SOLAR ENERGY IN RURAL AND REMOTE AREAS OF DEVELOPING COUNTRIES (CASE STUDY EGYPT)

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ABSTRACT

The energy needs of the population in rural and remote areas of developing countries are discussed. The sources of energy in these areas are reviewed. The most suitable types of energy for application are fixed. An economic analysis is given for the solar water heater and the solar desalination units used in Egypt

Keywords: Solar Energy - Desalination - Rural Areas - Egypt.

1. INTRODUCTION

The Majority of the people in developing countries live in rural and remote areas. They need energy for their daily life. In general, the sectors of energy requirements can be grouped as follows :-

1- Electricity generation sector.
2- Industry
3- Household and commercial sector
4- Transportation
5- Agriculture
6- General services

Energy resources differ from nation to another, also the requirements, even in the same country. Urban zones have energy facilities in the form of electricity and fossil fuels. But rural and remote areas should secure the energy requirements by all means, taking into account the environmental impacts on the society.

Also when planning an energy policy for the rural areas, the demand must be well studied to avoid any shortage of energy that may seriously affect the people.

In general, the average energy consumption in these areas is low and has a maximum of about 40 MJ/ca annually.

The total energy consumption in different countries is as follows : (MJ/ca annually).

Table 1. Average Energy Consumption in Different Countries.

Country	USA	Europe	Oil EXP Countries	Developing	LDC
Energy Consumption	300000	225000	200000	34000	1000 MJ/ca annually
	822	616.4	548	93.2	27.4 MJ/ca Daily

2- THE WORLD POPULATION

The world nations can be divided into 4 categories:-

A) Rich developed 1st world
B) Rich developing 2nd world
C) Developing 3rd world
D) LDC least Developing Countries 4 th world

The annual increase in population varies between 0.5% in developed countries and 4% in the LDC world. Table (2) gives one senario of world population during the 21st century.

Table 2. Expected World Population during 21st century (in milliard)

Year	1965	1973	1980	1990	2000	2010	2025	2050	2100
Popul.	3.3	3.75	5	5.3	6.2	7.1	8.3	10.5	15

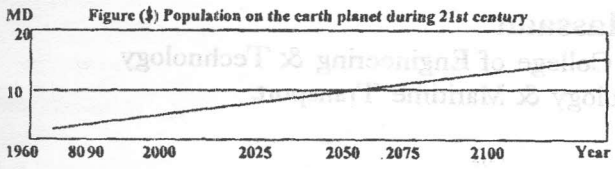

Figure 1. Population on the earth planet during 21st century.

In General, people gather around the fresh water sources and their density becomes smaller in the deserts where natural fresh water is rare.

Every human being on our planet has certain needs which will secure his life. These needs can be put into two categories :-

A) Essential life needs : Air, water & food.

In general life ends after 3 minutes without fresh air, 3 days without water in summer, 7 days without food.

B) Essential living needs : Housing, Energy, Transportation and Medical treatment.

Rich developed and rich developing countries form about 25% of the total global population, consume about 75% of the total World Energy Consumption, while 75% are poor and consume only about 25% !

3. SOURCES OF ENERGY IN RURAL AND REMOTE AREAS:

Settlements in such areas may include 100 - 1000 permanent residents. They can be working in agricultural areas as farmers or along the coastal zones as fishers.

The sources of energy in these areas can be either :-

A) Traditional : using fossil fuels like coal, benzene, kerosene, gas oil, mazout, N.G. or LPG.

B) Renewable : Solar, wind, biomass, biogas, minihydro, OTEC, Hydrogen ..

Electricity is either connected to the main grid or produced from separate diesel units. Sometimes fuel, wood, crop residues, and wind mills are used, and Butagas LPG if available.

The solar energy can be utilized in these areas. Solar cookers, Solar water heaters, Solar crop dryers, Solar water pumps, Solar desalination units can be used. Sometimes a combination between different sources is used (Electricity, Biomass, Wind, Solar).

