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Renewable energy options to overcome energy crisis in Pakistan

By

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By:
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SYNOPSIS

Pakistan, like many other developing countries, is confronted with acute energy crisis on account of ever-increasing demand for energy and high costs of fossil fuels. The increase in energy demand is inevitable due to sharp rise in population and growing national aspirations for better standard of living and improved socio-economic conditions.

The high costs of oil and the growing realization that the supply of fossil fuels would be exhausted at some future date have stimulated interest in the possibility of producing more renewable energy in the developing countries. This paper presents different technology options, based on renewable energy resources to overcome energy crisis in Pakistan.

1. INTRODUCTION

The economy of Pakistan is dominated by agriculture. More than 70 percent of its population is settled in rural areas which provide the essential agricultural base for the urban population and the industry. Low per capita income in rural areas is the main cause of overall low standard of living at the national level, which cannot be raised without changing the fortune of the rural masses. Thus the overall economic growth of the country is, to a large extent, dependent on how soon the rural areas are adequately developed. Electricity plays an important role in this regard. The Government of Pakistan, being aware of this fact, is giving top priority to rural electrification. It plans to provide electricity to 90 per cent of all villages in Pakistan, by 1990.

Out of a total of about 45,000 villages in Pakistan, around 23,000 villages (51%) were electrified by June 30, 1986, while 19,000 more will be provided with power over the next four years. It is estimated that an additional energy to the tune of 2,500 million kwh will be required for these 19,000 villages by the year 1990, corresponding to an additional power of about 600MW.

In the face of acute power shortage prevailing in the country on account of tremendous demand for energy and high costs of fossil fuels, the conventional methods of power generation will not be able to adequately fulfil the growing energy needs of our rural areas. Therefore, for rapid economic development of the country, the additional sources of energy will have to be tapped to supplement the existing resources so that energy needs of our rural areas are adequately met.

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2. RENEWABLE ENERGY OPTIONS

Considerable potential of indigenous renewable energy exists in Pakistan. The available renewable energy options for our rural areas are:

- Biomass
- Wind
- Solar
- Mini-Hydro

2.1 Biomass Energy.

The production of energy from 'Biomass' meets with growing interest. Biomass comes from regenerative sources and in many cases, in the processing of natural products, it occurs as waste such as sawdust, barks, rice-husks, bagasse, cotton-sticks/bolls, nut-shells. straws and animal-dung or virtually any organic-combustible material. These waste materials offer a source of energy which has not been effectively utilised so far.

The main Biomass Conversion routes are as follows:

2.1.1 Biogas

About 50 per cent of the animal dung in Pakistan, which is equivalent to several million tons of superior quality manure is being burnt as fuel, which can otherwise be saved for use to increase soil fertility. The fermentation of organic wastes such as animal-dung, sewage, agricultural wastes or food production residues under anaerobic conditions can produce a smokeless & low calorific value fuel gas mixture of mainly methane and carbon dioxide, known as 'Biogas'. Normally the methane content is 60-70%, the rest is carbon dioxide and traces of nitogen, hydrogen and hydrogen sulphide. The effluent from the fermentation unit is rich in nitrogen and has valuable properties as a fertiliser and soil conditioner. Rough estimates are that one ton of dry organic matter is equivalent to almost two barrels of oil or about 280 cubic meter of gas and 0.73 tons of fertilizer, in a biogas plant. The optimum efficiency of the system is obtained at round $35^{o}C$. At temperatures lower than $15^{o}C$, the process of evolution of gas decreases considerably.

Biogas is ovbiously an ideal choice for rural areas where it is easier to obtain the animal-dung. Biogas can be used for the purpose of cooking, lighting, and also for water heating and space heating, in winter.

According to the statistical data available, about 10 Kg. of dung is produced by one animal unit per day. One Kg. of fresh dung produces $0.05m^3$ of gas. The gas required for cooking and lighting needs per person per day is $0.6m^3$. Accordingly, a farmer with 6 family members, having 7 heads of cattle can meet his energy requirements for cooking and lighting. It is estimated that there were about 30 million domestic cattle* in Pakistan by 1984-85, sufficient to produce about 15 million cubic meter of gas every day (benefitting about 4.5 million rural households) and 40 million metric tonnes of wet manure annually. Thus a considerable potential exists for promotion of 'Biogas' in rural areas.

