	23.3	22.1	9.39
Juba	1957-1980	22.3	22.5	22.2	21.8	23.7	22.1	20.6	22.3	24.4	23.4	22.4	22.1	8.21
Kadugli	1973-1980	24.9	26.4	27.4	27.9	26.4	23.9	21.6	21.2	21.4	23.2	25.0	24.3	8.94
Malakal	1960-1980	23.2	24.7	25.7	25.6	23.3	20.9	20.7	22.4	22.0	22.2	23.3	22.8	8.42
Port Sudan	1957-1980	17.3	21.7	26.1	28.9	29.2	27.4	26.3	26.0	25.8	23.7	19.1	16.5	8.76
Shambat	1957-1980	23.3	26.2	27.1	29.6	28.3	26.9	26.3	26.1	26.3	24.7	23.7	22.4	9.45
Wad Medani	1957-1980	24.1	26.6	28.4	29.2	28.3	27.3	25.5	25.7	26.8	25.8	24.4	23.3	9.59
Tokar	1973-1980	12.6	15.8	19.6	24.9	23.3	22.4	20.0	19.4	20.1	19.0	14.7	12.2	6.88
Zalinge	1971-1980	25.1	27.5	29.5	29.5	28.9	27.2	24.0	23.1	25.0	26.3	26.3	24.9	9.65

SOURCE: Unpublished Data From Meterorological Department, Khartoum, Sudan.

Table 3.1 Monthly Mean Daily and Annual Total Solar Radiation (MJ/m^2/day, GJ/m^2/year)

(Averaged over recording period)

Mean Monthly Total (Direct and Diffuse) Solar Radiation (MJ/m^2/day)

Figure 3.1 Variation of A
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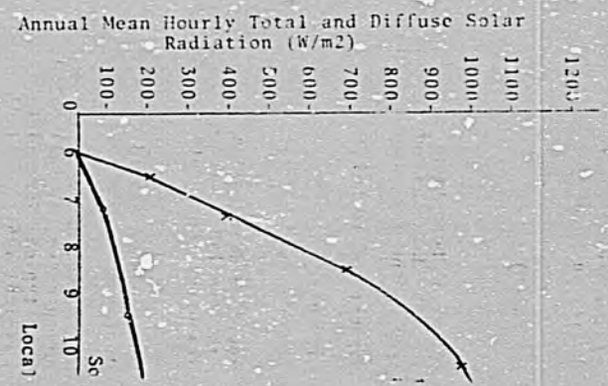

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- Meeting with Mr. El data collection and Department, Februar
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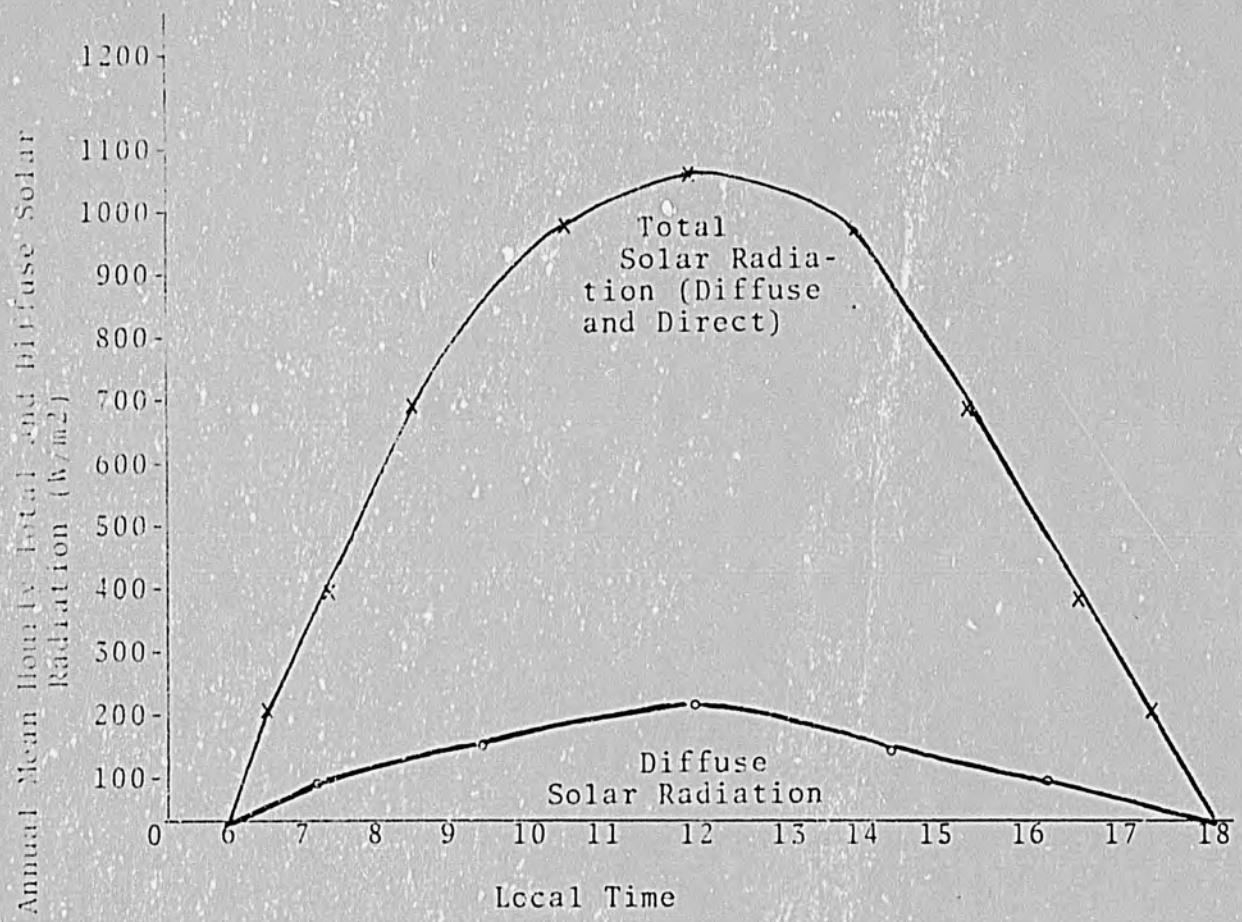
Figure: 3.1 Variation of Annual Mean Hourly Total and Diffuse Solar Radiation in Khartoum

(Shambat Meteorological Data, 1979)



References:

- Meeting with Mr. El-Tayeb Mousa, head of the meteorological data collection and processing section of the Meteorological Department, February 15 and 16, 1982.
- Solar radiation data supplied by Mr. Jalal El Din Awad, Meteorological Department, February 15 and 16, 1982.
- "Meteorological Aspects of the Utilization of Solar Radiation as an Energy Source",World Note 172, WMO No. 557, Geneva, Switzerland, 1981.

3.2 Wind Energy Data Base

The objectives of creating a wind resource data base for Sudan are as follows:

(1) Identify the wind energy potential in Sudan using available wind data from the Meteorological Department.

(2) Refine recorded data and develop a more accurate estimate of global wind-energy availability in Sudan.

(3) Identify wind characteristics required for the design of wind energy conversion systems (WECS).

I. Methodology

Available wind data from the Meteorological Department (Khartoum) was identified and summarized by hand. The data was subsequently stratified according to quality, based on the following factors:

1) Accuracy of the recording equipment and technique
2) Type of data collected
3) Exposure of the recording equipment
4) Recording period (years)
5) Recording rate/interval

Stratified data was then used to provide a description of the spatial and temporal variations in the available wind energy. The complete analysis of the wind resources represents a synthesis of:

1) Tabulation of annual mean wind speeds (averaged over the recording period) for all meteorological stations in Sudan.
2) Annual mean wind speed duration curve, and annual mean wind speed frequency distribution curve, for all meteorological stations in Sudan, for a typical year (1981).
3) Wind power density map for a typical year (1981) at a standard height.

All wind data was recorded at a standard height of 15.2m. Annual mean wind speed duration curve consists of a graph showing the number of hours per year that the windstream attains a specified hourly mean wind speed at a given site and at a given height.

Annual mean wind speed frequency distribution curve shows the frequency of occurence of mean wind speed values at a given site and at a given height. These curves will determine both the wind power density map which shows the patterns of annual wind power over Sudan (at a given height), and the power output from a WECS.

II Available Wind Data

Wind energy data from the Meteorological Department consists of mean hourly wind speed and wind direction measured at a height of 15.2 meters above ground, from 23 meteorological stations throughout Sudan (Table 3.2). Data was collected by relatively accurate and properly maintained anemometers. Dine's pressure-tube anemographs were used to record hourly mean wind speeds. For most of the stations the recording period was greater than 20 years, and the average recording interval of an hour was satisfactory (close to the WECS response time to the wind). The major parameter affecting the accuracy of the data was the exposure of the recording equipment.

Monthly wind speed frequency distribution is also tabulated. This data was utilized to determine annual wind speed frequency distribution, a major parameter in computing wind power density at a given site. This information determines, for a given year, the total number of hours the wind was blowing within a specific wind speed range (0-2 m/s, 2-4 m/s, 4-6 m/s, etc.)

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II. Wind Data Refinement

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Surface wind data is also collected at 21 agro-meteorological stations. At these stations, mean hourly wind speed is recorded using cup anemometers located at 50cm or at 200cm above ground level. Some stations (Shambat, Wad Medani and Zalinge) have anemometers located at various heights: 30/50/100/150/200/300/700/1000/1300/1550 cm above ground Table 3.2. This data is particularly useful in determining the shape of the boundary layer (the variation of wind speed with elevation). This information would prove helpful in siting a WECS .

Finally, daily information on wind speed and wind direction is available from aerogram data using radio sondes. These meteorological instruments are available at 6 sites throughout Sudan, namely Khartoum, Port Sudan, Malakal, El-Fasher, Dongola and Juba. They will operate for a pressure range of 10-1000 millibars (up to several thousand meters above ground).

II. Wind Data Refinement

According to officials from the Meteorological Department, the majority of the recording anemometers were located in urban areas, where the distance between the anemometer (at a standard height of 15.2m) and obstacles such as trees and buildings (average height of 5-7m) was of the order of 20 meters. Wind measuring devices should be located on an open-terrain so as to minimize the wind flow disturbances caused by local obstacles. An open-terrain is defined as an area where the distance between the anemometer and any obstruction is at least fifteen times the height of the obstruction.

Studies have shown that the zone of disturbed flow over a small building of height h extends to a distance of 20h downwind of the obstacle. Also, the effects of an undisturbed air flow encountering an obstruction of height h increase with the width of the obstacle and result in increased turbulence which reduces wind power by as much as 74% (at a downwind distance of 5h), 36% (10h) and 14% (20h), for a building of width 4h. Similar reduction in wind power was experienced with shelter belts and trees. Thus, the measurements from existing sites in Sudan are underestimates of the actual available wind energy at unobstructed sites.

Wind speed was corrected for differences in surface roughness (between poorly exposed meteorological stations with high roughness characteristics, and well exposed sites suitable for wind energy utilization with low roughness characteristics) utilizing the table of wind speed extrapolation factors derived by Tom Hiester (Battelle, Pacific Northwest Laboratories). This table estimates wind speed extrapolation factors for sites in areas of different surface roughness based on logarithmic wind profiles.

Since information on surface roughness was not available for the 23 stations, two cases were considered:

(1) High roughness case (High woods with many trees) with a windspeed extrapolation factor of 0.815 (at 15m).

(2) Low roughness case (Tall row crops or low woods) with a windspeed extrapolation factor of 1.08 (at 15m).

The surface roughness of well-exposed sites was assumed similar to that of low grass or fallow ground, with a corresponding wind-speed extrapolation factor of 1.2 (at 15m). This is a very conservative estimate.

The roughness correction factor (wind speed correction factor) is obtained by dividing the windspeed extrapolation factor of well exposed sites by that of the meteorological stations as follows:

Surface Roughness Correction Factor
(Wind speed correction factor)

High roughness case	1.2/ 0.815 = 1.47
Low roughness case	1.2/1.08 = 1.11

IV. Wind Data Analysis

Mean hourly wind speeds from monthly wind summary tables for 1981 were grouped in several wind classes and their frequency of occurrence was tabulated for the 23 meteorological stations. Mean annual wind power for a typical year (1981) was derived from the tables, and an annual wind power density map was subsequently developed for Sudan (at a standard height of 15.2m) for 1981 (Figure 3.2). This global wind energy assessment map is the first preliminary estimate of available wind energy ever completed for Sudan. It should be clearly stated that this map should be used only as an indication of wind energy availability on a global scale. There may be many high-wind sites due to local conditions in low wind areas, and conversely low-wind, sheltered locations in high wind regions. For any specific project on wind energy utilization, it is necessary to undertake site specific detailed wind resource assessment. Values of mean annual wind speeds (averaged over the recording period), and mean annual wind power density (for the three cases in 1981) for the 23 meteorological stations are shown in Table 3.3. Looking at Table 3.3, the actual power available at a given site can be several times that calculated on the basis of mean annaul wind speed (Casé 0). This is due to the cubic relation between wind power and wind speed. Hence, isovent maps are a very poor indication of available wind power in Sudan.

It is worth mentioning that the mean annual wind power density map in the high roughness case gives a similar picture of the wind energy potential in Sudan to that of the global map developed by Battelle Pacific Northwest Laboratories. This map of worldwide wind energy resource distribution estimates uses wind data received from National Meteorological Services in conjunction with upper-air data and topographical data. The enlarged map for Sudan indicates a mean annual wind power density spatial distribution quite similar in magnitude to that of the high roughness case map, underlying the importance of correcting wind speed data from poorly exposed meteorological sites.

Referring to Figure 3.2, the Northern region of Sudan (Dongola) has a very important wind energy potential with annual wind power density in excess of 400 W/m2 (Case III). In addition, the Khartoum and Gezira regions also enjoy important wind regimes with wind power density ranging between 285 and 380 W/m² (Case III).

For a detailed WECS design, other wind characteristics have to be considered such as:

(1) Vertical distribution of mean wind speed (or wind profile); This information is needed to select the height at which the wind turbine will be placed, and the length of the rotor blades.
This information is available only at a small number of agricultural meteorological stations (see previous section).

(2) Extreme wind speeds are required to define the aerodynamic loads on the rotor and support tower.

(3) Characteristics such as: turbulence or short period fluctuations (for fatigue analysis), frequency of occurence of abrasive and corrosive particles are also needed (sand storms, etc).

Data on maximum hourly mean wind speed and maximum gusts are also available from most meteorological stations.