In general, oil resources are depleting and by the end of the 21st, century, no Oil will be available. To prolong the life time of oil, the following steps are considered :

1- Introduce new efficient machines.
2- Save energy through waste heat recovery, insulation, ...
3- The wide spread use of renewable energy and training the users to maintain the equipments in good state.

4. THE ROLE OF RENEWABLE ENERGY:

Table no (3)

5- CALCULATIONS OF THE ENERGY NEEDS

To estimate the energy needs annually, some average figures from practice will be given. Actual figures vary according to :-

a- Standard of living.
b- Climate conditions.
c- Social customs.
d- Price of energy.

A family of 5 persons will be considered in the following analysis.

a- Lighting :-

200 watt lamps illuminate the house for 6 hours daily inclusive street lighting in front of the house.

Energy needed = 6 x 0.2 x 365 = 438 kWh/year.

b- Hot water :-

The family uses 100 litters hot water daily (from 20° to 60°C .

Energy needed = 100 (60-20) x 365 x 4.19 = 6.12 Mn kJ/year

c- Cooking :-

The family needs are about 12.57 Mn kJ/year

d- Space heating in winter :-

100 cold nights annually need 1 KW heaters for 6 hours daily. Thus needed will be 600 kWh/year.

e- Refrigerator:

The family uses a 10ft unit 0.1 KW. The energy needed will be 438 kWh/ year.

Thus the household requirements will be

Table 3. Uses of Renewable Energy in Rural and Remote Areas.

Item	
Lighting	Electricity from mini hydro stations Windmills driving DC generators. Biogas-alcohol - photovoltaics
Water heating	Solar water heaters Biomass fuelled stoves
Space heating	Flat plate collector-biogas - solar air conditioning
Cooking	Biomass combustion - biogas generators - solar cooking
Refrigerator	Solar absorption systems
Crop drying	Flat plate collector dryers Biomass direct combustion
Grop grinding	Windmills Biogas power Alkohol generators
Telecommunication	photovoltaics
Water network	Windmill Solar distillation Flat plate collector for purification photovoltaic pumps

Table 4. Annual Family Energy Needs.

Item no.	a	b	c	d	e
Energy units	438 kWh	6.12 Mn KJ	12 Mn KJ	600 kWh	438 kWh

Total Energy requirements 1476 kWh and 18.69 Mn KJ annually.
or 1476 x 0.22 x 42 + 1860 = 32330 MJ
This amount is valid for 5 persons. Thus per ca, the household energy needs will be :-

6.470 MJ/ ca annually.
or 17.7 MJ/ca daily

Other daily needs of energy:-

In a community, transportation, industries, and other services like water network, commercial units, schools, hospitals ..... etc. may reach 100% of the household needs.
Thus the actual needs will jump to :-
35.4MJ/ ca

NB. In one rural village in upper Egypt, the following average figures were obtained for the household :

60 liter kerosene/ca annually.x 42 MJ/kg =252034%
2.5Kg Butagas x45 MJ/kg =112.51.5%
70 kWh electricity x10.5 MJ/kWh 73510%
500Kg agriculture residues x8 MJ/kg = 400054%

7367.5

Thus the total energy consumption 7367.5 MJ/ ca annually = 20.2 MJ/ca daily.
Adding 100% for other needs, then the figure becomes 40.4 MJ/ca daily.

The energy used from agricultural residues form

about 54% of the daily energy needs. Thus the energy needs in rural and remote areas can rise up to 50MJ/ca daily.

6- THE SOLAR ENERGY:-

. . History :-

The warm belt on the Earth lies between latitude 40° north and 40° south of the Equator. The sun shines 3000 to 4500 hrs annually and the average solar insolation is about 5 - 7 kWh/m ^{2} day as the chart shows (Figure 2).