The present cost of a family size Biogas Plant of about $3.5m^3$ gas capacity is around U.S.$425 if the labour is supplied free. There are some recent developments which suggest that the future costs of such plants might be lower. Improved designs could reduce the cost to nearly one-third of the cost for a plant of the same size. Efforts should also be made to reduce the dependence on bovine animals by using more of the waste of other animals and increasing the proportion of vegetable wastes of all kinds in the slurry feed of the Biogas Plants.

*Buffaloes : 13.1 million , Cows/Bulls: 16.5 million

'Biogas' has been a great success in China and India. The Chinese have applied the technology very widely in certain provinces with mild winters, such as 'Sichuan'. Several million family size biogas units are in use in China. In India about 0.5 million Biogas units are operational. Apart from other noteworthy benefits, such units have surprisingly brought some physiological advantages to the rural population in India. It has been observed that, with the use of Biogas units the rate of 'CATARACT', dropped by 80% in comparison with those using cattle dung directly as a source of combustion. The direct use of cattle-dung is widely in vogue in Pakistan as well. The application of Biogas in rural areas, can thus bring about an improvement in the existing health standards, which is also an additional plus point for promotion of biogas plants in rural areas. The Government of Pakistan has already launched a campaign to promote the installation of Biogas units in rural areas, utilising cattle-dung. It plans to set up about 7000 units by the end of 1987.

Unfortunately, Biogas in Pakistan has not achieved the desired amount of success which was expected of it, mainly due to the following factors:

i) Poor public response because of aesthetic reasons, as the plant requires regular cleaning of the digester, and painting to avoid corrosion.

ii) Lack of education of the users regarding the operation of the unit itself, such as varying the amount of dung-water ratio, with the changing atmospheric temperature, for optimal operation.

iii) Lack of co-operation between the donors of animal-dung.

The use of 'Biogas' can, however, be promoted through public education and training.

The Biogas is also a clean fuel for internal-combustion engines, with low maintenance requirements. A 50KW generator based on 85m^3 of biogas and 65 horse power spark-ignition engine has been recently developed in SRI LANKA and would cost U.S.$ 23,000 i.e. U.S.$ 460/KW. Other studies show that a plant of this size may cost even lesser. In such systems, the biogas can be stored in adequate quantities in the gas holder and drawn and used in the engine, whenever required. The raw material i.e. animal dung and other wastes could be stored to cater for seasonal variations in load. A 85 cu. metre of gas supply (eq. 170 animals) can generate upto 113 KWh of electricity per day, (with conversion efficiency of about 23%) which should be more than adequate for lighting needs of most villages. Even if 50% of the total Biogas produced, is utilised for power generation, the 30 million domestic cattle in Pakistan can produce about 3,600 million KWh of Electrical Energy every year (or 815 MW of power)!

2.1.2 Biomass Combustion.

Burning is the obvious way to process biomass provided the fuel is reasonably dry. Steam engines were the main mechanical prime-movers for over a hundred years. They are in a sense technological extinct species. But recently, due to the scare of 1973 oil embargo and the decreasing oil-reserves, efforts have again been started for giving the steam engines a respected place by making them techno-economically feasible. Advancements have been made to upgrade engineering in steam engine technology to improve performance and decrease operational costs. Bio-mass energy systems have been developed to produce process steam for operating the steam-engine generators. The biomass fuel can consist of rice husks, wood chips, saw dust, barks, cotton bolls, nut-shells, bagasse, straws or virually

any organic combustible material. Such systems are now commercially available in the international market, over a range of 10 to 200 KW.

One of the main disadvantages previously has been the problem of fuel which was not dry. But with the recent system, the waste steam is used to pre-heat the fuel which is then put into the boiler. This system also provides simplicity of operation, long-system life of about 25 years and a very low maintenance cost. A typical system schematic diagram is illustrated in Figure-1 to explain the working principles involved in the system.

The heart of this system is a steam-generator which provides the following advantages over steam turbines.

i) Steam engines use approximately 40% less steam than turbines and are not as sensitive to the quality of the steam in terms of such factors as moisture content.

(ii) Steam engines are more tolerant of chemical contamination in boilers.