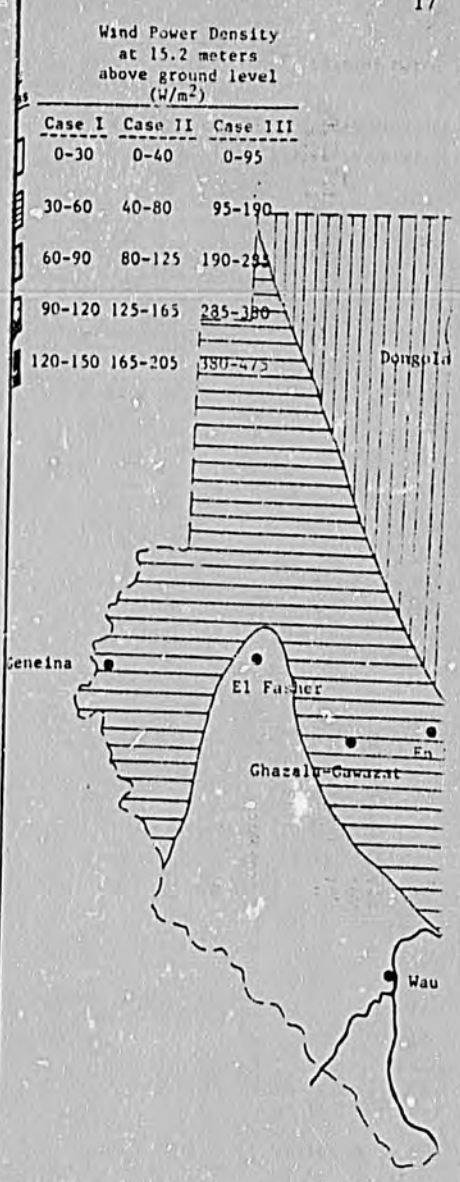

Figure 3.2 : Wind Power Density Map ground level

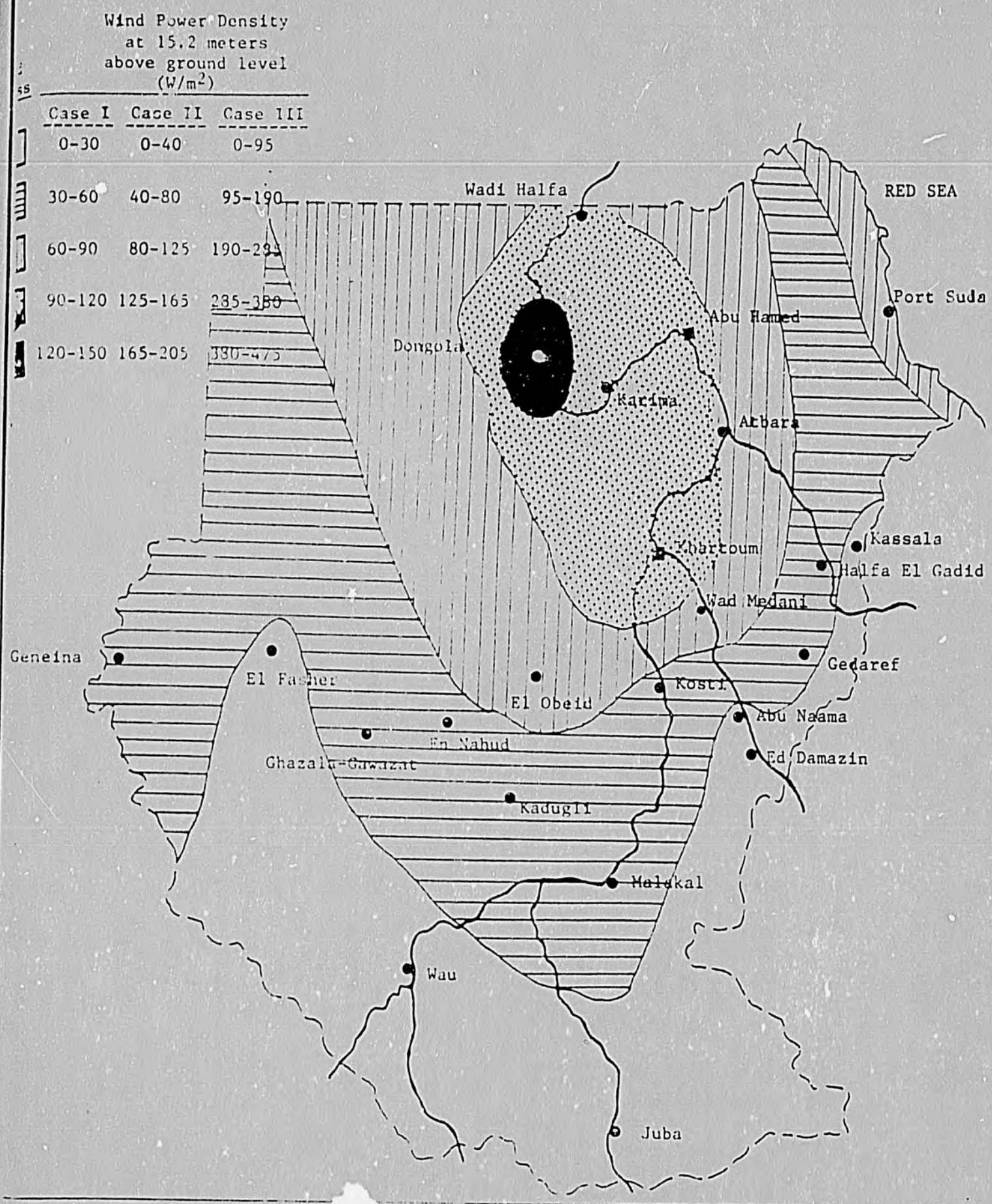

Figure 3.2 : Wind Power Density Map for Sudan (W/m^2) at 15.2 meters above ground level

References:

- Meeting with Mr. El Tayeb Moussa, head of the data collection and processing section of the Meteorological Department, February 15 and 16, 1982.

  Wind energy data provided by Mr. Ahmed Mohamed Sadek, head of the wind energy data collection section of the Meteorological Department, February 15 and 16, 1982.

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3.3 Biomass Data Base

As in the case of wind energy, no attempt has been made to estimate the Sudanese agricultural and animal residues resource base. Agricultural residues include residues from field crops (cotton, ground-nuts, etc), and residues from the sugar industry namely bagasse and molasses.

Animal residues consist of manure from the large livestock resource in Sudan.

Aquatic weeds such as water hyacinth were also included in this resource assessment because of their good utilization potential as an energy source.

Most of these residues can be utilized for energy purposes: Residues from agricultural crops can be burned as fuel briquettes in rural households and in small-scale industries (brick making, bakeries, etc.).

Bagasse can be dried (increasing its calorific value) and utilized as fuel in sugar processing industries. Molasses have a very good potential for the industrial production of alcohol (ethanol) for power use. Animal residues can be either dried and burned in rural households, or mixed with water to form the raw material for biogas digesters, producing medium quality gas which can be used as cooking and lighting fuel in rural areas. Similarly, water hyacinth can be dried and compressed in fuel briquettes, or can be digested in rural biogas producing units.

3.3.1 Agricultural Residues:

Agriculture is the largest sector of the Sudanese economy with field crops such as cotton, sorghum, groundnuts, millet and wheat accounting for the largest portion of the country's agricultural output. Table 3.4 shows annual estimates of cultivated area, production and average yield for the major crops in Sudan during the 1975-1979 period. (geographical distribution of crops production is also available (1) for more detailed anlaysis). In 1978/1979, the sharp decline in wheat and cotton production was due to the severe climatic conditions which have prevailed in the main producing areas (1) (Gezira and Halfa El Gadida). In the same year, groundnuts production also declined because of the drop in cultivated areas related to problems in transporting the crop in Western Sudan (in 1977/78), which made farmers reluctant to cultivate large areas. (1).

There is no exact data on the annual amount of agricultural residues produced in Sudan. Estimates have been made utilizing crop to residue factors which were developed for U.S. field crops (2), thus understating considerably the amount of crop residues produced in Sudan, since American crop plants are bred extensively for seed production.

The total amount of agricultural residues was estimated using annual crop residue yield factors (in metric tons/feddan) derived from Egyptian agricultural data (3). These factors, which were determined for several types of field crops, can be applied safely in the case of Sudan since Egyptian and Sudanese agricultural conditions (climatological conditions, land quality, etc.) and practices (irrigation, harvesting, etc.) are relatively similar.

In addition, these factors are somewhat compatible with estimates on crop to residue factors made by several agricultural agencies in Sudan (4).

It is important to note that only a fraction of the total amount of residues can be used as an energy source (mainly as solid fuel in rural areas). Indeed, a significant part is left on the ground, (efficiency of harvesting machines being less than 100%) acting as a fertilizer improving soil quality by providing necessary soil nutrients. Another fraction is used as animal feed and as building and handicraft materials (mud walls and domestic objects are

partly made of residues such as straw). Therefore, an availability factor was estimated for each type of field crops (5) so as to determine the actual amount of agricultural residues available for energy production.

The total amount of agricultural residues was estimated to be equal to 27.4 x 10^6 metric tons, out of which 15.9 x 10^6 tonnes can be used as an energy source, with a corresponding total energy potential of 250 x 10^{15} Joules (Table 3.5). However, the major problems of agricultural residues utilization as a fuel in rural areas are in its collection and transportation: No infrastructure currently exists for collecting and transporting the residues. Most of them are either returned to the soil, or burnt on the spot as in the case of cotton stalks being removed and burnt immediately after the cotton is picked because of the risk of black arm cotton disease. Taking this into account, a realistic figure for the energy potential amount or 50 x 10^{15} J.

3.3.2 Sugar Residues

The amount of sugar residues (bagasse and molasses) has been increasing steadily with three sugar factories coming on line during the last five years. The production of sugar in Sudan started back in 1962 with the construction of the Guneid factory (design capacity of 60,000 tonnes of sugar/year). It was followed by the identical New Halfa factory (60,000 tones of sugar) in 1965. Its design capacity was expanded to 95,000 tonnes in 1968/1969.

Sennar factory with a design capacity of 110,000 tonnes started production in 1976, followed by the identical Assalaya factory (110,000 tonnes) in 1979. In 1980, production started at Africa'a largest sugar factory located in Kenana (design capacity of 330,000 tonnes/year). The completion of Melut sugar factory with a design capacity of 100,000 tons is expected in 1982. Table 3.6 indicates the annual amount of sugar, molasses and bagasse produced during the last three years in all sugar factories in Sudan.

For a number of reasons, the industry as a whole is not efficient and all the plants are producing far below design capacity. In the case of the Guneid factory, this is due to insufficient irrigation water, causing cane stiffness, resulting in continuous breakdowns in the grinding machines. Shortage of manpower and lack of spare parts was experienced at the New Halfa factory. Continuous machinery breakdowns was blamed on unskilled Sudanese labor at the Sennar factory. In addition to the individual problems of each sugar plant there are common difficulties hindering the sugar industry as a whole, such as transportation problems, shortage of foreign exchange limiting imports of agricultural machinery and spare parts, and lack of resources to stockpile fuel.

To overcome these difficulties, the Government finally decided to increase the number of irrigation pumps, purchase new machinery and spare parts and provide training in the maintenance of various machinery. As a result of these measures, total annual sugar production is expected to reach 90% of total design capacity in the 1982/83 season.

Table 3.7 shows estimates of the energy potential of bagasse (when used as a solid fuel in sugar processing industries) and molasses(when fermented for the production of ethanol) for 1980/81. Two cases were considered for bagasse: bagasse with 50% moisture content(Case A) and a corresponding energy potential of 9.3x 10^{15} Joules, and dried bagasse with 30% moisture content (Case B) and a corresponding energy potential of 14.3 x 10^{15} Joules (availability factor - 1.0.) Ethanol production amounted to 205.2 x 10^3 bbl with a corresponding energy potential of 0.69 c 10^{15} Joules (availability factor - 1.0.)

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3.3.3 Animal Residues

Sudan has an estimated livestock population of over 49 million. (i) (1978). Animal residues, principally manure from cattle and camels can be used as a source of energy (solid fuel or biogas). Table 3.8 estimates the total quantities of manure produced in 1978 (3 using manure production factors derived for each livestock category. Only a fraction of this amount can be used for energy purposes since a large fraction of this nutrient-rich resource is left on the ground improving soil quality(35% for cows, goats and sheep and 80% for camels and horses, according to estimates(3). Animal manure is also burnt in rural areas so as to repel mosquitos.

Another parameter further reducing the residue availability factor is the nomadic nature of the livestock resource due to the life of its owners. The population is spread over the central mainlands and the tropical forests, which provide vast areas of natural pasture, making residue collection extremely difficult. The relatively low availability factor (estimated to be 0.1) can be increased with the establishment of seven major settlement areas for farming and ranching (as part of Sudan Six Year Plan). Also, an appropriate collection scheme can be achieved in places as market areas, dairy farms, slaughter houses and veterinary stations where livestock is stacked in large quantities for extended periods of time, further increasing the availability factor. Referring to Table 5, the total amount of animal manure was estimated to be equal to 257 x 10^6 tons/year, out of which 10% can be collected and used as an energy source with an estimated energy potential of 45.0 x 10^{15} Joules if used as a solid fuel, or 32.4 x 10^{15} Joules if converted to biogas.

3.3.4 Aquatic Weeds

Water hyacinth is a low density (80kg/m^3) (18), very prolific (dry weight productivity of 73-146 - tonnes /ha/year) (18), noxious aquatic weed which is spreading throughout the White Nile and its main tributaries since the late 1950's (19). Estimates (19) have shown that more than 3250 km of Sudanese rivers are infested by the weeds, mostly the White Nile River (From Lake No. to Jebel Aulia), Bahr El Jebel (From Lake No to Juba), Sobat and Pibor rivers. Water hyacinth is considered as a national pest; it is obstructing water flow, navigation and transportation (damaging steamers). It is affecting fishing activities and limiting fishable area (its dense cover prevents light penetration resulting in an oxygen-deficient water fatal to fish). It is also affecting irrigation practices by interfering with water pumps and contaminating irrigation canals and ditches. It generates all kinds of diseases and ailments brought about by insects and other creatures living among the mats of the weeds.

A variety of methods for controlling water hyacinth have been used: Chemicals (such as herbicides) were proven ecologically harmful to fish and crops such as cotton which is grown along the White Nile between Ed Dueim and Renk (19). Mechanical and manual removal of the weeds (draglines, dredging mills, nets, forks, backhoes, etc.) have been limited by material handling problems, intractibility caused by plant entanglement, inability of the machinery to perform efficiently in shallow water, and high capital and O&M costs for the Sudan. During the past years, several proposals and projects were concerned with the utilization of water hyacinth as an energy source, thus controling their infestations, providing fuel to rural house holds and reducing prevailing deforestation rates. One proposal (20) suggests harvesting the weeds using booms to deflect the material to the shore. The sun dried weeds are then compressed into fuel briquettes for direct utilization as an energy source in domestic stoves, and small-scale rural industries. Several experimental (21) and field work (22, 17) projects are analyzing the potential of biogas production from the digestion of water hyacinth. These weeds have an optimal carbon to nitrogen ratio (C/N = 30.1) for biogas production; laboratory results (21) have indicated that 0.75m^3 of biogas (60-80% methane content) can be obtained for each kilogram of dry matter (only 0.4m^3/kg of dry matter was achieved in field work projects (17)).

The utilization of papyrus for making fuel briquettes was also suggested (23). Those water weeds are covering large areas of the Sudd

swamps (60×10^3 km^2 in area), the Machar marshes and the Ghazal swamps. It was estimated that one feddan (4200 m^2) of papyrus generates 48 metric tons of carbon every year (23). A very conservative estimate (20) would place the dry weight annual productivity of water hyacinth and papyrus in the White Nile South of Khartoum at 9 million tonnes*. From April to July, winds blow from the South accumulating mats of water hyacinth at the North-most limit of Jebel Aulia where the dam acts as a physical barrier. Concurrently, the water level starts to recede leaving huge amounts of the weed on the shores of the White Nile between Renk and Jebel Aulia. Every year, quantities of water hyacinth are collected, dried up under the sun, and burnt down so as to prevent reinfestation. According to statistics (19), 471,674 m^3 of water hyacinth have been removed during the March to May period (1974) from Jebel Aulia to Renk (442,500 m^3 in May). Recent statistics (24) indicates that a total amount of 308,735 m^3 has been removed from the White Nile between July 1980 and June 1981. The energy potential of the global aquatic resources (water hyacinth and papyrus) is estimated at 135×10^{15} Joules (25) when used directly as fuel briquettes. Considering only the annual amount of water hyacinth collected from the shores of the White Nile, 0.57×10^{15} Joules can be obtained by fuel briquetting the weeds, and 1.32×10^{15} Joules by digestion of the weeds for the production of biogas (26).