The amount of solar insolation falling on the atmosphere around the Earth is almost about 1.35 kW/ m^2. This is divided into two parts :-

a) Direct solar radiation which reaches the Earth surface.
   This is about 80% or 1082 kW/ m ^{2}.
b) Diffusion solar radiation, about 20% or 271 kW/m^2

During the second half of the 20th century, developments were made to utilize the solar energy, through :-

1- Intensive research
2- Efficient improved designs
3- Careful manufacturing
4- Marketing
5- Training of technicians for careful operation and maintenance.

1950, the former USSR established the Solar Institute in Tashkand. Then similar institutes were formed in USA, India, England, France, Japan, Algier, Australia, Burma, Canada, Serylanca, Chilly, China, Egypt, Britain, Germany, Italy, Lebanon, South Africa, Spain, Switzerland and ... etc.

The solar energy is still receiving much attention since it is a pollution free and can lead to quick social developments in rural and remote areas.

7. SOLAR ENERGY SITUATION:-

Solar energy is a source that can be utilized everywhere when the sun shines, whether in developed or developing countries. This energy is utilized in several sectors and in rural and remote areas. A review of the world technology will be given hereafter.

1- Solar water heaters
2- Solar space heating
3- Solar air conditioning in summer
4- Solar refrigeration
5- Solar crop drying
6- Solar ponds
7- Solar desalination
8- Solar power stations and power towers
9- Solar photovoltaics
10- Solar greenhouses
11- Solar industrial units
12- Solar hydrogen production

1- Solar water heaters :-

This is used in many countries, mostly in the household sector. The flat plate solar collector together with the water storage tanks are extensively used. Sizes vary as follows :-

100 - 150 - 200 - 450 liters daily for household, more for hotels, hospitals, schools, big malls ... etc. Collector area 2 and 3 m ^{2} and multiples.

Sometimes the system is fitted with a 1kW electric heater to compensate for the cold days with little or no sun shine.

The thermosyphonic flow principle is generally used in small units, but in bigger ones (thousands of liters per day), forced circulation with thermostatic control are used.

These solar water heaters need less maintenance and their life time can exceed 10 years.

When dealing with solar water heaters, the following points must be considered :