(iii) The normal horse power rating of steam engines can be increased up to 20% without negative effect and can be sustained continuously, again without negative effect.

The combustible fuel is pre-heated first through the forced draft of Airflow Chamber. The fuel is then put in Storage Area where it is further dried with the help of steam from the Airflow Chamber. The moist-free fuel is then placed manually or automatically in Firebox/Grate. From the combustion of fuel, the water in the boiler is heated to a level which produces steam and this steam drives the Steam-Engine during its course. Steam-Engine is coupled with a generator, which in turns produces electrical energy. However, the steam continues its journey towards Heat Exchanger/Condenser from where by virtue of condensation of steam, water is collected and reaches the Feedwater-Tank, through Transfer Pump. In Feedwater-Tank, Chemical Feed is also introduced for water softening. The cycle is completed through Feed-water Pump, when water from Feedwater-Tank reaches back to the Boiler for production of steam.

A cost analysis was done to find out the economic viability of this system. For this purpose, a comparison was made between a Diesel Generating System and the Biomass Energy System of the same size.

An analysis of the 'Rural Electrification Master Plan in Pakistan', prepared by the author, shows that the average peak load per village ranges between 25 to 60 KW in different provinces. But for comparison purposes, a load of 30 KW per village has been considered to meet the electricity requirements of private households, community centres, small commercial units, small industrial units; tubewells/lift pumps and public lighting etc. (Refer Appendix-1). The analysis presented, therein, shows that the cost per KWh of electrical energy through the Biomass Energy System is around Re. 1.00 which is considerably lesser as compared to Rs. 2.12 per KWh, through Diesel-Generating set of the same size.

A study on 'Regional Energy Survey' was conducted recently by the Asian Development Bank, in which estimates of wood and biomass potential in different regions of Pakistan were prepared. In this study, the land use pattern in 1980, 1990 and 2000 was derived, using the existing pattern and the forest depletion rates derived from regression models, linking population, cultivable lands and forests. The results are shown in Table-1.

The table shows that the minimum annual net surplus quantity of Biomass available in the country, after meeting the domestic energy needs as fuelwood, in the rural areas, will be about 317,000 t.o.e. upto the year 2000. This quantity is sufficient to produce about 600 million KWh* of electrical energy every year, corresponding to a peak power demand of 135 MW.

From the preceding discussions, it is evident that the annual electrical energy availability in Pakistan through Biogas/Biomass combustion, will be as under:

- Biogas system 3,600 million KWh; 815 MW
- Biomass Combustion System: 600 million KWh; 135 MW

Total : 4,200 million KWh; 950 MW

TABLE-1

FORECAST OF WOOD/BIOMASS DEMAND – SUPPLY IN PAKISTAN

(000 t.o.e.)*

Province/Region	Year	Demand	Supply of			Surplus (+) or Deficit (–)
			Wood	Agricultural Waste.	Total	
NWFP	1980	159	171	74	245	+ 86
	1990	212	164	82	246	+ 34
	2000	283	149	97	246	– 37
FATA	1980	46	68	22	90	+ 44
	1990	63	65	27	92	+ 29
	2000	84	60	33	93	+ 9
FEDERAL CAPITAL ISLAMABAD	1980	4	1	4	5	+ 1
	1990	6	1	4	5	– 1
	2000	8	1	4	5	– 3
PUNJAB	1980	711	411	452	863	+ 152
	1990	953	370	493	863	– 90
	2000	1273	370	493	863	– 410
SIND	1980	265	281	222	503	+ 238
	1990	359	266	237	503	+ 144
	2000	474	266	237	503	+ 29
BALUCHISTAN	1980	39	729	69	798	+ 759
	1990	73	729	69	798	+ 725
	2000	69	729	69	798	+ 729
TOTAL :	1980	1,224	1,661	843	2,504	+ 1280
	1990	1,667	1,595	912	2,507	+ 840
	2000	2,191	1,575	933	2,508	+ 317

Source: ADB Energy Survey Report, 1982.

*1 t.o.e. (ton of oil equivalent) = 39.68 million Btu.

* @ Conversion efficiency = 16%.