* 3000KM^2 of infested area x dry weight productivity of 30 tonnes /ha/year (very conservative figure when compared to the 73-146 tonnes /ha/year value derived in reference 18)

Production (000 Tonnes) and Average Yield (KG/ Feddan)

1978/1979

1977/1978

1976/1977

hes and the Ghazal
m^3) of papyrus generates
ry conservative estimate
ivity of water hyacinth
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accumulating mats of
l Aulia where the dam
water level starts
the shores of the White
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, and burnt down so as
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March to May period
May). Recent statistics
m^3 has been removed
1981. The energy
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of water hyacinth
.57 x 10^{15} Joules
and 1.32 x 10^{15}
ction of biogas (26).

ductivity of 30
gure when compared
erived in reference

Production (000 tonnes) and Average Yield (KG/ Feddan)

	1975/1976			1976/1977			1977/1978			1978/1979		
	Area	Production	Av. Yield	Area	Production	Av. Yield	Area	Production	Av. Yield	Area	Production	Av. Yield
Cotton	981	516	522	1006	459	456	1120	559	499	1036	407	392
Sorghum	6311	1991	315	6287	1800	287	6662	2017	303	7202	2408	334
Millet	2701	370	136	2773	472	170	2948	487	166	3078	550	179
Wheat	690	255	370	639	294	460	602	317	527	586	177	302
Rice	17	7	411	23	11	478	28	13	464	20	10	500
Maize	210	53	252	149	42	281	139	42	303	145	45	310
Groundnuts	2321	796	342	1880	748	391	2661	1027	391	2328	798	343
Sesame	2216	218	98	2288	247	108	2349	245	104	2057	214	104

TABLE 3.5 AGRICULTURAL CROP RESIDUES IN SUDAN (1978/1979)

CROP	AREA (1) (000 Feddans)	Residue(5) Yield Factor (tonnes/ Feddan)	Total Amt. Of Residues (000 tonnes)	Avail. Factor	Net Amt. of Residues for Energy purposes (000 tonnes)	Calorific Value of Residues (6) (GJ/ tonnes)	Energy Potential Of Residues (10^{15}J)
Cotton	1036	1.5	1,554	1.0	1,554	13.3	20.7
Sorghum	7202	2.15	15,484	0.5	7,742	14.3	110.7
Millet	3078	1.06	3,263	0.4	1,305	14.3	18.7
Wheat	586	2.06	1,207	0.5	604	17.5	10.6
Rice	20	1.6	32	0.5	16	5.9	0.1
Maize	145	1.85	268	0.8	214	11.6	1.5
Groundnuts	2328	1.26	2933	0.8	2346	23.3	54.7
Sesame	2057	1.29	2654	0.8	2123	14.3	30.4
TOTAL	16452		27,395		15,904		248.4

	GUNEID			NEW HALFA			SENNAR			ASSALAYA			KENANA			TOTAL		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Sugar Production	36.5	26.7	55.9	64.9	45.1	50.0	18.2	39.0	32.0	-	7.7	12.6	-	24.4	91.8	119.6	143.8	222.3
Bagasse Production	203.4	143.4	179.3	311.1	271.4	252.0	104.8	173.8	180.0	-	42.7	65.0	-	122.0	459.0	619.3	699.3	1133.3
Molasses Production	13.3	11.0	14.8	24.2	20.6	22.8	9.1	18.4	19.6	-	3.5	6.5	-	11.1	41.7	46.6	64.5	105.2
Design Capacity for Sugar Production		60			90			110			110			330			700	

I = 1978 - 1979 Season
II = 1979 - 1980 Season
III = 1980 - 1981 Season

Table 3.6 ANNUAL SUGAR, BAGASSE AND MOLASSES PRODUCTION IN SUDAN (000 Tonnes) - 1978/79, 1979/80, 1980/81 Seasons

	BAGASSE			MOLASSES	
	Production (000 tonnes)	Energy Potential (10) (10^{15}J)		Production (000 tonnes)	Energy Potential (11) (10^{12} J)
		Case A	Case B		
Guneid	179.6	1.47	2.26	14.8	97.5
New Halfa	252.0	2.07	3.18	22.8	150.3
Sennar	180.0	1.48	2.27	19.6	129.2
Assalaya	63.0	0.52	0.79	6.28	41.4
Kenana	459.0	3.76	5.78	41.73	275.0
TOTALS	1133.26	9.3	14.28	105.21	693.4

Sugar Production	60	90	110	110	330	700

I = 1978 - 1979 Season
II = 1979 - 1980 Season
III = 1980 - 1981 Season

Table 3.6 ANNUAL SUGAR, BAGASSE AND MOLASSES PRODUCTION IN SUDAN

(000 Tonnes) - 1978/79, 1979/80, 1980/81 Seasons

	BAGASSE			MOLASSES	
	Production (000 tonnes)	Energy Potential (10) (10^{15}J)		Production (000 tonnes)	Energy Potential (11) (10^{12} J)
		Case A	Case B		
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Kenana	459.0	3.76	5.78	41.73	275.0
TOTALS	1133.26	9.3	14.28	105.21	693.4

TABLE 3.8

ANIMAL RESIDUES IN SUDAN (1978)

LIVESTOCK CATEGORY	NUMBER (000)	MANURE PRODUCTION FACTOR (3) (Ton/Year/Animal)	TOTAL AMT. of Manure 10^6 Ton/Year	NET AMT. of Manure For Energy Purposes (13) (10^6/Ton/Year)	ENERGY POTENTIAL Of Manure (10^{15}J/YEAR)	
					AS SOLID	AS BIOGAS
Cattle	17,299	10.95	189.4	18.94	33.7	23.9
Sheep	17,143	1.83	31.4	3.14	5.6	4.0
Goats	12,246	1.83	22.4	2.24	4.0	2.8
Camels	2,524	5.48	13.8	1.38	2.3	1.7
TOTALS	49,212		257.0	25.7	45.8	32.4

Table 3.7 ENERGY POTENTIAL FROM BAGASSE AND MOLASSES (1980/1981)

Sources:

(1) "Current Agricultural Statistics", Statistics Section, Department of Agricultural Economics, Ministry of Agriculture, Food and Natural Resources, Khartoum, June 1979.

(2) "Mohammed Hamid Abdallah." Energy Potential from Crop and Crop Residues in the Sudan". Department of Agricultural Economics and Rural Sociology, Ohio State University, July 1978.

(3) "Renewable Energy in Egypt: An Analysis of Options: MITRE Corporation, McLean, Virginia, July, 1980.

(4) F.A.O. : Estimates of Residue to Crop ratio For Rice (1.5) and Wheat (2.3).
Fodder and Pasture Depratment, Ministry of Agriculture: estimates of residue to crop ratio for wheat (1.4) and sorghum(3.0).
Sudan Oil Seeds Co. Ltd.: estimates residue to crop ratio for groundnuts (o.54 in western region, 0.72 in central region).
Mechanized Agricultural Corporation, Ministry of Agriculture: estimates of residue yield factor for sorghum (2-5 metric ton/feddan), sesame (1.15) and cotton (3).

(5) Data provided by Dr. Suleiman Jaber, Head of Cellulose, Chemistry and Technology Unit, National Council for Research, Khartoum, Sudan.

(6) E/DI Memorandum on Energy Conversion Factors, October 30, 1981.

(7) Department of State Airgram, Embassy of Khartoum, "Sudan's Sugar Industry", July 8, 1980.

(8) M. Milukas, P. Thorne. "An examination of the Impact of Energy Supply Problems on Sudanese Industry and a Review of Energy Use and Energy Efficiency", for USAID and the NEA, Government of the Democratic Republic of Sudan, by Energy/Development International, Nov. 1981.

(9) Unpublished data from the Sugar Production Corporation and Kenana Sugar Factory.

(10) Assumptions:
- Case A: Bagasse with 50% moisture content and calorific value of 8.2 GJ/Tonne (6)
- Case B: Bagasse with 30% moisture content and calorific value of 12.6 GJ/Tonne (6)

(11) Assumptions:
- Ethanol production = 310 liters/tonne of molasses (12)
- Ethanol calorific value of 3.38 GJ/bbl (6)

(12) "A Plan for Ethanol Production at Kenana Sugar Company." ABA International Inc. Nov. 1980.

(13) Assumption: Animal manure availability factor of 0.1.

(14) Assumption: Animal manure calorific value of 8.9 GJ/tonne as stated in (6) (dry basis) water content = 80%

(15) Assumptions: Biogas production from animal manure = 0.06 m^3/kg of manure (16) wet basis

Calorific value of biogas = 21MJ/m^3 (17)

(16) Abu Talib, Kathryne Ford. "Bio-Energy Handbook for Developing Countries "Mitre Corporation, McLean, Virginia, 1981.

(17) G.M. Von der Goltz, A. Perwanger "Utilizing Water Hyacinth in the Democratic Republic of the Sudan", GTZ, July 1980.

(18) Larry O. Bagnall "Water Hyacinth Energy Aquaculture" American Society of Agricultural Engineers, San Antonio, Tx. June 15-18, 1980.

(19) Kamil Beshir El Tigani. "The Problem of Water Hyacinth with Special Reference to the Sudan". Head, Water Hyacinth Control Section, Plant Protection Administration, Khartoum, Sudan, 1974.

(20) Asim. I. El Moghraby "Turning Aquatic Weeds into Energy Resources". Freshwater Ecosystem Management Group, Institute of Environmental Studies, Khartoum, Sudan, 1980.

(21) Hassan Bashir El-Amin (Crop Protection Department, Ministry of Agriculture) is completing his Masters thesis on biogas production from water hyacinth under the supervision of Dr. Hamed Drar (Faculty of Agriculture, University of Khartoum).

(22) M.M. Ahmed, F. Ibrahim. "Report about Visit to Tawila: Biogas from Water Hyacinth". National Energy Administration, Feb. 1981.

(23) Asim I. El Mogharby "Proposal for Swamp Macrophytes Briquetting" Director, Hydrobiological Research Unit, University of Khartoum, 1982.

(24) Unpublished data from Kamil Beshir El Tigani, Head of Water Hyacinth Control Section, Plant Protection Administration, Khartoum, Sudan.

(25) Assumptions:
- Dry Weight Annual Productivity of Water Hyacinth and Papyrus = 9 million metric tonne (20).
- Average calorific value of dried water hyacinth and papyrus = 15 GJ/ tonne.

(26) Assumptions:
- Annual amount of water hyacinth collected (1974) = 471,674 m^3
- Density of water hyacinth = 80 kg/m^3 (18)
- Calorific value of dried water hyacinth = 15 GJ/ tonne.

- Biogas Production from water hyacinth= 0.4m^3/kg of water hyaciath (17) (dry basis))
- Calorific Value of biogas = 21 MJ/m^3 (17)

4.0 PRELIMINARY IDENTIFICATION AND ANALYSIS OF RENEWABLE ENERGY COMBINATIONS

A preliminary list of several combinations of renewable energy resources (solar, wind, biomass and hydro), appropriate technologies (improved wood stoves, water pumps, solar collectors, etc.) and energy end-uses (cooking, water heating, water pumping, lighting, etc.) was developed. These combinations were chosen as having a good potential for being integrated into Sudanese technical, economic, socio-cultural and institutional conditions. The combinations, which were selected after a preliminary review of Sudan's basic energy needs and resources, consist of the following:

1. Biomass Combinations:

   - Improved charcoal kilns for charcoal production
   - Improved charcoal and woodstoves for rural and urban household applications (cooking, etc.)
   - Fuel briquetting of agricultural residues for utilization in rural and urban households and in industrial boilers
   - Ethanol production from sugar molasses
   - Charcoal production from banana residues
   - Anaerobic digestion of animal residues and water hyacinths for biogas production for rural cooking and lighting
   - Biomass plantation for firewood production

2. Wind Energy Combinations:

   - Windmills for water-pumping applications
   - Windmills for crop grinding
   - Windmills for electricity generation

3. Solar Energy Combinations:

   - Solar water heating for low-temperature commercial and industrial applications
   - Solar drying of agricultural products
   - Solar stills for water desalination
   - Solar photovoltaic cells for remote small-scale applications

4. Hydro Combinations:

   - Micro and mini-hydro plants for electricity generation

A list of these combinations was submitted to several Sudanese and in-country foreign experts from private, academic and governmental institutions who have been involved in the research, development, and demonstration of appropriate renewable energy technologies in Sudan (Table 4.1). These experts were asked to analyze and screen these combinations by attributing a weight to each of seven selection parameters for every combination (refer to enclosed letter to Sudanese experts). For the purpose of this preliminary screening phase, each parameter was given the same weight.

As a result of this screening phase a limited number of renewable energy combinations were selected, as having a substantial overall utilization and market potential in Sudan. The combinations selected for a more detailed analysis consist of the following:

1) Ethanol production from sugar molasses.
2) Windmills for water pumping applications.
3) Charcoal production from banana residues.
4) Fuel briquetting of agricultural residues for utilization in rural and urban households and in industrial boilers.
5) Anaerobic digestion of animal residues and water hyacinths for biogas production for rural cooking and lighting.
6) Solar water heating for low-temperature commercial and industrial applications.
7) Improved charcoal kilns for charcoal production.

TABLE 4.1

LIST OF RENEWABLE ENE
PARTICIPATED IN THE S

NAME
Professor Ahmad Abdul Rahman El-Agi
Dr Yahia H. Hamid
Dr. Farouk Habbani
Dr. Suleiman Jaber
Dr. Anthony Eagan
Dr. El Tayeb Idris Eisa
Dr. Mohammed Osman Sid Ahmed
Dr. Adil R. Elia
Mr. Mohammed El Tayeb Mansour
Mr. Shommo Sha'a Eldin Ali

TABLE 4.1

LIST OF RENEWABLE ENERGY EXPERTS WHO PARTICIPATED IN THE SCREENING PHASE

NAME	POSITION
Professor Ahmad Abdul Rahman El-Agib	President of the National Council for Research
Dr Yahia H. Hamid	Head of Mechanical Engineering Department, University of Khartoum
Dr. Farouk Habbani	Head of Physics Department, University of Khartoum
Dr. Suleiman Jaber	Head of Cellulose, Chemistry and Technology Unit, National Council for Research
Dr. Anthony Eagan	Senior lecturer, Physics Dept. University of Khartoum
Dr. El Tayeb Idris Eisa	Head of Wind Energy Group, National Council for Research
Dr. Mohammed Osman Sid Ahmed	Head of Solar Energy Group, National Council for Research
Dr. Adil R. Elia	Private Energy Consultant, coordinator of the Sudan Alcohol Program
Mr. Mohammed El Tayeb Mansour	Solar Energy Group, National Council for Research
Mr. Shommo Sha'a Eldin Ali	Head of Biomass Group, National Council for Research

National Energy Administration
P.O. Box 2649
Khartoum, Sudan

Dear Sir:

As you may already know, the National Energy Administration is undertaking a renewable energy assessment for the Sudan as part of its overall National Energy Assessment project. In this context several combinations of renewable energy resources (solar, wind, biomass and hydro), appropriate technologies (improved wood stoves, water pumps, solar collectors, etc.) and energy end-uses (cooking, water heating, water pumping, lighting, etc.) have been identified as having a good potential for application in the Sudan.

Your contribution is needed so as to help us screen and analyze these combinations based on the following factors:

1) Resource availability (amount of available solar radiation, wind energy, agricultural residues, etc.)
2) Potential market (number of potential end-users).
3) Economic viability (system capital cost, O&M costs, system life, cost of competing energy sources).
4) Socio-cultural impacts (how well the combinations be received by end-users).
5) Existing Sudanese infrastructure and technical capability (as far as manufacturing, installing, and maintaining the combinations).
6) Macro-economic impacts (amount of oil displaced, balance of payment effects, etc).
7) Appropriateness of the technology (local availability of construction materials).

The following table lists all the combinations identified, together with the corresponding seven screening factors. Your input is very valuable in order to guarantee the quality of the selection process. Based upon your several years of experience in the research, development and demonstration of renewable energy resources and technologies, I will ask you to attribute a weight to each of the seven screening parameters for every combination. The weight will be either excellent (A), good (B), or poor (C).

For example, if you decide that irrigation windmills have a good resource availability, excellent potential market, poor economic viability, excellent socio-cultural impacts (i.e. no social obstacles for implementation), and that the existing Sudanese infrastructure is poor, but that the combination will have an excellent macro-economic impact (will displace a large amount of fuel), and its technology appropriateness is excellent (all components are locally available), the result of your screening process should look like this:

Combination	Resource Availability	Potential Market	Economic Viability	Socio-cultu-Impact	Existing Infrastruc	Macro Economic Impacts	Techno-Appropriateness
Irrigation Windmills	B	A	C	A	C	A	A

Any additional remarks are welcomed. If you have any question or if you need any information do not hesitate to contact me at the National Energy Administration (Phone 73315).

I am looking forward to receiving the result of your analysis before Sunday March 7th 1982.

Thank you very much for your cooperation. It will help back-up the on-going analytical selection process based on technical and economic assessment of each combination, thus providing a global picture of the renewable energy market potential in the Sudan.