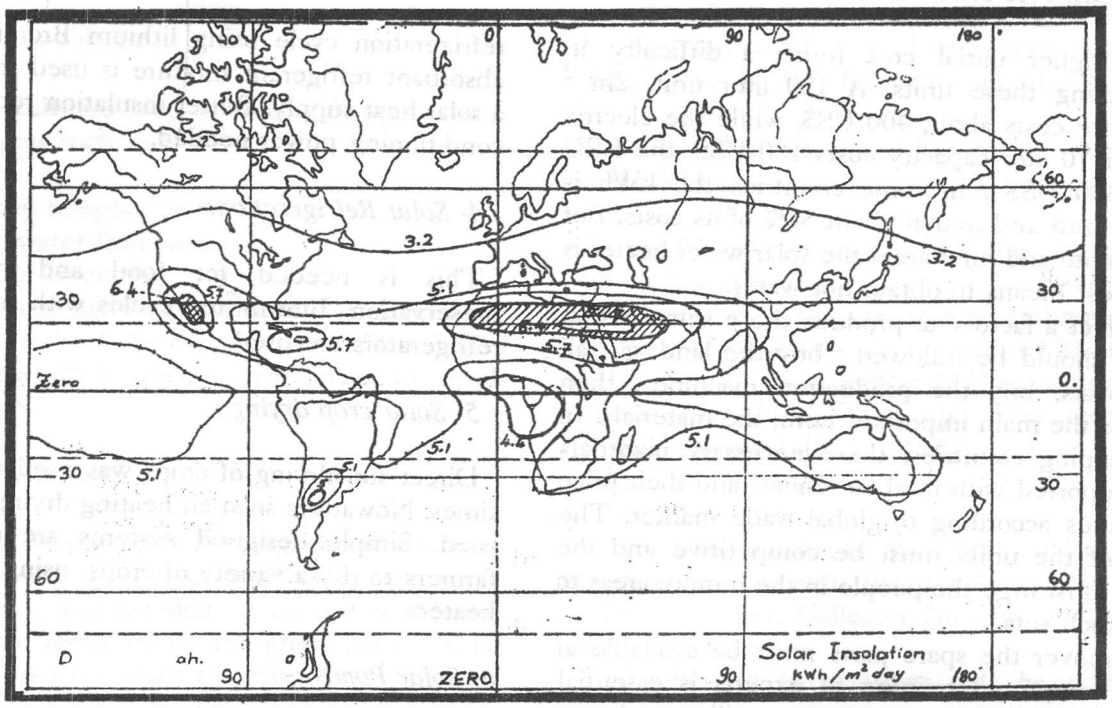

Figure 2. Global solar insolation.

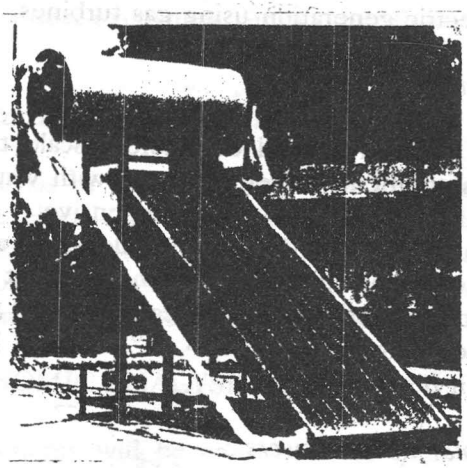

Figure 3. Solar water heater (standard size) collectors area 2 m^2 capacity 150 liter/day hot water maximum temperature 80°C rate of flow 53 cm^3/sec.

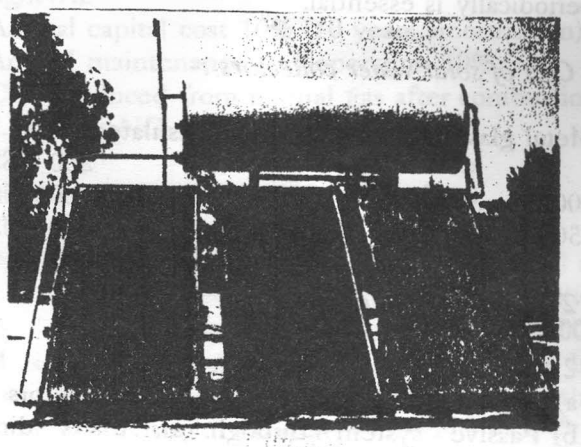

Figure 4. Solar water heater (compound) standard collectors connected in parallel to increase the plant capacity 3 collectors each 2 m^2 give a capacity of 450 1/day.

A. The higher initial cost forms a difficulty in marketing these units. A 150 liter unit, 2m ^{2} collector costs about 400 US$, while the electric heater 10 liter capacity costs 100 US$, the LPG one 300 US$. In some countries the kWh is subsidized and sold at about 50% of its costs. But in remote and rural areas the solar water heater is the best means to obtain hot water.

B. To erect a factory to produce these sets, several steps should be followed : buy the land, get all approvals, buy the production machines, then comes the main important item, the materials. In developing countries, these necessary materials are imported with hard currencies and their price oscillates according to global trade market. The cost of the units must be competitive and the state must urge the people in the remote areas to buy such sets.

C. Moreover the spare parts must be available at all times, and training of experts is essential since lack of experience will result in maintenance problems.

The maintenance of the unit is very important to get the best efficiency of the set. For example dust collection on the glass of the collector must be removed always. The impurities and salts in the water cause corrosion and cleaning of the set periodically is essential.

Cost of solar water collectors :-

Metal glass collector unit with insulated tank

	200 US$/m^2
200 liter 3 m^2	600 US$
150 liter 2 m	400 US$

2- Solar Space Heating:-

2 systems are in use, either :-

a) Active system through hot water radiators

b) Passive system through air ducts directly exposed to the sun

The system is used only through the cold weather time but not all over the year. The solar collector is big in size.