In view of these findings, it is felt that the use of 'Biomass Energy Plants' should be systematically promoted, particularly in those rural areas where the Biomass wastes and animal dung are abundantly available to fulfil the need of sustained requirements for power generation. The Government should give subsidies for this purpose on the same principle on which initially subsidies were given for fertilizers. Banks should also be induced to give loans to farmers for the installation of Biomass plants.

2.2 Wind Energy

Wind is a free-occuring natural form of diffused energy available on earth. According to World Energy Conference, the total power of the wind in the entire atmosphere is estimated to be about 2600×10^{12} million KWh per year, of which about one quarter is over the land.

The power extracted from the wind is given by the formula;

P (KW) $= 0.00035\ n\ AV^3$, where

A = Area in m^2 swept by the turbine blades

V = Wind speed in m/sec.

n = Efficiency of the system ($\leqslant 0.6$)

Wind mills have been used from time immemorial for providing mechanical energy. Commercially well-designed windmills are available in the market. The cost of a reciprocating cylinder pump with capacity to deliver upto several hundred gallons of water per hour, depending on the depth of the well, the diameter of the pump cylinder and wind velocity, ranges from U.S.$ 400 to U.S.$ 1200, excluding the cost of tower. Besides, high costs, windmills have many maintenance problems.

Generation of electricity from wind power can be done competitively through the use of a wide selection of commercially available systems. That is why wind power is finding greater application in the present days for use even by large electricity generating utilities, including CEGB, England, who commissioned their first 200 kw unit at Carmarthen Bay, in 1982.

The wind generators of 50 to 100 KW, particularly suitable for our rural areas, are very easy to get in the international market. Such generators become significantly cheaper than solar photovoltaic system (Refer Para 2.3.2) for similar duties, with mean wind speeds exceeding 4.5 m/sec. The 3.0 to 4.5 m/sec. range is a 'Grey Area' for which other factors must be weighed in choosing between solar and wind systems. The estimated cost of energy generated through wind will be around Rs. 1.11/KWh, which is slightly higher than that generated through 'Biomass Combustion System.'

Average wind intensity is generally much higher in coastal regions than inlands. In view of limited coastal areas in Pakistan and the prevailing wind conditions, the use of wind energy may find application mostly in the lower Sind and the coastal areas of Baluchistan only.

2.3 Solar Energy

Solar Energy is considered, at present, a very promising and limitless sources for meeting the energy requirements in remote rural areas. Solar power could also eliminate most of the serious environmental problems associated with fossil fuels because chemical air pollution could be minimized.

Pakistan lies entirely in the high solar radiation belt between 40°N and 40°S and has abundance of sunshine throughout the year. Studies show that solar energy received in the country is around 2000 KWh/m^2 during the whole year. There are two primary solar energy conversion techniques, thermal and photovoltaic.

2.3.1 Solar Thermal System

This system employs conversion of sun's radiations into useful heat. It essentially needs a collector device that can concentrate the Solar Radiations to temperatures of about 300°C and a heat transmission system which could transfer the heat collected. The collector device can be employed for cooking and water heating.

Most of the low-cost solar cookers are based on concentrating solar radiations with locally fabricated parabolic devices at the focal centre of which the cooking utensils could be kept for heating. However, such cookers are not generally acceptable to the rural population as the cooking has to be done in the open when sunlight is available.

The solar energy can find greater application for water heating. The flat plate collectors capable of delivering heat upto 100°C – 120°C are mounted on the roof tops and the heated water is stored in an insulated tank. Solar water heaters with 30-50 gallons water storage capacity are now commercially available at a reasonable price of Rs. 2,500-4,000 and finding greater application for domestic use.

2.3.2 Solar Photovoltaic System

A Solar Photovoltaic Cell for electrical power is made of a single crystal of silicon into which a doping material is diffused to form a semi-conductor that generates electricity when it absorbs light. As photons are received, free electrical charges are generated that can be collected on contacts applied to the surface of silicon cell. Because solar cells are not heat engines, and therefore, do not need to operate at high temperatures, they are adapted to the weak energy flux of solar radiations. The operating efficiency of this system is about 12 to 15% and decreases fairly rapidly with increasing temperatures. Each cell produces typically 0.3 to 0.7 volts at maximum power.