Gaafar El-Faki
Acting Director

Sincerely yours,
Constantin Salame
Energy Consultant

Resource/Technology/End-Use Combination	Resource Avail.	Potential Market	Economic Viability	Socio-Cultural Impacts	Existing Infrast.	Macro Eco.	Tech. Appro.	Remarks
Biomass Combinations:								
- Improved charcoal kilns for charcoal production								
- Improved charcoal and woodstoves for rural and urban household applications								
- Fuel briquetting of agricultural residue for utilization in rural and urban households and in industrial boilers								
- Ethanol production from sugar molasses								
- Charcoal production from banana residues								
- Anaerobic digestion of animal residue and water hyacinths for biogas production								

ional Energy Administration
. Box 2649
rtoum, Sudan

nal Energy Administration
ment for the Sudan as
ssment project. In this
a energy resources (solar,
chnologies (improved wood
tc.) and energy end-uses
lighting, etc.) have been
r application in the Sudan.

to help us screen and analyze
l factors:

f available solar radia-
resources, etc.)
ntial end-users),
al cost, O&M costs,
nergy sources).
the combinations

and technical capability
ling, and maintaining

f oil displaced, balance

y (local availability

ombinations identified,
ening factors. Your input
e quality of the selection
experience in the research,
e energy resources and tech-
weight to each of the seven
n. The weight will be either

igation windmills have a
ntial market, poor economic
s (i.e. no social obstacles
f Sudanese infrastructure
e an excellent macro-
unt of fuel), and its
ll components are locally
rocess should look like

	Exist-ing Socio-cultu- Infra- Impact struc	Macro Techno- Economic Approp- Impacts riate-ness
A	C	A A

If you have any question
itate to contact me at the
15).

result of your analysis

ion. It will help back-up
based on technical and
hus providing a global
ential in the Sudan.

erely yours,
tantin Salame
gy Consultant

Resource/Technology/End-Use Combination	Resource Avail.	Potential Market	Economic Viability	Socio-Cultural Impacts	Existing Infrast.	Macro Eco.	Tech. Appro.	Remarks
Biomass Combinations:								
- Improved charcoal kilns for charcoal production								
- Improved charcoal and woodstoves for rural and urban household applications								
- Fuel briquetting of agricultural residue for utilization in rural and urban households and in industrial boilers								
- Ethanol production from sugar molasses								
- Charcoal production from banana residues								
- Anaerobic digestion of animal residue and water hyacinths for biogas production for rural cooking and lighting								
- Biomass plantation for firewood production								
Wind Energy Combination:								
- Windmills for water-pumping applications								
-Windmills for crop grinding								
-Windmills for electricity generation								
Solar Energy Combinations								
- Solar water heating for low-temp. Commercial and industrial applications								
- Solar drying of agricultural products								
- Solar stills for water desalination								
- Solar photovoltaic cells for remote small-scale applications								
Hydro Combinations:								
-Micro and mini-hydro plants for electricity generation								

SCREENING OF RENEWABLE ENERGY RESOURCE/TECHNOLOGY/END - USE COMBINATIONS

5.0 Renewable Energy Project Identification

5.1 Ethanol Production From Sugar Molasses in Sudan

1) Introduction

The annual amount of sugar molasses produced in Sudan has been increasing steadily with three sugar factories coming on line during the last five years. Table 5.1 indicates the total amount of molasses produced from the five sugar factories in Sudan.

The Kenana factory alone which started operation in February 1980, is expected to reach full capacity (330,000 tonnes of refined sugar/year) during the 1983-1984 season, producing an estimated 150,000 tonnes of sugar molasses per year. Its 1981-1982 sugar production is projected to reach 180,000 tonnes, with 82,000 tonnes of molasses produced as a by-product.

During recent years, most of the molasses produced at the sugar factories has been sold to United Molasses of the United Kingdom and to two other Sudanese companies. In addition, 5,000 tonnes are utilized locally for the manufacture of animal feed.

However, with the recent drop in the international price of molasses ($55/tonne, New Orleans, Nov. 81 March 82) and with the relatively high transportation costs of molasses from the sugar factories to Port Sudan (LS50-60/tonne depending on location) the disposal of molasses is causing an important problem to the sugar industry.

This chemically active substance cannot be dumped in the river nor in the fields without causing major ecological and environmental impacts.

Kenana Sugar Company is even considering the possibility of paying United Molasses $10/tonne of molasses so as to get rid of this by-product, if the international cost of molasses is going to be further reduced.

Sugar molasses can be converted to ethanol(by classical fermentation) which in turn can be blended with gasoline (up to 20%) and used in conventional automotive engines without any need for mechanical modification.

This "gasohol" mixture has been extensively used during the past years in countries such as Brazil where a major effort is concentrated to develop a large ethanol industry based on sugar cane and cassava.

The construction of a fermentation plant will solve the molasses disposal problem, generate significant savings to the sugar industry and displace a large amount of imported gasoline reducing balance of payments deficit.

II) Technology Description

Sugar molasses is converted to ethanol by classical fermentation: yeast is added to the molasses which interacts with the sugars resulting in a chemical reaction. The ethanol is then separated from the molasses by distillation and evaporation. The final product, an hydrous ethanol (99.6% alcohol) can be blended with gasoline up to 20% and used in conventional automotive engines, substituting for external fuel requirement.

In a typical fermentation system, 310 liters of ethanol can be extracted from every tonne of molasses processed, using a continuous fermentation system.

In addition, methane is produced from the stillage (residue) left after the ethanol has been fermented and distilled from the molasses) through a process of anaerobic digestion so as to clean the stillage of potentially harmful pollutants. Typically, 0.42 x 10^6 Kcal of methane are produced for each tonne of molasses.

Excess yeast is also extracted from the molasses at a rate of 10.5 kg/tonne of molasses processed.

III. Technology Cost Characteristi

The performance and cost cha
molasses fermentation plant (capac
year) are shown in Table 5.2. The
the costs of the steam and electri
process water installations, ferme
and dehydration tanks, yeast produ
ing facilities and stillage conver
maintenance costs include the price
fuel, labor, transporation and han
miscellaneous costs (insurance, et
the ethanol produced which will be
gasohol (10-20% ethanol, 80-90% ga
obtained from excess yeast extract
produced from the stillage.

IV. Implementation Issues:

The molasses fermentation pl
molasses producing center namely t
of transporting the molasses extra
and Assalaya) and at New Halfa and
plant, have been included in the c

A preliminary micro-economic
technical and cost characteristics
project internal rate of return to

In addition, on a macro ecor
plant will be displacing 50 millic
annually, resulting in significant
19 million for 1982 alone). It wil
sugar factories solve their molass

References:

1) Meeting with Mr. Csama El Nazir
Manager), and Mr. Abdel Sayed Tak
Company, March 27 and 28, 1982.
2. Meeting with the Director of the
New Halfa, Sennar and Assalaya su
3. "A Plan for Ethanol Production
International, Inc. Hawaii, Novem
4. Department of State Airgram, E
Industry", July 8, 1980.
5. Unpublished reports from the S
Company.

III. Technology Cost Characteristics:

The performance and cost characteristics of a continuous molasses fermentation plant (capacity of 160,000 tonnes of molasses/year) are shown in Table 5.2. The capital costs of such a plant include the costs of the steam and electricity generating systems, cooling and process water installations, fermentation equipment, distillation and dehydration tanks, yeast production plants, ethanol storage, pumping facilities and stillage conversion facilities. Operating and maintenance costs include the price of molasses feedstock (25$/tonne) fuel, labor, transporation and handling, repair and maintenance, and miscellaneous costs (insurance, etc). Savings are generated by selling the ethanol produced which will be blended with gasoline to form gasohol (10-20% ethanol, 80-90% gasoline). Additional savings are obtained from excess yeast extracted from the molasses, and from methane produced from the stillage.

IV. Implementation Issues:

The molasses fermentation plant will be located near the major molasses producing center namely the Kenana Sugar Factory. The cost of transporting the molasses extracted at nearby factories (Sennar and Assalaya) and at New Halfa and Guneid factories to the fermentation plant, have been included in the O&M costs.

A preliminary micro-economic analysis of the project using the technical and cost characteristics shown in Table 5.2 estimates the project internal rate of return to be equal to 34.3%.

In addition, on a macro economic scale, the molasses fermentation plant will be displacing 50 million liters of imported gasoline annually, resulting in significant savings in foreign exchange (LS 19 million for 1982 alone). It will also generate employment and help sugar factories solve their molasses disposal problem.

References:

1) Meeting with Mr. Osama El Nazir (Director), Mr. Omar Hassan (Adm. Manager), and Mr. Abdel Sayed Taka (Financial Analyst), Kenana Sugar Company, March 27 and 28, 1982.
2. Meeting with the Director of the Sugar Association (Guneid, New Halfa, Sennar and Assalaya sugar factories), March30, 1982.
3. "A Plan for Ethanol Production at Kenana Sugar Company", ABA International, Inc. Hawaii, November 1980.
4. Department of State Airgram, Embassy of Khartoum, "Sudan's Sugar Industry", July 8, 1980.
5. Unpublished reports from the Sugar Association and Kenana Sugar Company.

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TABLE 5.1 ANNUAL AMOUNT OF MOLASSES PRODUCTION IN SUDAN

(Tonnes)
(000)

Sugar Factory	1978/79	79/80	80/81	81/82 *	82/83 *	83/84 *
Guneid	13.3	11.0	14.8	14.8	14.8	14.8
New Halfa	24.2	20.6	22.8	22.8	22.8	22.8
Sennar	9.1	18.4	19.6	19.6	19.6	19.6
Assalaya	-	3.5	6.3	6.3	6.3	6.3
Kenana	-	11.1	41.7	82.0	126.0	151.0
TOTAL	46.6	64.6	105.2	145.5	189.5	214.5

* Molasses production for Guneid, New Halfa, Sennar and Assalaya sugar factories is estimated to remain constant to the 1980/81 production level although their design capacity is 23.0, 35.0. 43.0 and 43.0 metric tonnes of molasses/year, respectively.

Kenana sugar factory is expected to produce 180,000 tonnes of sugar in the 1981/82 season, 275,000 tonnes (1982/32) and reach the design capacity of 330,000 tonnes in 1983/84. If all sugar factories were operating at design capacity, the total amount of molasses produced in 1983/84 will be 295,000 tonnes.

TABLE 5.2

PERFORMANCE AND COST CHARACTERISTICS OF A MOLASSES FERMENTATION PLANT

Performance Characteristics*	
Design Capacity:	160,000 tonnes of molasses/year
Ethanol Production:	49.6 x 10^6 liters of ethanol/yr.
Yeast Production:	1680 tonnes of yeast/year
Methane Production:	67.2 x 10^9 Kcal/year
Construction Period:	3 years
Equipment Life:	20 years
Cost Characteristics (1982)**	
Capital Costs:	$31.8 million
Operating and Maintenance Costs:	$10.4 million/year
Savings From:	
Ethanol:	$14.6 million/year
Methane:	$ 1.3 million/year
Yeast:	$ 0.7 million/year
Total Savings	$16.6 million/year
Internal Rate of Return (%):	34.3
(O&M costs escalation rate (10%/yr)	
(Ethanol prices escalation rate (12%/yr.)	

* One tonne of molasses produces 310 liters of ethanol, 10.5 kg. of yeast and 0.42 x 10^6 Kcal of methane.

** Capital Costs = $0.53/liter of ethanol produced annually.
O&M Costs = $0.21/liter of ethanol produced annually.
Savings: Ethanol price = gasoline price = LS 0.383/liter (Khartoum depot, Nov. 1981, or $0.295/liter (exchange rate $1 = 1.35LS)
- Yeast price = $0.4/Kg.
- Methane price = $20/million Kcal of methane

5.2 Windmills For Water Pumping Applications

I) Introduction

There is a large potential for wind energy applications in Sudan, by virtue of the very high wind regimes prevailing in several regions of the country. According to the wind power density map developed from wind speed data from all meteorological stations in Sudan, regions such as Khartoum, Gezira, and Upper Nile Provinces as well as the Red Sea Coast and the northern part of the White Nile and Blue Nile Provinces have annual wind power density in excess of 150 W/m^2. Most of these regions with high wind regimes consist of large agricultural schemes where irrigation is carried out by more than 12,500 diesel engine driven pumps with an estimated installed capacity of 127MW.

In these regions, there is a large potential for appropriately designed and locally manufactured windmills for water pumping applications. The introduction of these systems in agricultural area is an interesting and economically justifiable energy project: water pumping windmills which are more economical than conventional diesel engines, will result in employment generation and in considerable savings on foreign exchange (by displacing imported fuel and imported diesel engines for water pumping.

II) Technology Description

Water pumping windmills that can be manufactured locally are the "American-type" , multi-bladed windmills, which have been used for decades for pumping irrigation and domestic water in rural communities in the Gezira area in Sudan. Although most of these windmills are not operating presently, due to a number of mechanical problems, the locally manufactured, multi-bladed systems are best suited for direct water pumping applications, because of their simple construction and low speed, high torque operating characteristics. Maintenence is easier with spare parts manufactured locally instead of being imported.

III) Technology Cost Characteristics

The performance and cost characteristics of a typical water pumping windmill which can be locally manufactured and maintained is shown in Table 5.3. The system capital cost includes the cost of the galvanized steel tower, the rotor, the water storage tank and the cost for manufacturing, erecting and installing the system. The operating and maintenance costs include labor costs for repairing and maintaining the windmills as well as the cost for locally manufactured spare parts.

Annual savings are calculated from the amount of diesel fuel needed to operate a diesel engine, which will have the same annual energy output.

The micro-economic analysis of this energy project, based on the cost characteristics shown in Table 5.3, gives an internal rate of return of 12.05 - 28.9% (assuming escalation rate of diesel prices = 12% year, and that of O&M costs = 10%/yr.) depending on the annual wind power density at the site.

IV) Implementation Issues:

The number of diesel engine driven pumps in Sudan is in excess of 12,500 with an estimated total installed capacity of 127MW. Most of these pumps are located in agricultural areas with high wind regimes (annual wind power density ranging from 150-300W/m^2). In addition there is about 3000 deep well pumps in Sudan using diesel engines for pumping water from the several thousand existing boreholes, mostly for supplying domestic water for the rural communities in Eastern and Western Sudan (total deep well pump installed capacity of 35MW).

In order to project the future contribution of wind mill for water pumping applications in Sudan, three implementation scenarios were considered: a low case, a medium case and a high case scenario depending on government policies and incentives, and an institutional consideration such as the building of a Wind Energy Center. Table 5.4 summarizes the three scenarios and identifies the fraction of the total Sudanese water pumping market (162 MW of installed capacity) that can be captured by windmills in 1985, 1990 and 2000.

In the medium case scenario where the projected total market penetration is 0.4% in 1985, 2% in 1990 and 6% in the year 2000 the total savings on foreign exchange (in 1982)is LS 1.3 Million for 1985, LS 6.5 Million for 1990 and LS 19.5 million for the year 2000.*

The introduction of windmills for water pumping according to the scenarios identified in Table 5.4 requires the creation of a Wind Energy Center which will design, develop, test, and disseminate water pumping windmills that are suitable for local manufacture in the Sudan.

Such a project is scheduled to be carried out as a cooperative program between the Energy Research Council of the National Council for Research and the Netherlands-based SWD Steering Committee Wind Energy Developing Countries which will provide the required technical assistance.

The program includes the training of Sudanese staff in topics such as wind data analysis, site selection, windmill design (pump, rotor and tower), windmill construction and installation, output predictions from windmills, and windmill testing and monitoring.

Windmills, manufactured in local workshops, will be erected in well-exposed sites and problems limiting the wide spread utilization of these systems (technical, social, economic and institutional) will be identified, analyzed and solved.

* 10 windmill units (total installed capacity of 10KW) will displace 30 tonnes of diesel/year (LS 331,85/tonne) and one 10KW capacity diesel pump (LS10,000/pump).

References:

1. NEA Memorandum. "Status of Water Pumping Systems in Sudan" April 1, 1982.
2. Y.H. Hamid and W.A.M. Jansen, "Wind Energy in Sudan". SWD Steering Committee Wind Energy Developing Countries.
3. NEA Memorandum, "Wind Energy Data Base in Sudan". February 1982.

TABLE 5.3 PERFORMANCE AND COST CHARACTERISTICS OF A WINDMILL FOR WATER PUMPING APPLICATIONS

Performance Characteristics:

Windmill Type: Multi-bladed, "American type", horizontal axis windmill
Rotor Diameter: 7 meters
Tower Height: 20 meters
Mean Coefficient of Performance: 0.15
Annual Wind Power Density: $150W/m^2$ - $300W/m^2$
Swept Area: $38.5m^2$
Mean Power Output: 0.87KW - 1.74KW
Mean Annual Energy Produced: 7590 KWH/Year - 15180 KWH/year
Equipment Life: 15 years

Cost Characteristics (1982):

Capital Costs:	Tower, rotor & labor	LS3,600
	Water Storage Tank	3,600
	(Volume: $260m^3$)	
		LS7,200
Operating and Maintenance Costs: (5% of capital cost)		LS 360/yr.
Savings*:		LS 857.5/yr. - LS1715/yr.
Project Internal Rate of Return: (Escalation rate of diesel prices = 12%/yr. and that of O&M Costs = 10%/yr.		12.05 - 28.9%

* Diesel engine producing an equal amount of energy will be burning 2.6-5.2 tonnes of diesel per year (efficiency of diesel engine =25% and calorific value of diesel = 42.3 GJ/tonne)
Price of diesel = LS 331.85/tonne (Khartoum Depot, Nov. 1981).