3- Solar Air Conditioning in summer :-

The solar energy is converted into mechanical energy to operate a compressor. Also the absorption refrigeration cycle using lithium Bromide/water as absorbant refrigerant mixture is used together with a solar heat supply. Better insulation reduces the air conditioning power needed.

4- Solar Refrigeration:-

This is needed for food and medicaments preservation. Intermitted cycles with solar powered refrigerators are used.

5- Solar crop drying:-

Direct sun drying of crops was used since ancient times. Nowadays solar air heating drying systems are used. Simple designed systems are used by the farmers to dry a variety of crops, using flat plate air heaters.

6- Solar Ponds :-

Solar lakes have salt concentration gradients which increase with increasing depths. Temperatures up to 110°C can be maintained in the lower layers if the wind effect is avoided. This heat can be utilized in heating, absorption machines working at temperatures less than 100°C, in desalination plants, and electric generation using gas turbines.

7- Solar Desalination :-

It is used on a small commercial scale to supply small settlements in remote areas with water, since the transportation of water is expensive.
The production of fresh water depends upon the presence of the sun. The life time of a unit depends upon the material used and can reach 20 years. At latitudes ranging from 15° - 45°, about 4 liters/m^2/ day can be produced.

8- Solar Power Towers :-

Through concentration of the incident solar energy on a boiler, steam can be generated and through a steam turbine electricity will be generated. (1 MW station in Sicily, Italy).

Moreover, the concentrated solar heat can be used in melting metals. (Odeilo furnace South France gives 3000°C to melt metals).

9- Solar Photovoltaics :-

Silicon solar cells are used in small scale applications at remote areas such as :-

a) Lighting
b) Emergency telephones
c) Pumping water from wells.
d) Medical Refrigeration

Great progress had been achieved in developing photovoltaic cells. 1970 the cost was 15000 US$ / kW, by year 2000 this is expected to reach 1000/US$/ kW.

10- Solar Greenhouses:-

To protect plants against freezing in cold climates, the greenhouse is heated through the solar energy during the day, and through an air heater through the night. The temp. inside the greenhouse can be adjusted to assist the plant to grow.

11- Solar Industrial Units :-

For industrial process heat, high temperatures are required (100° - 500°C). Parabolic concentrators are to be arranged to give the required temperature. Oil is generally used as medium in such units and through a heat exchanger, air or other fluids can be heated.

12- Solar Hydrogen Production :-

Electrolysis of water is one method of producing H_2. The electric energy needed can be obtained from solar photovoltaics or Solar Tower electric generation. This system is still very expensive. In one estimation, it costs 7000US$/ Ton H_2 .

8- ECONOMIC ANALYSIS OF SOLAR ENERGY

Two systems will be considered to evaluate the economy of using solar energy equipments in rural and remote areas.

a) Domestic solar water heater.
b) Desalination plant.

The solar water heater will be compared to a N.G. set and an electric one. The desalination plant will include photovoltaic unit to produce electricity which drives the pumps used in the Reversed Osmosis plant.The prices of the elements relate to the Egyptian market conditions, and expressed in US$, [1US$ = 3.39 Egyptian pound] .

9- ECONOMIC ANALYSIS OF SOLAR WATER HEATERS :-

In the following demonstration 3 hot water heaters will be examined :-

For a family of 5 persons, in rural and remote areas, an average hot water consumption of 30 liters daily at 50°C. will be considered. The water will be heated from 20°C. Thus the total heat energy needed will be about 19 MJ/day.

a) Electric heater 10 liters 1.2 kW price about 100 US$.
b) N.G. water heater 10 liters price 300 US$.
c) Solar water heater, flat plate collector and 150 liter container. Collector 2m^2. price 400 US$.

The following informations will be used in the analysis :-

1- Natural gas cost 100 US$ / ton. LCV = 48 MJ/Kg
2- Electric energy from the main grid 6 cent/kWh.
3- Specific fuel consumption in the main central electric power station using NG is about 0.22 kg/kWh.
4- Annual capital cost 10% (10 years amortization).
5- Annual maintenance and operation 10%.
6- CO_2 produced from natural gas after combustion 2.57 kg/kgNG.