The electric energy produced by photovoltaic cells is stored by means of batteries, and whenever electricity is needed as alternating current, for ordinary motors, or electric devices, etc., necessary equipment is to be provided to convert DC into AC power. (Refer Schematic diagram at Fig-2). This conversion is costly both in terms of capital expenditure and power dissipation.

Though silicon is one of the earth's most abundant material, it is expensive to extract (from sand) and refine to the purity required for solar cells. The great barrier to solar cell application lies in the prevailing cost of the cells themselves (U.S. $ 7 per watt). There are signs that the price is ready to drop in the coming years through expansion in production of mono-crystalline silicon cells, more competition, better manufacturing techniques etc.

Economic studies recently carried out for rural areas in Pakistan show that, at present, solar plants, because of their high costs, are not competitive when compared with conventional sources of energy. But in the near future (say within 5-10 years) these plants may become economically feasible because of lowerng of their costs and because of the

increase of the prices of conventional energy sources, particularly the fossil fuels. It has been estimated that the energy generated through solar photovoltaic system, at present, costs Rs. 5.06/KWh, which is exhorbitantly high, as compared to other available sources.

In order to assess the economic viability of village electrification through photovoltaic solar system, a study in comparison with the power supply from existing WAPDA network has been made and is presented in Appendix-2. The comparison shows that the annual fixed and maintenance costs for the two alternatives become equal when the distance of the villages is about 48 Km from the existing network of WAPDA beyond which electrification from solar photovoltaic system is economical.

2.4 Mini — Hydro Energy

A considerable potential of mini-hydro power is available in the mountainous regions of NWFP Province and on the irrigation canals in Punjab Province where sufficient water and feasible water-heads are available. It has been estimated that several thousand megawatts of power can be commercially tapped from mini-hydro potential at a number of locations in Pakistan. The cost of a mini-hydro station would consist of the cost of constructing a dam across the water-way so as to regulate its water supply, the cost of water conveyor system and the cost of the turbine-generator. Recent studies show that the capital cost of mini-hydro power plants, in Pakistan, is around U.S. $ 1800/KW. The economics of mini-hydro power generation would improve considerably for plants constructed on the irrigation canals from which, by simple civil works water could be diverted for hydro-generation. The cost of such plants would be about U.S. $ 1200/KW. Mini-hydro stations do not generally require water storage facilities as in most locations the water flow is available when electricity is required. Mini-hydro also has the advantage that once the project is constructed, the operation of the plant requires no great technical skill. In many remote locations in the northern mountainous areas of NWFP Province, mini-hydro system could be the only decentralized energy source. The cost per kwh generated through Mini-Hydro Plants would vary from Re. 0.63 to 0.95, depending upon the location of the Plant. (Refer Appendix-3).

Mini-hydro, on the basis of current technologies, is a promising and economically viable option as a renewable energy source in Pakistan. The Government of Pakistan is already aware of this fact and a number of new sites with total installed capacity of about 400 MW are being commercially developed till the year 1996. Further investigations and studies are necessary to identify larger number of techno-economically feasible sites, in the northern areas of NWFP Province, and on the irrigation canals, in the Punjab.

3. COST PER KWH GENERATED FROM DIFFERENT ENERGY SOURCES

A cost comparison of electrical energy which can be generated through different available renewable energy options, particularly for rural areas in Pakistan, is presented in Appendix-3. The results are summarized in Table-2.

TABLE-2

COST PER KWH GENERATED

ENERGY SOURCE	COST OF ELECTRICAL ENERGY GENERATED
Non-Renewable (Conventional).	
– Diesel Engines	Rs. 2.12/KWh
Renewable Sources.	
– Biogas	Rs. 1.32/KWh
– Biomass Combustion	Re. 1.00/KWh
– Wind	Rs. 1.11/KWh
– Solar (Photovoltaic).	Rs. 5.06/KWh
– Mini-Hydro (Remote Sites)	Re. 0.95/KWh
(On Canals)	Re. 0.63/KWh

It is evident that 'Mini-Hydro' offers the cheapest source of renewable energy in Pakistan. Vigorous efforts are to be made to exploit, this potential wherever found feasible. The next most promising option is the utilisation of Biogas/Biomass potential which offers a considerable source of energy at very reasonable costs. Wind energy, although a competitive source, can find application in the coastal areas only. It is strongly felt that every possible effort is to be made to usefully exploit the various renewable energy options available, without delay, to supplement the existing sources of energy so as to bridge the gap between the Supply and Demand of energy in the country.