TABLE 5.4

WATER PUMPING WINDMILLS IMPLEMENTATION SCENARIOS

	1985	1990	2000
Low Case Scenario			
Fraction of total Market (%)	0.2	1.0	3.0
Number of Units*	324	1,620	4,860
Displaced diesel** Fuel (tonnes/yr)	972	4,860	14,580
Medium Case Scenario			
Fraction of total Market (%)	0.4	2.0	6.0
Number of Units*	648	3,240	9,720
Displaced diesel** Fuel (tonnes/yr)	1,944	9,720	29,160
High Case Scenario			
Fraction of total Market (%)	0.6	3.0	9.0
Number of Units*	972	4,860	14,580
Displaced diesel**	2,916	14,580	43,740

* Total Water Pumping Market = 162MW of installed capacity:Mean Power output from windmill = 1.0KW (Annual wind power density of $175W/m^2$.)
** Mean annual energy produced from windmill = 8.76MWH/yr equivalent to 3 tonnes of diesel fuel/year(Efficiency of diesel engine - 25% calorific value of diesel fuel = 42.3 GJ /tonnes).

5.3 Charcoal Production From Banana Residues

I) Introduction:

In Sudan, bananas are cultivated in four areas which are close to large, charcoal consuming, urban centers (Khartoum, Kassala, Wad Medani and Sennar). The waste product from banana processing (banana trunks) are left to rot in the fields. The geographical distribution of these residues is shown in Table 5.5. The supply of charcoal to these large population centers is becoming a major problem with increased desertification, resulting mainly from fuelwood consumption and charcoal production, turning into a national issue. As a result of current critical deforestation rates around large Sudanese towns, charcoal is trucked from distances reaching more than 500 kilometers with transportation costs accounting for nearly a third of the market price.

In an attempt to solve this charcoal supply problem, banana residues can be collected, sun-dried and utilized in improved stationary kilns for the production of charcoal. This will result in a reduction in deforestation rates and in charcoal prices due to the drop in transportation costs.

II) Technology Description:

Sun-dried banana trunks can be collected from the plantation fields and utilized in improved stationary kilns for charcoal pruduction. Due to the hot and dry weather prevailing in North Sudan, the moisture content of banana residues will drop significantly (from 90% to 10%) if these residues are left outdoors for a period of one month. The performance characteristics of an improved stationary kiln (masonary kiln) is shown in Table 5.6. This kiln made out of cement, clay, bricks and stainless steel can be located in the banana plantation and provided with a continuous supply of banana trunks throughout the year.

III) Technology Cost Characteristics:

The masonary kiln has been used in several african countries and can be readily manufactured in Sudan. The estimated cost of a single unit is LS3000 (1982). The construction of 36 units (total cost of LS 108,000) will provide about 3200 tonnes of charcoal annually. (90 tonnes/kiln). On a micro-economic point of view, this energy project has an internal rate of return of 364.5% (Costs breakdown for the IRR analysis are shown in Table 5.7).

IV) Implementation Issues:

The technical issues facing charcoal production from banana residues has never been addressed in developing countries before. Demonstration plants should be constructed and tests should be conducted so as to determine factors such as:

i Charcoal production yields
ii Quality and handling characteristics of charcoal briquettes
iii Calorific value of charcoal briquettes
iv Effect of moisture content and size of banana trunks on quality and quantity of charcoal produced.

If the charcoal briquettes produced are too brittle, they can be mixed with a binding material such as starches and molasses (6-10% typically) and compressed in small manual presses, thus improving their compactness and handling characteristics. The creation of a charcoal production center will help accelerate the introduction of improved kilns in banana plantations. This center will coordinate various activities involved in the construction, maintenance and operation of stationary brick kilns through the training of Sudanese personnel.

5.4 Anaerobic Digestion of Animal

I) Introduction

The anaerobic digestion of produces a gas mixture of methane known as biogas, which can be used and modified gas-refrigerators in of simply designed, low-cost, bioc offers the advantages of displacin used for cooking and lighting, red areas and producing a residue (slu be used as a fertilizer and a soil

In addition, the large scal in biogas digesters will provide a aquatic weed throughout the White acinths which are threatening a nu navigation, transportation, fishin an optimal chemical composition (c 1) for biogas production.

II) Resource Availability:

Sudan has an estimated live (1981) including over 20 million i geographical distribution of cows

Due to the nomadic nature o small fraction of the total amount annually can be utilized in biogas wastes is very much facilitated in livestock is kept for extended per Table 5.9 lists major dairy farms total amount of cow manure which c

In the case of water hyacin tivity of the weeds in the White N to be equal to 9 million metric to of water hyacinths are collected f (between Renk and Jebel Aulia), su prevent reinfestation. According t 300 to 500 thousand cubic meters o from the White Nile during the Mar

III) Technology Description:

Anaerobic digestion is a th which organic matter (animal resid verted to biogas in the absence of production, it is important to uti to nitrogen) ratio of 25-30/1, an matter in the digester charge to 7 temperature, degree of acidity, an mance of the biogas digesters. Exp temperature range is 35°-38° C, an is 7.0-8.0. For large digesters, m installed so as to prevent the thi face of the slurry prohibiting the

Biogas digesters can be cla used for collecting the gas, namel type (or "Chinese" fixed dome dige (or "Indian" digester with or with gas holder digester.

The operation of digester u - 10m^3) and small village (digest demonstrated in several developing curing in China and India.

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5.4 Anaerobic Digestion of Animal Residues and Water Hyacinths

I) Introduction

The anaerobic digestion of animal residues and water hyacinths produces a gas mixture of methane (60-80%) and carbon dioxide (20-40%) known as biogas, which can be used to operate gas stoves, gas lights and modified gas-refrigerators in rural households. The introduction of simply designed, low-cost, biogas digesters in rural communities offers the advantages of displacing conventional fuel such as kerosene, used for cooking and lighting, reducing fuel wood consumption in rural areas and producing a residue (sludge), rich in nitrogen, which can be used as a fertilizer and a soil conditioner.

In addition, the large scale utilization of water hyacinths in biogas digesters will provide a way to control the spread of this aquatic weed throughout the White Nile and its tributaries. Water hyacinths which are threatening a number of national interests such as navigation, transportation, fishing, irrigation and health, have an optimal chemical composition (carbon to nitrogen ratio of 30 to 1) for biogas production.

II) Resource Availability:

Sudan has an estimated livestock population of 56 million (1981) including over 20 million heads of cattle. The 1975/1976 geographical distribution of cows in Sudan is shown in Table 5.8.

Due to the nomadic nature of the livestock resource, only a small fraction of the total amount of animal residues produced annually can be utilized in biogas digesters. The collection of animal wastes is very much facilitated in places where a large number of livestock is kept for extended periods of time. In this context, Table 5.9 lists major dairy farms in Khartoum Provinces and the estimated total amount of cow manure which can be collected from these farms.

In the case of water hyacinths, the dry weight annual productivity of the weeds in the White Nile South of Khartoum, was estimated to be equal to 9 million metric tonnes. Every year, significant amounts of water hyacinths are collected from the shores of the White Nile (between Renk and Jebel Aulia), sun dried, and burnt down so as to prevent reinfestation. According to the Plant Protection Administration, 300 to 500 thousand cubic meters of water hyacinths are removed annually from the White Nile during the March to June period.

III) Technology Description:

Anaerobic digestion is a three-stage biological process in which organic matter (animal residues, water hyacinths, etc), is converted to biogas in the absence of oxygen. To guarantee optimum biogas production, it is important to utilize raw materials with a C/N (carbon to nitrogen) ratio of 25-30/1, and to keep the concentration of dry matter in the digester charge to 7-9%. In addition, factors such as temperature, degree of acidity, and mixing rate affects the performance of the biogas digesters. Experience has shown that the optimum temperature range is 35°-38° C, and the optimum PH for biogas production is 7.0-8.0. For large digesters, mechanical means of stirring must be installed so as to prevent the thickening and caking of scum on the surface of the slurry prohibiting the escape of gas into the gas holder.

Biogas digesters can be classified according to the arrangement used for collecting the gas, namely combined digester/gas holder type (or "Chinese" fixed dome digester), the floating gas holder type (or "Indian" digester with or without a water seal),and the separate gas holder digester.

The operation of digester units for both family (digester volume - $10m^3$) and small village (digester volume - $50m^3$) use has been demonstrated in several developing countries with the largest use occuring in China and India.

TABLE 5.6 Performance Characteristics of an Improved Charcoal Kiln

Name: Masonary Kiln
Type: Stationary
Internal Volume: 25-30m^3
Cycle Time: 10 days
Output: 3 tonnes of charcoal/cycle
Number of cycles/year: 30
Equipment Life: 7 years
Conversion Efficiency:30%
Annual Capacity: 300 tonnes of banana trunks/year
Material: Stainless steel (24m^2 of sheets, 3-5mm thick)
Standard Bricks (7,000)
Clay or Cement (500 Kg.)
Cost (1982): LS3000 ($2000; at 1$US = LS 1.35)
(including material and labor).

TABLE 5.7 Costs Breakdown for IRR Analysis

Annual amount of dried banana trunks available for charcoal production:	10,642 tonnes/year
Annual capacity of charcoal Kiln:	300 tonnes of banana trunks/yr
Number of kilns:	36
Annual Amount of Charcoal produced/Kiln:	90 tonnes/yr.
Total Charcoal production:	3240 tonnes/year.
Capital Costs (1982): 36 x LS 3000=	LS 108,000
Operating and Maintenance Costs (1982) (5% of Capital Costs)	= LS 5,400/yr.
Transportation Costs (1982): Labor=	LS 11,340/yr.
Truck=	LS 21,600/yr.
TOTAL	= LS 32,940/yr.
Savings(2) (1982): 3240 tonnes x LS 130/tonnes =	LS 421,200/yr.

IRR = 364.5%

Assuming that O&M and transportation costs, and charcoal prices escalate at 10% yr.

(1) One medium-sized truck has a capacity of 6 tonnes and will require 1 man-day worth of labor for loading and unloading operations.

Truck rental = LS 40/(for a 50 km trip, which represents the day average.
Labor rates = LS21/day/average distance between banana plantations and towns).

(2) The market price of charcoal varies depending on the distance separating charcoal supply centers from large towns:

	Khartoum	Wad Medani	Kassala	Sennar	Mean
Charcoal Market Price (LS/tonne)	124	150	121	125	130

In Sudan, several biogas digesters using water hyacinths are producing gas which is piped to adjoining households where it is utilized to operate modified gas refrigerators, gas ovens and lamps.

IV) Cost Characteristics:

The estimated capital cost of a $10m^3$ "Chinese" type brick digester including the costs for gas utilization equipment (distribution and appliances), ranges between LS 70 to LS 1350 ($50-$1000) depending on the availability and cost of materials required.

For an investment of LS1000, and assuming operating and maintenance costs to be equal to LS 50/year (5% of the capital investment), the $10m^3$ digester will be producing an average of $2m^3$ of biogas daily.

The macro-economic analysis of this energy project gives an internal rate of return of 36.3% when displacing charcoal and 30.1% when displacing kerosene (assumptions are shown in Table 5.10).

V) Implementation Issues:

Based on results obtained from biogas government programs in China, India and the Republic of Korea, some technical, and economic issues have been identified as a possible cause of the limited adoption of the technology in certain geographical areas: the high initial capital investment, the lack of space in densely populated villages, the significant water requirement to make the slurry mixture (water to raw material ratio equally one to one), the availability of livestock and the reduced gas production during cold months.

In china, the Government's promotion of biogas has followed a policy of "self-reliance with public assistance" where the village will purchase the building materials from loans advanced by the regional banks, and the government will provide free technical training courses for constructing and maintaining biogas digesters.

In order to project the future contribution of biogas in rural household applications, a scenario was considered based on the availability of cow dung in dairy farms and of water hyacinths removed from the White Nile (Table 5.11). With a projected cow manure collection rate of 1% in 1985, 2% in 1990 and 5% in the year 2000, and a water hyacinth removal rate of 5% (1985), 10% (1990) and 25% (2000), the total amount of displaced kerosene is projected to be 10160 tonnes in 1985, 20320 tonnes in 1990, and 50,800 tonnes in the year 2000 (for displaced charcoal, 30350 tonnes for 1985, 60700 tonnes for 1990 and 151750 tonnes in the year 2000).

References:

1. NEA Memorandum, Sudan Agricultural and Animal Residues February 24, 1982.
2. NEA Memorandum, Overview of Renewable Energy Activities in Sudan, March 4, 1982.
3. Meeting with Mr. Abdel Rahman Ramadan, Inspector of Dairy Farms, Ministry of Agriculture, Food and Natural Resources, March 30, 1982.
4. Unpublished Data from the Animal Resources Economics Administration, Ministry of Agriculture, Food and Natural Resources.
5. "Guide book on Biogas Development", Energy Resources Development Series No. 21. Economic and Social Commission for Asia and the Pacific, United Nations, New York, 1980.
6. "Biogas Fertilizer System", Technical Report of a Training Seminar in China, United Nations Environment Programme, Nairobi, 1981.

TABLE 5.8 Cow Distribution in Sudan (1975/1976)

Region	Number of Cows	Fraction of Total (%)
Khartoum	56871	0.4
Nile	43717	0.3
North	14198	0.1
Kassala	642883	4.1
Red Sea	36488	0.2
Blue Nile	899558	5.7
Gezira	508916	3.2
White Nile	1563568	10.0
North Kordofan	937128	6.0
South Kordofan	1467367	9.3
North Darfur	952081	6.1
South Darfur	3735360	23.8
Upper Nile	1428092	9.1
Gungli	1404593	8.9
Bahr El Ghazal	1227707	7.8
Buhairat	700714	4.5
Equatoria	78003	0.5
TOTAL	15,697,244	100%

TABLE 5.9 Major Dairy Farms in Khartoum Province (1980)

Location	Number of Farms	Number of Cows	Annual Amt. of Cow Manure Produced (1) (Tonnes/year)
Khartoum North:			
Safia	1	13	142.35
Shambat	1	225	2463.75
Halfaia	12	301	4171.95
El Deroshab	1	20	219
Kadaro	1	38	416.1
Kafory	1	950	10402.5
Kuko	5	20464	224080.8
Khartoum			
Burri El Lamab	5	299	3274.05
El Manshia	1	8	87.6
Gereif Gharb	7	150	1642.5
Soba Gharb	72	2296	25141.2
El Kalakla	4	84	919.8
El Goz	1	9	98.55
Omdurman	13	269	2945.55
TOTAL	123	25206	276,005.7

(1) 1 Cow (450Kg) produces an average of 30KG of wet manure daily (water content of 80-90%)

TABLE 5.10 Technical and Cost Characteristics of Brick Digester

Technical Characteristics:

Type of Digester: "Chinese", brick biogas digester
Volume of Digester: $10m^3$
Materials:

Cement	= 250Kg
Lime paste	= 110Kg
Coal Ash	= 170Kg
Sand	= 400Kg
Clay paste	= 100Kg
Lime	= 40Kg
Crushed Stone	= $0.27m^3$
Brick	= 920 units

Biogas Production: $3m^3$/day
Amount of raw materials needed:

50 Kg of cow dung/day (wet basis)
or 75 Kg of water hyacinths/day (dry basis)
Calorific Value of biogas: 21 MJ/m^3

Capacity Factor of biogas Digester: 0.95

Annual Amount of Energy Produced: 21.85 GJ/year

Annual Amount of Charcoal Displaced : 2.27 tonnes/year (biogas stove efficiency = 60%; Charcoal stove efficiency = 20%; Charcoal Calorific Value = 28.9GJ/Tonne)

Annual Amount of Kerosene Displaced: 0.76 tonnes/year (kerosene stove efficiency = 40%; kerosene calorific vaule = 43.1 GJ/tonne)

Equipment Life : 20 years.

Cost Characteristic (1982)

Capital Costs	LS1000 (Materials, labor and gas utilization equipment)
Operating and Maintenance Costs (5% of Capital Costs)	LS 50/year
Savings	LS 295 (when displacing charcoal, at LS 130/tonne)
	LS 264 (when displacing kerosene, at LS 347.54/tonne, Khartoum Depot, Nov. 1981)
IRR	36.34% (displacing charcoal) 33.09% (displacing kerosene)

(assuming escalation rate for O&M Costs = 10%/year , and that for charcoal and kerosene prices = 12%/year

TABLE 5.11 Implementation Scenario for Biogas Digesters

	1985	1990	2000
Cow Dung			
Fraction of Total Market (1) %	10	20	50
Number of Units ($10m^3$)	12500	25200	65000
Water Hyacinths			
Fraction of Total Market (2)%	5	10	25
Number of Units	770	1540	3850
Total Displaced Kerosene (tonnes/year)	10,160	20,320	50,800
Total Displaced Charcoal (tonnes/yr.)	30,350	60,700	151,750

(1) Assumption: 10% of the number of cows in Sudan are in dairy farms (2 million cows producing 21.9×10^6 tonnes of cow menure annually).

(2) Assumption: 500 thousand m^3 water hyacinths are removed from the White Nile every year, with a total market potential of 40,000 tonnes/year. (water hyacinth density = $80 kg/m^3$).