10- SOLAR DESALINATION :-

Solar water desalination units are very beneficial in rural and remote areas where small communities live along the seas and wells. Salt sea water of 45000 PPM and brackish water of 3000 PPM can be converted to fresh drinkable water utilizing both the solar energy and reversed osmosis system RO.

The combination of solar photovoltaic with RO system is used.

The electric current generated through the photovoltaic unit drives the pumps of the RO unit. The RO system can be multiphase to ensure the required PPM of the water needed.

The recent progress in photovoltaics and membranes make the cost of producing 1 m3 fresh water in the order of 1.5 to 2 US$/ m3.

Table 5. (Comparison between 3 types of hot water units) [5].

	Electrical	N.G.	Solar
Efficiency of the unit	75%	65%	40%
Annual fuel consumption kg	-	22.1	-
Annual kWh (4.4 hrs daily)	2570	-	-
Equivalent fuel kg annually	565	-	-
Capital annual cost 10% US$	10	30	40
Other running costs annually	10	30	40
	154.2	22.1	-
Total annual costs US$	174.2	82.1	80
	218%	103%	100%
CO2 emissions annually kg	145	568	-

General data :-

Family size units (5 persons) 50 - 100 liter /day
Community size (100 - 1000 persons) 5 - 100 m^3/day
The land area needed for the system is about 0.3m^2/ liter fresh water daily.

Photovoltaics :-

Initial cost including storage installation 3000US$/ kW peak.
Power input to the RO system about 7 kWh/m3.

11- ECONOMIC ANALYSIS OF SOLAR DESALINATION UNITS :-

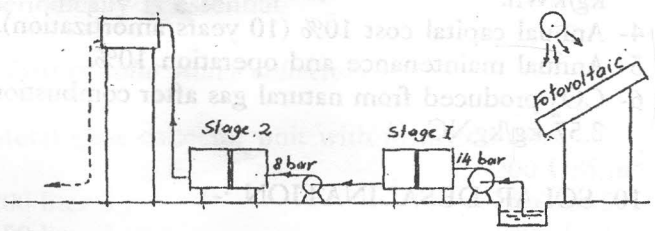

Figure 5. The Photovoltaics-RO system.

A typical example will be given : The abuGhossoun unit on the red sea about 900kms from Cairo.
300 inhabitants each consumes 40 liters / day
Total daily consumption about 12 m^3.
Photovoltaic unit produces 8.3 kWp. with storage batteries 65kWh.
Coupled to a diesel generator as back up.
2 Stage RO system designed for water salinity 4500 PPM feed.
After the *first* stage RO, the water salinity reaches 550 PPM, after the second stage 300 PPM

Cost of producing 1m^3 fresh water:

Photovoltaic unit 8.3 kW_p x 3000 =24900 US$
Diesel unit 6 x 600 kW_p =3600 US$
Pumps, containers, ... etc. =3000US$
Land =3500US$

Total capital cost =35000 US$
Annual amortization 10% =3500
Operation and maintenance 10% (because of the membranes) =3500
Total annual costs (without diesel fuel) =7000
Cost of producing 1m^3 fresh water =7000/ 12 x 365 =1.6 US$

Thus the system cost is 1.6 US$ / m^3 fresh water

12- THE EFFECT OF USING SOLAR ENERGY ON GLOBAL WARMING POTENTIAL :-

Considering the example of the solar water heater, Table no (5) shows that the total annual costs of the electric water heater are the highest. Moreover, the emissions from the exhaust gases, especially CO_2, contribute to the global warming phenomena. Using the solar energy will reduce this effect.

13- CONCLUSIONS :-

A general review of the energy needs in rural and remote areas of developing countries was given. Then the role of renewable energy to meet the needs of the residents in these areas was explained. The solar energy situation was examined . Then two examples were chosen to demonstrate the advantage of using solar energy in solar water heaters and desalination plants both economically and environmentally in Egypt.

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