4. CONCLUSIONS

To sum up, we conclude that:

4.1 Rapid rural development is very necessary for overall economic growth of the country which necessitates the fulfilment of energy needs of the rural areas. It has been estimated that additional electrical energy needs of our rural areas are increasing by about 415 million KWh every year. It means, during the next 6 years, about 2,500 million KWh of electrical energy is required for rural areas alone, corresponding to a power of 600 MW.

4.2 In the wake of acute energy crisis prevailing in Pakistan, the available renewable energy sources are ought to be commercially exploited, on merits, to supplement the existing conventional resources which are badly falling short of the increasing energy demands.

4.3 'Mini-Hydro' offers the cheapest source of renewable energy in Pakistan. Although a number of mini/micro hydro-sites are already being developed by the Government of Pakistan, yet further investigations and studies are urgently required to identify and commercially exploit a large number of prospective sites, especially in the northern areas of NWFP Province and on the canals in Punjab.

4.4 'Biogas' offers a considerable source of energy in Pakistan at very reasonable costs. There is a potential of producing about 15 million cubic metre of gas per day which is sufficient for about 45 lacs rural families, apart from producing about 40 million tonnes

of wet manure annually. Even if half of the total biogas is used for power generation, it can produce about 3,600 million KWh of electrical energy every year (or 815 MW of power).

4.5 Power generation from direct combustion of biomass fuel e.g. wood chips, saw dust, rice husks, barks, cotton bolls, nut-shells, bagasse, straws or virtually any organic combustible material, through the 'Biomass Energy System' should be systematically promoted, particularly in those rural areas where Biomass wastes are abundantly available. After meeting the fuelwood needs in the rural areas, about 600 million KWh of energy each year can be generated from the remaining quantity of Biomass upto the year 2000, corresponding to a power of about 135MW – which is nearly equal to the installed capacity of the existing Nuclear Power Plant in Karachi!

4.6 The Biomass Energy Plants, both based on Biogas as well as Biomass Direct Combustion should be systematically promoted in the rural areas. This will reduce dependence on imported fuel oils, resulting in substantial saving of foreign exchange. The Government of Pakistan should give subsidies for this purpose and the Banks should also be induced to give loans to the farmers for the installation of Biogas/Biomass Plants on large scale.

4.7 The use of wind energy, though very competitive is envisaged mostly in the Lower Sind and the coastal areas of Baluchistan only and thus finds a limited application.

4.8 'Solar Thermal System' for domestic water heating should be encouraged. 30-50 gallon capacity solar water heaters are now available at competitive costs.

4.9 'Solar Photovoltaic System' for power supply in rural areas is not feasible, at the moment, but is likely to become competitive within a period of next 5-10 years because of the expected decrease in solar cell prices and relatively higher prices of fossible fuels.

4.10 'Solar Photovoltaic System' can, however, be utilised (if utmost necessary and when other renewable sources are not available) for electrification of those remote villages which are at a distance of 48 Km or more, from the existing integrated electricity network.

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APPENDIX-1

COST PER KWH GENERATED, DIESEL VS BIOMASS ENERGY SYSTEM

			Diesel-Generating System.	Biomass Combustion System
Comparison Factors				
–	Engine Rating.	:	30KW (Maximum)	30KW
–	2-Hour Overload	:	Not Advised	38KW (Maximum)
–	Fuel	:	Light Diesel Oil	Any Organic Combustible matter.
–	Calorific Value (BTU/Kg)	:	40,474	16,000 (Average)
–	Fuel Cost per Kg.	:	$ 0.30	$ 0.003
Operating Factors				
1.	Installed Cost	:	$ 13,000	$ 35,000
2.	Service Life of Plant (Year).	:	15	25
3.	Annual Capital charge* with 12% interest rate.	:	$ 1,872	$ 4,445
4.	B.T.U./Hr at full plant Capacity	:	341,200 **	639,750***
5.	Fuel Kg/Hr at full load.	:	8.43	39.98
6.	Fuel Kg/Year @ 50% Annual Load Factor.	:	36,923	1,75,112
7.	Fuel Cost per Kg.	:	$ 0.30	$ 0.003
8.	Fuel Cost per Year.	:	$ 11,077	$ 525
9.	Lubricants etc.	:	$ 2,200	$ 800
10.	Operation & Maintenance Cost per year.	:	$ 1,250	$ 2,000
11.	Total Annual Costs (3) + (8) + (9) + (10).	:	$ 16,399	$ 7,770
12.	KWh Generated per year @ 50% Load Factor.	:	131,400	$ 131,400
13.	Cost/KWh Generated.	:	$ 0.125	$ 0.059
		:	(Rs. 2.12)	(Re. 1.00)