5.5 Fuel Briquetting and Gasification of Agricultural Residues for Utilization in Rural Households and Industrial Boilers

I) Introduction

The production of fuel briquettes from agricultural residues provides a source of fuel with improved combustion characteristics, which can be utilized in a variety of applications in Sudan such as cooking in rural households, and steam generation in industrial boilers. In addition, the utilization of fuel briquettes in rural households will reduce the human costs incurred by rural settlers (mostly women and children) which are spending an increasing amount of time collecting scarce fuel sources such as fuel wood. It will guarantee a continuous supply of energy sources to these rural communities while limiting prevailing deforestation and desertification rates around these communities. In addition, the utilization of fuel briquettes in industrial boilers will displace significant amount of fuel oil resulting in substantial foreign exchange savings.

II) Resource Potential:

Agriculture is the largest sector of the Sudanese economy with field crops such as cotton, sorghum, groundnuts, millet and wheat accounting for the largest portion of the country's agricultural output.

The total amount of agricultural residue produced in Sudan was estimated using annual crop residue yield factors (in metric tons/ feddan) derived from Egyptian Agricultural data (Table 5.12).

These factors, which were determined for several types of field crops, can be applied safely in the case of Sudan since Egyptian and Sudanese agricultural conditions (climatological conditions, land quality, etc,) and practices (irrigation, harvesting, etc.) are relatively similar. In addition, these factors are compatible with estimates on crop to residue factors made by several agricultural agencies in Sudan.

With a significant amount of agricultural residues used as fertilizers, animal feeds and construction and handicraft materials (mud walls and domestic objects are partly made of residues such as wheat straw), only a fraction of this total amount can be utilized for fuel

briquetting applications: an availa
type of field crops. Out of a total
million tonnes of agricultural resi
briquetting applications.

III) Technology Description:

Briquetting is a process i
compacted into products of higher
uniformity in both size and materi
residues in their natural state.

The briquetting making proc
of integrated steps:

1) Collection of agr
2) Chopping and/or s
3) Natural drying in
from rain
4) Mixing the dried
such as animal ma
5) Compressing the m

Fuel briquetting of agricultural re
cluding:

1) Greater bulk dens
storage and handl
2) Uniform thermal a
combustion charac
even combustion b
rural household s

Fuel briquettes which can
and/or piston extruder devices, ar
presses consisting of two drums wi
at the moment of compaction. Plant
collection point and availability
and seasonal respectively.

Large briquetting plants c
agricultural residue availability
small simple briquetting press car
communities.

IV) Technology Cost Characteristic

Technical and cost charact
plant and a small briquetting pre
plant has an annual production of
(18.6GJ/tonne), with a potential
(41GJ/tonne) burnt annually to in
of charcoal briquettes (28.9GJ/to
households. The small press produ
annually and has a potential to d
quettes used in rural communities.

In the case of a large fu
costs for collecting the agricult
the fuel briquettes to the major
coal consuming centers, a micro-e
rate of return of 193.88 and 255
fuel oil and charcoal briquettes,
rate for O&M costs = 10%/yr.) and
= 12% /year). In the case of sma
rural communities, the internal r
ment project was 109.48 (similar

V) Implementation Issues:

The major implementation

46

o for Biogas Digesters

1990	2000
20	50
25200	65000
10	25
1540	3850
20,320	50,800
60,700	151,750

ows in Sudan are in dairy
producing 21.9×10^6 tonnes of cow

hyacinths are removed from the
with a total market potential
(water hyacinth density =

of Agricultural Residues
ls and Industrial Boilers

s from agricultural residues
combustion characteristics,
pplications in Sudan such as
generation in industrial
f fuel briquettes in rural
incurred by rural settlers
pending an increasing amount
such as fuel wood. It will
sources to these rural
eforestation and desertification
tion, the utilization of fuel
isplace significant amount of
gn exchange savings.

r of the Sudanese economy
m, groundnuts, millet and wheat
he country's agricultural output.

residue produced in Sudan was
ld factors (in metric tons/
ral data (Table 5.12).

ined for several types of field
of Sudan since Egyptian and
tological conditions, land
, harvesting, etc.) are rela-
rs are compatible with estimates
ral agricultural agencies in

icultural residues used as
ion and handicraft materials (mud
de of residues such as wheat
ount can be utilized for fuel

briquetting applications: an availability factor was estimated for each type of field crops. Out of a total amount of 27.4 million tonnes, 15.9 million tonnes of agricultural residues can potentially be used for briquetting applications.

III) Technology Description:

Briquetting is a process in which residues are mechanically compacted into products of higher bulk density, less moisture and greater uniformity in both size and material properties, than exhibited by residues in their natural state.

The briquetting making process typically consists of a series of integrated steps:

1) Collection of agricultural residues
2) Chopping and/or screening the residues
3) Natural drying in well-ventilated places protected from rain
4) Mixing the dried residues with binding materials such as animal manure, sugar molasses.
5) Compressing the mixture in a mechanical press

Fuel briquetting of agricultural residues offers several advantages including:

1) Greater bulk density, minimizing transportation, storage and handling problems and costs.
2) Uniform thermal and physical properties, improving combustion characteristics with more controlled and even combustion both in industrial boilers and in rural household stoves.

Fuel briquettes which can be produced with a variety of screw and/or piston extruder devices, are usually manufactured in rolling presses consisting of two drums with half impressions which line up at the moment of compaction. Plant scale is closely related to the collection point and availability of residue supply which are scattered and seasonal respectively.

Large briquetting plants can be located in areas of concentrated agricultural residue availability such as in the Gezira province, and small simple briquetting press can be located in rural agricultural communities.

IV) Technology Cost Characteristics:

Technical and cost characteristics for both a large briquetting plant and a small briquetting press are shown in Table 5.13. The large plant has an annual production of 10,000 tonnes of fuel briquettes (18.6GJ/tonne), with a potential to displace 4540 tonnes of fuel oil (41GJ/tonne) burnt annually to industrial boilers, or 6440 tonnes of charcoal briquettes (28.9GJ/tonne) used as a cooking fuel in rural households. The small press produces about 17.3 tonnes of fuel briquettes annually and has a potential to displace 4.2 tonnes of charcoal briquettes used in rural communities.

In the case of a large fuel briquetting plant, excluding the costs for collecting the agricultural residues, and for transporting the fuel briquettes to the major industrial boilers and/or to the charcoal consuming centers, a micro-economic analysis indicates an internal rate of return of 193.88% and 255% when the fuel briquettes are displacing fuel oil and charcoal briquettes, respectively (assuming that escalation rate for O&M costs = 10%/yr.) and that for charcoal and fuel oil prices = 12% /year). In the case of small fuel briquetting press located in rural communities, the internal rate of return for this energy investment project was 109.48% (similar assumption as with the large plant).

V) Implementation Issues:

The major implementation issue with this energy project is the

collection and transportation of the agricultural residues. Providing the infrastructure for this collection function in rural areas could pose significant institutional problems. The operation of a village-sized press will introduce institutional considerations such as who pays for the installation, how to compensate individual villagers for delivered agricultural residues, training and renumeration of operating personnel, and pricing of fuel briquettes produced.

The potential of agricultural residues for fuel briquetting applications is very large (15.9 million tonnes/year). However, due to the institutional problems associated with the collection and transportation of the residues, only a small fraction of these residues can be utilized for the production of fuel briquettes.

Table 5.14 summarizes the three scenarios used to project the future contribution of agricultural residues for briquetting applications in Sudan. The fraction of the total amount of agricultural residues which can be collected in 1985, 1990, and 2000, was indicated for each scenario.

In the medium case scenario 96, 193, and 386, hundred thousand tonnes of charcoal will be displaced in 1985, 1990, and 2000 respectively. This represents 2.7, 5.5, and 11% of the estimated current annual charcoal consumption in Sudan (3.5 million tonnes/year). In addition, 4540 tonnes of fuel oil will be displaced in 1985, 9080 tonnes in yr. 1990, and 18160 tonnes in the year 2000, respectively, 4.5%, 9% and 18.8% of the estimated current annual fuel oil consumption in industrial boilers in Sudan. (100,000 tonnes/year mainly in sugar, textile, soap and oil factories).

VI) Alternative Utilization of Agricultural Residues:

Another option for the utilization of agricultural residues (mainly cotton stalks and groundnut shells) is their conversion into producer gas (low BTU gas supplying heat for crop drying, or cotton ginning), and the production of electricity via an internal combustion engine and an electrical generator. There is a significant market for such compact systems producing both thermal energy (producer gas) and other textile factories, oil mills, nut processing plants, food processing plants, etc.

The majority of these factories are located in the Khartoum area and in Gezira province.

A typical system consists of a gas producer unit, gas cleaning equipment (gas scrubber, dust collector, filter/demister, and p essure blower), a gas engine and an electric power generator. The technical and cost characteristics of a 37.5KW unit which has been utilized in several countries is shown in Table 5.15.

This system utilizes about 1000 tonnes of agricultural residues/year, to produce 263 MWH/year, displacing 90 tonnes of diesel fuel annually. The internal rate of return for such a project is 13%.

gricultural residues. Providing function in rural areas could s. The operation of a village- al considerations such as who ensate individual villagers raining and renumeration of el briquettes produced.

residues for fuel briquetting on tonnes/year). However, due ed with the collection and small fraction of these ction of fuel briquettes.

e scenarios used to project l residues for briquetting the total amount of agricultural 5, 1990, and 2000, was in-

, 193, and 386, hundred thou- ced in 1985, 1990, and 2000 , and 11% of the estimated Sudan (3.5 million tonnes/ l oil will be displaced in 60 tonnes in the year 2000, e estimated current annual lers in Sudan. (100,000 tonnes/ d oil factories).

tural Residues:

tion of agricultural residues ills) is their conversion into t for crop drying, or cotton icity via an internal combus- r. There is a significant ing both thermal energy (pro- , oil mills, nut processing

, are located in the Khartoum

gas producer unit, gas clean- ector, filter/demister, and electric power generator. of a 37.5KW unit which is shown in Table 5.15.

) tonnes of agricultural re- lisplacing 90 tonnes of die- f return for such a project

CROP	AREA (000 Feddans)	RESIDUE Yield Factor (tonnes /feddan)	TOTAL AMOUNT OF Residues (000 tonnes)	AVAILABILITY Factor	NET AMOUNT OF Residues for Fuel Briquetting Applications (000 tonnes)	HARVESTING Period	REGIONS
Cotton	1036	1.5	1,554	1.0	1,554	Jan./Feb.	Gezira, Rahad, Blue Nile
Sorghum	7202	2.15	15,484	0.5	7,742	N.A.	Kassala, Blue Nile, Gezira
Millet	3078	1.06	3,263	0.4	1,305	Aug./Sept.	North Kordofan, Darfur
Wheat	586	2.06	1,207	0.5	604	Mar./April	Gezira
Rice	20	1.6	32	0.5	16	N.A.	Gezira, Southern Region
Maize	145	1.85	268	0.8	214	N.A.	Blue Nile, Southern Region
Groundnuts	2328	1.26	2933	0.8	2346	Dec./Jan.	North Kordofan, South Darfur, Gezira
Sesame	2057	1.29	2654	0.8	2123	Oct./Nov.	North Kordofan, Blue Nile Southern Region, Kassala
TOTAL	16452		27,395		15,904		

Table 5.12 AGRICULTURAL CROP RESIDUES IN SUDAN FOR FUEL BRIQUETTING APPLICATIONS (1978/1979)

TABLE 5.13 Technical and Cost Characteristics of Large-Scale and Small-Scale Briquetting Plant

Large Briquetting Plant	Small Briquetting Plant
Capacity 1.6 tonnes/hr. Capacity Factor = 7.1 (6250 hours/year) Moisture Content Of Fuel Briquette = 5-10%	Capacity = 0.05 tonnes/day Capacity Factor = 0.95 Moisture Content of Fuel Briquette = 5-10%
Average Calorific Value of Fuel Briquette = 18.6 GJ/tonne	Average Calorific Value of Fuel Briquette = 18.6 GJ/tonne
Annual Fuel Briquette Production = 10,000 tonnes/year	Annual Fuel Briquette Production = 17.3 tonnes/year
Equipment Life = 20 years	Equipment Life = 10 years
Capital Costs: -Building and Site Preparation = LS 54,000 ($40,000) - Equipment =LS148,500 ($110,000=) LS 202,500	Capital Costs: -briquetting press =LS675 ($500) -binding material mixing unit =LS675 ($500) LS 1350.
Operating and Maintenance Costs = LS 270,000 ($200,000)	Operating and Maintenance Costs =LS 135 (10% of total Capital Cost)
Savings: (1)=LS635,000 (when displacing oil) LS 837,200 (when displacing charcoal)	Savings:(1) LS 1450 (when displacing charcoal)
IRR (2) = 193.8% (when displacing fuel oil)	IRR(2) = 109.4%(when displacing charcoal)

(1) 1 tonne of fuel briquette from agricultural residues (18.6GJ/tonne) will displace 0.454 tonne of fuel oil (41GJ/tonne and LS 140/tonne, Khartoum Depot, Nov. 81). It will displace 0.644 tonne of charcoal briquette (28.9GJ/tonne, LS 130/tonne, average price for main urban centers in Sudan, March 1982.)

(2) Escalation rate of O&M costs = 10%/yr. and that of charcoal and fuel oil prices = 12%/yr.

TABLE 5.14 Fuel Briquetting Imp

	1985
Low Case Scenario	
Fraction of Total Market (%)	0.5
Number of Units Large Small	 - 4595
Displaced Charcoal (tonnes/year):	51464
Displaced Fuel Oil (tonnes/year):	
Medium Case Scenario	
Fraction of Total Market (%)	1
Number of Units: Large Small	 1 861
Displaced Charcoal (tonnes/year):	96466
Displaced Fuel Oil (tonnes /year)	4540
High Case Scenario	
Fraction of Total Market(%)	2
Number of Units: Large Small	 2 17225
Displaced Charcoal (tonnes/year):	192922
Displaced Fuel Oil (tonnes/year):	9080

1) Assumption:

- Large units (10,000 ton will only displace fuel boilers at a rate of 45 unit,
- Small units (17.2 tonne only displace charcoal a rate of 11.2 tonnes c
- One large unit is built units.

ristics
ale

Small Briquetting Plant

pacity = 0.05 tonnes/day
pacity Factor = 0.95

isture Content
Fuel Briquette = 5-10%

erage Calorific
lue of Fuel Briquette
18.6 GJ/tonne

nual Fuel Briquette
oduction = 17.3 tonnes/year

uipment Life = 10 years

pital Costs:
riquetting press =LS675 ($500)

inding material
ixing unit =LS675
($500)

LS 1350.

erating and Maintenance
sts =LS 135
0% of total Capital Cost)

vings:(1) LS 1450 (when displacing charcoal)

R(2) = 109.4%(when displacing charcoal)

ultural residues (18.6GJ/
fuel oil (41GJ/tonne and
81). It will displace
28.9GJ/tonne, LS 130/tonne,
in Sudan, March 1982.)

/r. and that of charcoal

TABLE 5.14 Fuel Briquetting Implementation Scenarios (1)

	1985	1990	2000
Low Case Scenario			
Fraction of Total Market (%)	0.5	1	2
Number of Units			
Large	-	1	2
Small	4595	8613	17225
Displaced Charcoal (tonnes/year):	51464	96466	19292.2
Displaced Fuel Oil (tonnes/year):		4540	9080
Medium Case Scenario			
Fraction of Total Market (%)	1	2	4
Number of Units:			
Large	1	2	4
Small	8613	17225	34452
Displaced Charcoal (tonnes/year):	96466	19292.2	385864
Displaced Fuel Oil (tonnes /year)	4540	9080	18160
High Case Scenario			
Fraction of Total Market(%)	2	4	8
Number of Units:			
Large	2	4	8
Small	17225	34452	68904
Displaced Charcoal (tonnes/year):	192922	385864	771728
Displaced Fuel Oil (tonnes/year):	9080	18160	36320

1) Assumption:

- Large units (10,000 tonnes of briquettes/year) will only displace fuel oil used in industrial boilers at a rate of 4540 tonnes of fuel oil/year/unit.
- Small units (17.2 tonnes of briquettes/year) will only displace charcoal used in rural households at a rate of 11.2 tonnes of charcoal/year/unit.
- One large unit is built for every thousand, small units.

Table 5.15 Technical and Cost Characteristices of a Gasifier/Electric Generator Plant Using Agricultural Residues

Technical Characteristics:

Sub-Systems:
- Down draft, batch feeding gas producer (50 ft^3 /mn gas rate)
- Counter current, 4 stages, gas scrubber
- cyclone dust collector
- filter/demister
- centrifugal pressure blower (½KW)
- four stroke, compression ignition gas engine (60KW)
- self-exciting, self-regulating generator (37.5 KW)

Annual gas producer: 1000 tonnes of agricultural residues/year.
Capacity actor : 0.8
Overall plant efficiency: 10%(gasification = 65%:mechanical power generation = 20%: electric power generation and transmission = 80%)
Annual electricity produced: 262.8 MWH.
Equipment Life: 15 years

Cost Characteristics (1981)

Capital Costs: Equipment Costs:	Engine-Generator	LS	33,700
	Gas Producer	LS	7,425
	Gas Cleaning System	LS	7,020
	Other Accessories	LS	5,805
			53,950
Installation Costs:		LS	4,000
Building, structures and transmission lines:		LS	27,000
TOTAL		LS	65,000
Operating and Maintenance Costs:			
	Fuel	LS	5,000/yr.
	Labor	LS	15,000/yr.
	Lubricants	LS	2,700/yr.
	Spare Parts	LS	2,810/yr.
TOTAL		LS	25,510/Yr.

Savings (1): LS 29,700/yr.
IRR (2): 12.85%

(1) Diesel generator with an efficiency of 25% requires about 89.5 tonnes of diesel (42.3 GJ/tonnes) to produce 262.8 MWH?year. Diesel prices = LS 331,85/tonne (Khartoum Depot, Nov. 1981).

(2) Escalation rate of O&M Costs = 10% year, and that of diesel prices = 12%.

References:

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2) Meeting with Mr. Osman El Farouk, Head of Marketing Research Department, Ministry of Agriculture, Food and Natural Resources.
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4) T. Reed, B. Bryant, "Densified Biomass: A New Form of Solid Fuel". Solar Energy Research Institute, July 1978.
5) C.N. Sarine, "Pilot Electrification of a Barrio Using Agricultural Waste Materials as Fuel". Economic Development Foundation, Manilla, Philippines, 1981.

5.6 Solar Water Heating for Low-Te
Industrial Applications

I) Introduction

Solar water heating will dis
fuels such as diesel and fuel oil
and hospitals), and in low-tempera
and food processing industries).

The relatively low temperatu
(60-70°C for commercial buildings
cesses), the abundant solar radiat
solar energy incident on a horizon
year), and the comparatively high
bine to create very favorable econ
simply-designed, low-cost solar wa

The utilization of these sys
applications will create an in-cou
employment and building up on indi
technological field which has the
exchange component of conventional

II) Water Heating Requirements of
Applications

Hot water is used in several
(hotels, hospitals, schools, etc.)
is used in the rooms, the kitchen,
in the swimming pools. (Hilton)

Table 5.16 indicates the hot
major hotels in Khartoum. Inlet wa
25-27°C in the winter and 28-30°C
to 60-65°C either directly in a di
(Araak and Meridien hotels) or inc
the steam produced from a conventi
ship Palace). In the case of the (
trical hot water systems (capacity
liters in the kitchen).

Hot water is also utilized i
processes. Oil and soap manufactur
90°C) for the treatment of oil wit
acids (neutralization). Food proc
in washing (85°C) and pasteurizin
preparation of beverages (75-80°C)
tensive amount of hot water (60-9

1. Sizing of spun yarn
2. Washing of scoured, blea
3. Washing of dyed goods
4. Washing of reactive and
5. Preparation of "naphtola
6. Preparation of finishing

Table 5.17 indicates the hot wate
of industries with low temperatur

III) Technology Description

Solar water heating system
which already has widespread appl
The active solar system which use
a storage tank through the collec
and industrial buildings where el
available. A typical flat plate c
cover plate, an absorber plate wh

eristices of a
r Plant Using

feeding gas producer
te)
stages, gas scrubber
tor

e blower (½KW)
ssion ignition gas engine

-regulating generator

ricultural residues/year.

tion = 65%:mechanical power
on = 20%: electric power
on and transmission = 80%)

Generator	LS	33,700
lucer	LS	7,425
aning System	LS	7,020
ccessories	LS	5,805
		53,950
	LS	4,000
	LS	27,000
	LS	65,000
Costs:		
	LS	5,000/yr.
	LS	15,000/yr.
ats	LS	2,700/yr.
irts	LS	2,810/yr.
	LS	25,510/Yr.

y of 25% requires about 89.5
to produce 262.8 MWH?year.
nartoum Depot, Nov. 1981).

year, and that of diesel

and Animal Residues Data Base,

ead of Marketing Research De-
Food and Natural Resources.
al, Animal and Forest Resi-

ss: A New Form of Solid Fuel".
ly 1978.
of a Barrio Using Agricultural
Development Foundation,

5.6 Solar Water Heating for Low-Temperature Commercial and Industrial Applications

I) Introduction

Solar water heating will displace the utilization of conventional fuels such as diesel and fuel oil in commercial buildings (hotels and hospitals), and in low-temperature industrial processes (textile and food processing industries).

The relatively low temperature requirements of these applications (60-70°C for commercial buildings and 70-90°C for industrial processes), the abundant solar radiation prevailing in Sudan (annual solar energy incident on a horizontal surface ranges between 7-10GJ/m^2/year), and the comparatively high cost of fossil fuel alternatives combine to create very favorable economics for locally manufactured, simply-designed, low-cost solar water heating systems.

The utilization of these systems in commercial and industrial applications will create an in-country manufacturing base providing employment and building up on indigenous capability in a growing technological field which has the potential of reducing the foreign exchange component of conventional fuels.

II) Water Heating Requirements of Selected Commercial and Industrial Applications

Hot water is used in several institutional and commercial buildings (hotels, hospitals, schools, etc.) in Sudan. In hotels, hot water is used in the rooms, the kitchen, the laundry section and occasionally in the swimming pools. (Hilton)

Table 5.16 indicates the hot water requirements in the five major hotels in Khartoum. Inlet water temperature ranges between 25-27°C in the winter and 28-30°C in the summer. Water is heated to 60-65°C either directly in a diesel-fired or fuel-oil fired boiler (Araak and Meridien hotels) or indirectly in a heat-exchanger by the steam produced from a conventional boiler (Hilton hotel and Friendship Palace). In the case of the Grand Hotel water is heated in electrical hot water systems (capacity of 50 liters in the rooms, and 500 liters in the kitchen).

Hot water is also utilized in several low-temperature industrial processes. Oil and soap manufacturing factories use hot water (80-90°C) for the treatment of oil with caustic soda to eliminate fatty acids (neutralization). Food processing industries utilize hot water in washing (85°C) and pasteurizing processes (60-65°C) and in the preparation of beverages (75-80°C). Textile factories utilize an extensive amount of hot water (60-90°C) in the following processes.

1. Sizing of spun yarn
2. Washing of scoured, bleached, and mercerized cloth
3. Washing of dyed goods
4. Washing of reactive and "naphtol" prints
5. Preparation of "naphtolation" baths
6. Preparation of finishing liquors

Table 5.17 indicates the hot water requirement of a selected number of industries with low temperature processes.

III) Technology Description

Solar water heating system is a well-demonstrated technology which already has widespread application on a world wide basis. The active solar system which uses a pump to circulate water from a storage tank through the collector, is most appropriate in commercial and industrial buildings where electricity and running water are available. A typical flat plate configuration consists of a glass cover plate, an absorber plate which can be made from a variety of

materials (steel, copper or aluminum) insulation and a wood casing. The other components of the solar water heating system beside the collector panels, include storage tanks, structures for collector mounting, piping, pumps and controllers.

IV) Technology Cost Characteristics

The performance and cost characteristics of a typical solar water heating system which can be manufactured locally is shown in Table 5.17.

A one square meter collector system costs LS 180, with annual operating and maintenance costs amounting to LS 9/m^2/year, resulting in LS 18.5/m^2/year of savings when displacing fuel oil, and LS 42.5/m^2/year when displacing diesel.

The micro-economic analysis indicates that such an energy investment project has an internal rate of return of 8.85% when displacing fuel oil and 20.6% when displacing diesel.

V) Implementation Issues:

The manufacture of solar water heating units in Sudan involves no significant technical constraints or resource limitations with nearly all the components of these systems being locally produced. The requirements for technical labor for assembly and installation are also well within Sudanese capabilities. Training courses in the design, manufacture, installation, operation and maintenance of solar water heating systems will be needed so as to form a technical team of Sudanese engineers capable of introducing these systems in the commercial and industrial sectors.

The extent of solar water heating utilization in Sudan depends largely on government policies. Market penetration is a function of fuel costs and supply, solar system costs, capital availability and government actions (tax deductions, subsidies on solar system costs, and extent of subsidies on conventional fuels).

Table 5.18 reflects the number of solar water heaters (and square meters of collector area) installed by 1985, 1990 and 2000 in the low case, medium case and high case implementation scenarios. In the medium case scenario(market penetration: 2% in 1985, 4% in 1990 and 10% in the year 2000), 836 solar units (2m^2 /unit) will be installed in 1985 displacing 10 tonnes of diesel/year and 210 tonnes of fuel oil/year. In 1990, 1672 units will displace 20 tonnes of diesel/ year and 420 tonnes of fuel oil/year, and in the year 2000, 4180 units will displace 50 tonnes of diesel/year and 1050 tonnes of fuel oil/year.

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heating system beside the
structures for collector

eristics of a typical solar
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g to LS 9/m²/year, resulting
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cates that such an energy
of return of 8.85% when
acing diesel.

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resource limitations with
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rket penetration is a func-
tem costs, capital availa-
tions, subsidies on solar
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r units (2m² /unit) will be
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ll displace 20 t nnes of
year, and in the year 2000,
esel/year and 1050 tonnes

TABLE 5.16 Hot Water Requirements of Major Hotels in Khartoum

Hotel	Number of Rooms	Annual Fuel Consumption For Water/ Heating (tonnes/yr)	Type of Fuel	Hot Water Utilization
Hilton	274	260.3	Fuel Oil	Rooms, Kitchen Laundry and Swimming Pool
Friendship Palace	200	210.3	Diesel	Rooms, Kitchen, Laundry
Araak	181	113.7	Diesel	"
Grand	145	276.1MWH/yr. (1)	Electricity	Rooms and Kitchen
Meridien	95	28.5	Diesel	Rooms, Kitchen, Laundry

(1) Assumptions: Average occupancy rate = 70%
Average inlet water temperature = 30°C
Average outlet water temperature = 65°C
Water Consumption in rooms = 50 liters /day
Water Consumption in Kitchen = 500 liters/day
Efficiency of electric water heater = 30%

TABLE 5.17 Performance and Cost Characteristics of a Solar Water Heating System

Performance Characteristics

Type: Active (pumped) flat plate solar water heating system

Components: Solar collector panels (2m²/panel)
Storage tank (100 liters/panel)
Structures for collector mounting
Piping, pump and controller

Mean Annual Collector efficiency: 40%
Mean Annual Solar Radiation: 9.5GJ/m²/year (Khartoum)
Mean Annual Energy Produced: 3.8GJ/m²/year
Annual Amount of fuel displaced (1) : 0.132 tonne of fuel oil/m²/year
0.128 tonne of diesel/m²/year

Equipment Life : 15 years

Cost Characteristics

Capital Costs: Collector : LS 120/m²
Piping, support structure and pump: LS 60 /m²
TOTAL LS 180/m²

Operating and Maintenance Costs : LS9/m²/year
(5% of Capital Costs)

Savings:
LS 18.5/m²/year (displacing fuel oil at LS 140/tonne, Khartoum Depot, Nov. 1981).
LS 42.5/m²/year (displacing diesel at LS 331.85/tonne, Khartoum Depot, Nov. 1981).

IRR : 8.85% (displacing fuel oil) 8.61% (displacing diesel)
(escalation rate of O&M Costs = 10% year,
and that of fuel oil and diesel prices = 12%/year).

(1) Boiler efficiency = 80%
Piping losses = 10%
Calorific value of fuel oil = 41GJ/tonne, that of diesel = 42.3GJ/tonne

Table 5.16.1 Hot Water Requirements of Selected Industries

Industry	Hot Water Requirements (tonnes/day)	Average Hot Water Temp. (0°C)	Annual Fuel Consumption for Water Heating (tonnes/year)	Type of Fuel	Hot Water Utilization
Sudan Textile	1600	80	3501	Fuel Oil	Washing, sizing and preparation of baths.
Oasis Oil Company	160	85	385	Fuel Oil	Neutralizing acid oil w/caustic mixture
Karima Food Processing Factory	1728	62.5	2364	Fuel Oil	Washing and Pasteurizing
Babanoussa Karkade Factory	62.5	77.5	137	Fuel Oil	Beverage Production

TABLE 5.18 Implementation Scenarios for Solar Water Heating Systems

Low Case Scenario	1985	1990	2000	Medium Case Scenario	1985	1990	2000	High Case Scenario	1985	1990	2000
Fraction of Total Market (1)%	1	2	5		2	4	10		5	10	25
Number of Solar Units ($2m^2$/Unit)	418	836	2090		836	1672	4180		2090	4180	10450
Annual Amount of Diesel Displaced (tonnes/year)	3	10	25		10	20	50		25	50	125
Annual Amount of Fuel oil displaced	105	210	525		210	420	1050		525	1050	2625

(1) Total estimated commercial market = 500 tonnes of fuel oil/year and 500 tonnes of diesel/year.
Total estimated industrial market 110,000 tonnes of fuel oil/year.

References:

1. Meeting with Head of Maintenance Department of the Meridien Hotel (Mr. Magid Saleh), Friendship Palace (Mr. Duk-gyu Lee), Araak Hotel (Mr. Abdel Fatah Ahmed Taha), Grand and Hilton Hotels, April 12, 13, and 14, 1982.
2. *Meeting with Dr. Adel Sadik (Production Manager, Sudan Textile Industries Limited), April 15, 1982*
3. Meeting with Mr. Ibrahim Adam Moussal (Chief Eng.) Oasis Oil Company and Satti Soap Factory, 4/15/82.
4. Meeting with Institute of Energy Research Team (National Council for Research) regarding cost estimates for solar water heating systems manufacture in Sudan.

5.7 Improved Charcoal Kilns for

I) Introduction

In Sudan, the traditional carbonize the wood in pits dug hill (pit kilns) or to cover a f are mud (earth kilns) so as to charcoal production methods req constructed entirely from local lacking technical experience. H kilns have a very low yield (8-1 produced is difficult to control cutting and gathering of wood f and charcoal has led to increas and large rural communities, res deterioration, decline in agric and degradation of the range lar

In an attempt to reduce c improved charcoal kilns (station introduced in Sudan. The wide-st which have a much higher yield will produce a better quality c from substantially less wood an through the associated firewood and charcoal distribution and m

II) Technology Description

Improved charcoal kilns i which can be made of brick, cem kilns. The two most popular imp masonry kiln (derived from the portable steel kiln (Mark V Kil

The production of charcoa in quality as well as in quanti these kilns is restricted to pl supply of wood such as fast-gro plantations having an annual al hectare. The construction and m presents no difficulties. Each of the floor from which the gas cover is stainless steel, resis floor and walls made out of bri loading and unloading of the ki consists of paving mud slurry t heating. A mixture of clay and or clay alone, may be used as a built in one or two weeks by a

Portable steel kilns cons steel shells, a conical lid and is that they can be used to imp forest, utilizing the non-comme with commercial ones. However, such as steel-plate welding and In addition, they are subject t a result of local overheating) l sections of the shell. The low can slow down the exothermic de kiln walls (action of rain and production of partly carbonized to block form (typically 50cm 1 20cm). The steel kiln requires and unloaded over the top rim o a more laborious undertaking th and cost characteristics of a s metal kiln are shown in Table 5

I) Introduction

In Sudan, the traditional method of producing charcoal is to carbonize the wood in pits dug in the ground or on the side of a hill (pit kilns) or to cover a pile of packed firewood with earth and mud (earth kilns) so as to prevent complete combustion. These charcoal production methods require almost no capital and can be constructed entirely from locally available materials by people lacking technical experience. However, traditional pit and earth kilns have a very low yield (8-10%) and the quality of charcoal produced is difficult to control. In addition, the increased cutting and gathering of wood for fuel in the form of firewood and charcoal has led to increased deforestation rates around urban and large rural communities, resulting in desert encroachment, soil deterioration, decline in agricultural output and food production and degradation of the range lands.

In an attempt to reduce existing critical deforestation rates, improved charcoal kilns (stationary and portable types) can be introduced in Sudan. The wide-spread dissemination of those kilns which have a much higher yield (15-25%) than traditional kilns will produce a better quality charcoal (higher calorific value) from substantially less wood and will generate significant employment through the associated firewood collection, preparation and burning and charcoal distribution and marketing activities.