* With Plant Residual Value : 10%

** Engine to Busbar efficiency. : 30%

*** Boiler to Busbar efficiency. : 16%

Exchange Rate 1 U.S. $ = Rs. 17.00

APPENDIX-2

COST COMPARISON FOR RURAL ELECTRIFICATION THRU SOLAR PHOTO-VOLTAIC SYSTEM VS WAPDA NETWORK

A. SOLAR PHOTOVOLTAIC (PV) SYSTEM

1.	Installed Power of the System	:	30 KW
2.	**PV Cells Cost:**		
i).	Material Cost @ 7 $/watt.	:	$ 210,000
ii).	Transportation & Erection @ 15%.	:	$ 31,500
iii).	Civil Works incl. battery room etc.	:	$ 6,000
	Sub-Total	:	$ 247,500
iv).	System Service Life.	:	40 years.
v).	Annual Capital Charge* @ 12% interest rate	:	$ 29,948 ..... (a)
3.	Storage Battery Cost:		
i).	Cost of storage battery, incl. charge regulator etc.:		$ 45,000
ii)	Transportation & Erection @ 15%.	:	$ 6,750
	Sub-Total	:	$ 51,750
iii)	Service Life	:	8 years
iv).	Annual Capital Charge @ 12% interest rate.	:	$ 8,125 ..... (b)
4.	Total Annual Capital Cost (a) + (b).	:	$ 38,073
5.	Operation & Maintenance Cost.	:	$ 1,000
	Total Annual Cost (4) + (5)	:	$ 39,073 ..... (c)
6.	Annual Energy Generated with 50% Load Factor.	:	$ 131,400 KWH
7.	Cost per KWh Generated (c)/(6)	:	$ 0.2974 (= Rs.5.06)/KWh).

*With Plant Residual Value: 10%
Exchange Rate: 1 U.S.$ = Rs. 17.00

B. SUPPLY FROM WAPDA NETWORK

Let the village be 'x' Km from the existing WAPDA Network.

i)	Cost of 'x' Km of 11KV lines @ $ 3,900 per Km	:	$ 3,900 x
ii)	Cost of Step-down Transformer Substation, 11/0.4KV, 50KVA.	:	$ 2,200
	Sub-Total	:	$ (3900x + 2200)..... (a)
iii)	With Construction & Erection Cost etc. @ 26.5% of (a), total cost.	:	1.265(3900x + 2200)
iv)	Service Life of the equipment.	:	25 years.
v)	Annual Capital Charge* @ 12% interest rate.	:	$ 0.142 x1.265(3900x + 2200) = 0.18 (3,900x + 2,200) ..... (b)
vi)	Annual Energy requirement.	:	131,400 KWh.
vii)	Average Cost of Energy Supply by WAPDA @ $ 0.0365 per KWh.	:	$ 4,796 ..... (c)
viii)	Total Annual Cost (b) + (c).	:	$ 0.18 (3900x+2200)+4,796

C. FOR BREAK EVEN ANNUAL COST

Annual Cost with WAPDA Network. = Annual Cost with Solar Photovoltaic System

0.18(3,900x + 2,200) + 4,796 = 39,073

from where x = 48 Km.

D. CONCLUSION

This means that in order to electrifiy a villages, which is away from the existing power supply network of WAPDA by 48 Km or more, it is economically more feasible to supply it from 'Solar Photovoltaic System' rather than electrifying it by extending the power lines from the existing WAPDA Network.