II) Technology Description

Improved charcoal kilns include fixed or stationary kilns which can be made of brick, cement or clay and portable metal kilns. The two most popular improved kilns consist of the stationary masonry kiln (derived from the American Missouri kiln) and the portable steel kiln (Mark V Kiln).

The production of charcoal by the masonry kiln is the highest in quality as well as in quantity (25% yield). The utilization of these kilns is restricted to places with abundant and continuous supply of wood such as fast-growing forest species (Eucaluptus) plantations having an annual allowable cut in excess of $20m^3$ per hectare. The construction and maintenance of the masonry kiln represents no difficulties. Each kiln has an opening in the center of the floor from which the gases are vented into a chimney. The cover is stainless steel, resistant to high temperatures, the floor and walls made out of bricks, and two doors allow easy loading and unloading of the kiln. The only maintenance needed consists of paving mud slurry to seal possible cracks due to overheating. A mixture of clay and Portland cement, or cement alone, or clay alone, may be used as a binder. One masonry kiln may be built in one or two weeks by a mason and two assistants.

Portable steel kilns consist typically of two cylindrical steel shells, a conical lid and four chimneys. Their main advantage is that they can be used to improve the stands of the tropical forest, utilizing the non-commercial species and replacing them with commercial ones. However, they require back-up maintenance such as steel-plate welding and heavy sheet-metal working capability. In addition, they are subject to the occurence of hot spots (as a result of local overheating) leading to buckling and collapse of sections of the shell. The low insulation value of the steel kiln can slow down the exothermic decomposition of the wood near the kiln walls (action of rain and wind), resulting in an excessive production of partly carbonized wood. The wood has to be reduced to block form (typically 50cm in length with diameter not exceeding 20cm). The steel kiln requires the wood and charcoal to be loaded and unloaded over the top rim of the bottom section of the unit, a more laborious undertaking than with the masonry kiln. Technical and cost characteristics of a stationary masonry kiln and a portable metal kiln are shown in Table 5.19.

III) Technology Cost Characteristics

A typical stationary masonry kiln costing 3000LS (1982) will produce 104 tonnes of charcoal annually from 416 tonnes of firewood while requiring 14 man-months worth of annual labor for collecting, preparing and burning the firewood. A portable steel kiln costing 650LS (1982) will produce 44 tonnes of charcoal annually from 220 tonnes of firewood requiring 24 man-months of annual labor.

On a micro-economic point of view, the construction and operation of a stationary kiln and a portable metal kiln will have an internal rate of return of 1070.5% and 59.4 % respectively (see details in Table 5.20)

IV) Implementation Issues

The annual consumption of charcoal in Sudan was estimated at 500,000 tonnes with about 90% of the charcoal used in urban and rural households and the rest used in small scale industries (brick making, etc). In order to project the future contribution of improved kilns for charcoal production in Sudan, three implementation scenarios were considered depending on government policies and incentives, and on institutional considerations such as the creation of a charcoal center. This center will train Sudanese personnel to build, maintain, and operate several types of kilns (fixed masonry and portable steel kilns) with good utilization potential in Sudan. It is desirable also to create metal workshops in highly forested regions so as to provide maintenance back-up to portable steel kilns (with steel-plate welding and heavy sheet-metal working equipment). The activities of the training center and workshops should be coordinated by the Forestry Department in Khartoum.

Table 5.21 summarizes the three scenarios considered and identifies the fraction of the total Sudan charcoal market which can be captured by improved charcoal kilns in 1985, 1990 and 2000. In the medium case scenario where the projected total market penetration is 1% in 1985, 2% in 1990 and 8% in the year 2000, 42 fixed kilns and 14 portable kilns will be saving about 30,000 tonnes of firewood in 1985; in 1990 twice as much and in the year 2000 eight times as much.

TABLE 5.9 Technical and Cost Characteristics of a Stationary Masonry and Portable Metal Kiln

Type of Kiln	Stationary Masonry Kiln	Portable Steel Kiln
Materials	Stainless steel ($24m^2$ of flat sheets, 5-8mm thick). Standard bricks (7000), Clay or cement (500kg), Metal rods and bolts.	Stainless steel Metal rods & bolts
Internal Vol (m^3)	25-30	6-7
Cycle-time (days)	10	2
Charcoal production (tonnes/cycle)	3	0.3
Typical yield (%)	25	20
Life of kiln (years)	7	3
Labor Required (man month)	1.2	2
Capacity factor	0.95	0.8
Annual charcoal production (tonnes/yr)	104	44
Investment Cost (1982LS)	3000	6750

ECA/FAO Forest Industries Advisory Group, Data on Charcoal Kilns and Retorts, E. Uhart, Regional Advisor for Charcoal Industry Development, Jan. 1976.

"Charcoal Making for Small Scale Enterprises," International Labour Office, Geneva, 1975.

E. Uhart, "Charcoal Development in Kenya," United Nations Economic Commission for Africa. ECA/FAO Forest Industries Advisory Group for Africa, Addis Ababa, July 1975.

TABLE 5.20 Micro-Economic Analysis of a Stationary Masonry Kiln and a Portable Metal Kiln

Type of Kiln	Stationary Masonry Kiln	Portable Steel Kiln
Annual Charcoal Production (tonnes/yr)	104	44
Amount of firewood required (tonnes/year)	416	220
Amount of firewood required for traditional kilns (tonnes/year). (assuming 10% yield)	1040	440
Amount of firewood saved (tonnes/year)	624	220
Life of Kiln (years)	7	3
Investment Costs (LS)	3000	6750
Operating and Maintenance Costs (LS/year) (1 man-month = 400LS)	5600	9600
Savings (LS/year) (assuming price of firewood= 60LS/tonne)	37440	13200
IRR (%) (assuming O&M costs and firewood prices escalate at 10%/year)	1070.5	59.4

References: Same as Table 5.19

TABLE 5.21 Improved Charcoal Kilns Implementation Scenarios

Low Case Scenario	1985	1990	2000
Fraction of total Market (%)	0.5	1	4
Number of Stationary Units	21	42	168
Number of Portable Units	7	14	16
Annual Amt. of Firewood Saved (tonnes/year)	14,644	29,288	117,152
Medium Case Scenario			
Fraction "	1	2	8
Number of Stationary Units	42	84	336
Number of Portable	14	28	112
Firewood Saved	29,288	58,576	234,304
High Case Scenario			
Fraction "	2	4	16
Stationary Units	84	168	672
Portable Units	28	16	224
Firewood Saved	58,576	117,152	468,608

Assumptions - Estimated annual charcoal production = Total market = 500,000 tonnes/yr
- Number of Stationary Units is three times greater than the number of portable units
- A stationary kiln saves an annual amount of 642 tonnes of firewood (Table 5.20)
- A portable kiln saves 220 tonnes of firewood/year when compared to traditional charcoal production methods (Table 5.20)

6.0 Recommendations for a National Renewable Energy Program In Sudan

The market potential of renewable energy technologies in Sudan appears to be significant by virtue of several factors such as the availability of renewable energy sources (solar energy, wind energy, agricultural residue, etc.), the decentralized nature of energy consumption in Sudan and the country's increased dependence on imported petroleum products. Renewable energy sources can make a significant contribution in meeting future Sudanese energy demands, displacing increasingly expensive and unreliable imported oil thus reducing balance of payment deficits. The utilization of renewable sources can also reduce critical deforestation and desertification rates around urban and rural communities while guaranteeing a continuous supply of energy sources. It will create a manufacturing base for renewable energy technologies, resulting in employment generation and in substantial foreign exchange savings.

However, several constraints limit the application of renewable energy technologies which appear technically and economically justifiable. The creation of a National Renewable Energy Program is needed to overcome these obstacles and develope strategies and policies which will encourage the widespread utilization of renewable energy resources and technologies most appropriate to Sudanese technical, economic and social conditions. The major constraints to the implementation of renewable energy policies include the following:

1. The lack of government and private institutions and organizations capable of developing, testing and maintaining renewable energy systems and of coordinating such systems with agricultural and rural development activities.
2. The lack of technical experts and technicians capable of analyzing the renewable technologies to be employed in specific situations, servicing the equipment to be installed and managing the overall operation in a technically and economically efficient manner.
3. The lack of effective means of information exchange and technology transfer between advanced industrial countries and Sudan in the field of renewables.
4. Shortage of small-scale, low-cost, simply designed renewable energy technologies which are appropriate to Sudanese conditions; the tendency of the developed countries has been to develop large-scale, high-technology systems requiring sophisticated pools of skilled manpower (PV, solar thermal and mini-hydro systems)
5. General public unawareness of the benefits of renewable energy sources, particularly in rural areas.
6. A lack of interest toward renewables on the part of Sudanese governmental and private sector policy makers who believe that the technologies are not economically competitive with conventional energy systems, and that further research and development is needed before commercialization of these technologies.

7. Lack of practical experience and information about the performance, operating and cost characteristics, and reliability of renewable technologies in order to clarify issues that must be faced in major investment decisions.
8. Lack of financing sources necessary to undertake renewable energy research, development and demonstration projects in Sudan.

The National Renewable Energy Program, which will help overcome these constraints, should address technical, economic/financial and institutional issues in an effort to support and encourage renewable energy technology development in Sudan.

6.1 Technical Issues:

Technical efforts should be directed at the research, development and demonstration of most promising and appropriate renewable technologies for application in Sudan. For most renewable technoligies the major requirements appear to be in the development and demonstration phases rather than in basic research. In this context, a Renewable Energy Demonstration Program will be very appropriate: the installation and operation of a limited number of renewable energy projects which have been already identified will acquaint Sudanese technical and energy planning personnel with the renewable energy options available and will permit them to acquire operating experience under Sudanese conditions. These field tests should employ a standardized evaluation procedure which addresses system reliability and maintainability, system economics and performance characteristics relative to currently available energy options, implementation issues and energy supply/ distribution implications. Based on the results obtained from this demonstration program, renewable energy systems most appropriate for manufacture and use in Sudan will be identified. Socio-cultural and institutional issues which could significantly impact the widespread utilization of these systems will also be analyzed.

Several renewable energy projects which may be included in the demonstration program have been identified and their technical and economic characteristics have been analyzed. They include:

a. The installation of windmills for water pumping applications in agricultural schemes with high annual wind power density in excess of $200W/m^2$ (Khartoum, Gezira and Upper Nile provinces).
b. The introduction of improved stationary brick kilns in banana plantations for the production of charcoal from banana trunks.
c. The construction of anaerobic digesters in dairy farms (biogas production from animal residues) and in rural communities along the White Nile (biogas production from water hyacinths).
d. The installation of solar water heating systems in commercial applications (Friendship Palace, Hilton, Meridian, Grand and Araak hotels), and in selected low-temperature industrial applications (textile industry; Sudan Textile Co., soap and oil industry: Oasis Oil Co,; food processing industry: Karima Food Processing Factory and Babanoussa Karkade Factory).
e. The introduction of briquetting plants in agricultural schemes (cotton, groundnuts, etc.) for the production of fuel briquettes to be utilized in rural households and industrial boilers.
f. The installation of agricultural residue gasifiers for electricity production in agriculturally-based industries.
g. The introduction of fixed masonry kilns and portable metallic kilns for improved charcoal production.
h. The introduction of improved charcoal stoves and woodstoves in rural areas.

6.2 Economic/Financial Issues:

In an attempt to encourage the R&D and commercialization of renewable energy resources and technologies, the Sudanese government should adopt legislation and pass laws favoring the utilization of renewables in the industrial, commercial and residential sectors, as part of its National Renewable Energy Program. Economic and financial measures should be designed to create a more favorable investment climate for renewable energy. In this context, the Sudanese government can offer several types of economic and financial incentives.

a) Income tax deduction: the costs incurred in the manufacture of renewable energy systems, facilities and projects will be fully deductible from gross income.
b) Reduction of tariff duties and importation tax: Sudan will have reduced tariffs on imported renewable energy systems which are not available or manufactured locally.
c) Exemption from tariff duties and importation tax: Raw materials needed for the manufacture of renewable energy systems will be exempted from tariff duties and importation tax.
d) Provision of low-interest loans: Government financial institutions and private banking institutions should provide low-interest loans to individuals and companies involved in R &D activities and in the manufacture and installation of renewable energy systems and projects.
e) Subsidizing the installation of renewable energy technologies in government buildings.
f) Mandatory installation of solar water heating systems for all new government constructions and new commercial and institutional buildings (hotels, hospitals, etc).
g) Accelerated depreciation in the industrial sector: Depreciation allowances for manufacturing machinery used for producing renewable energy systems, and for large scale renewable energy projects installed by industrial firms should be relatively high (30%).
h) Provision of grants to rural households: Government grants should be provided to rural households with limited funds for purchases of renewable energy systems.
i) Subsidizing the price of gasohol and provision of tax benefits and low-interest financing for establishing molasses distilleries for the production of ethanol.

These financial incentives (low-interest loans, tax deduction, capital subsidies, grants and exemption from tariff duties) require funds which can be obtained from the amount of foreign exchange savings generated by displacing imported petroleum products.

6.3 Institutional Issues:

a) Increased information dissemination:

Wide distribution of information on renewables will foster greater awareness of the potential role of renewable technologies in Sudan. The information, which can be disseminated through organized trade shows, technical seminars and conferences, include the following:

i. Cost, performance, operating, maintenance and reliability characteristics of renewable energy technoligies most appropriate to Sudanese technical, economic and institutional conditions.
ii. Description of current renewable energy research and development programs; technical and operating data of current demonstration and field-testing projects.
iii. Availability of equipment from manufacturers.
iv. Technical, economic and social benefits of renewable energy systems.

b) Establishment of Performance Standards for Renewable Energy

Renewable energy systems must be tested for conversion efficiency, technical performance, reliability and operating characteristics by a government or by a private research institution with adequate technical capabilities. Acceptable systems will receive a certificate of worthiness from the Ministry of Energy and Mining. This measure of consumer protection will boost the confidence of potential users in renewable energy technologies.

c) Training Programs:

There are important needs for technical training at many levels:

i. Training of Sudanese National Energy Administration personnel in establishing a network to provide planning and implementation support to regions and villages.
ii. Training of Sudanese energy planners in the technical, economic, and institutional assessment of renewable energy systems.
iii. Training of field personnel necessary for the design, manufacture, installation, operation and maintenance of renewable technologies.

These needs could be achieved through the implementation of several renewable energy training programs in Sudan which will form technical experts, planners and technicians capable of supervising and coordinating the design, manufacture and dissemination of renewable technologies as part of the National Renewable Energy Program. In addition, teams of Sudanese officials could be brought to the U.S. for a hands-on training program in the various aspects of renewable energy R &D and for an extensive tour of U.S. renewable energy facilities.

APPENDIX I

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APPENDIX II

LIST OF RENEWABLE ENERGY OFFICIALS INTERVIEWED

DATE	NAME	POSITION
February 9, 1982	Dr. Yahia H. Hamid	Head of Mechanical Engineering Dept. University of Khartoum.
February 10, 1982	Mr. Shommo Sha'a	Head of Biomass Group, IER
	Eldin Ali	NCR (CSTR).
	Mr. Mohammed El-Tayeb Mansour	Solar Energy Group, IER, NCR (CSTR).
February 11, 1982	Dr. Mohammed Osman Sid Ahmed	Head of Solar Energy Group, IER, NCR(CSTR).
February 13, 1982	Dr. Adil R. Elias	Coordinator of Sudan National Alcohol Program.
	Dr. Ansim El Moghraby	Institute of Environmental Studies, University of Khartoum.
February 14, 1982	Mr. Des Fortes	FAO Program Officer.
	Dr. El Tayeb Idris	Head of Wind Energy Group.
	Eisa	IER, NCR, (CSTR)
February 15, 1982	Dr. Suleiman Jaber	Head of Cellulose, Chemistry and Technology Unit, NCR (CSTR).
February 16, 1982	Mr. Hassan Beshir	Plant Protection Administration Ministry of Agriculture.
	Dr. Hamed Drar	Faculty of Agriculture, University of Khartoum.
	Dr. Saleman Hassan	Faculty of Agriculture
	El-Awad	University of Khartoum.
February 18, 1982	Dr. Farouk Habbani	Head of Physics Department University of Khartoum.
February 20, 1982	Prof. Ahmed Abdul Rahman El-Agib	President of NCR (CSTR).
February 21, 1982	Dr. Anthony Eagan	Physics Department, University of Khartoum.

APPENDIX III

RENEWABLE ENERGY ASSESSMENT TASK FORCE

The following individuals participated in producing this report:

Gaafar El Faki Ali	National Energy Administration
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