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* With Plant Residual Value : 10%

& Operation and Maintenance Cost : 1.5%

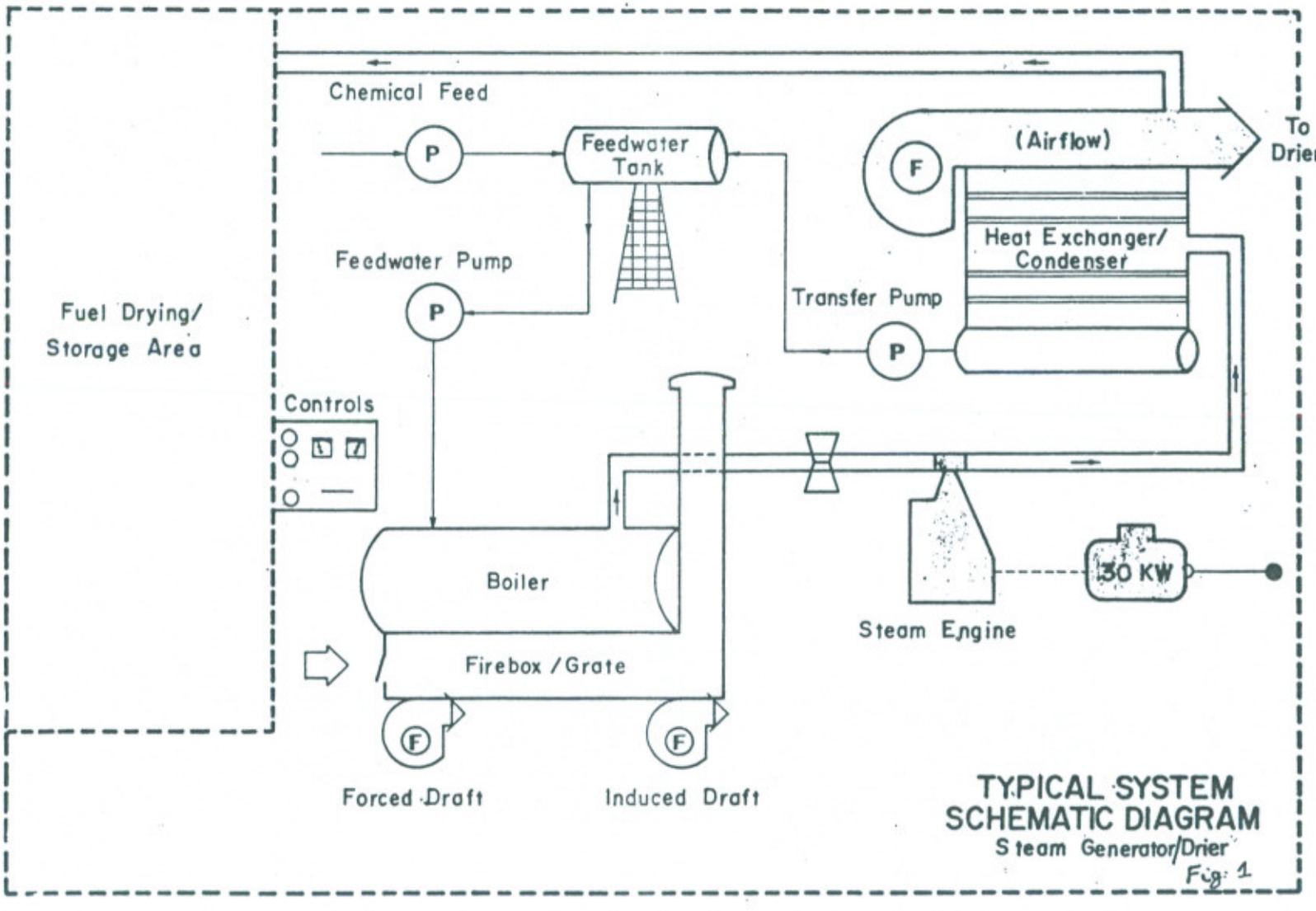
APPENDIX-3

COMPARISON OF COST PER KWH GENERATED THROUGH DIFFERENT SOURCES OF ENERGY

				Biomass				Mini-Hydro	
			Diesel	Biogas	Biomass Combustion	Wind	Solar (Photovoltaic)	Remote Sites	On Canals
1.	Installed Cost	($/KW) :	433	1,550	1,167	1,500	10,500	1,800	1,200
2.	Economic Plant Life	(Years) :	15	15	25	10	40	40	40
3.	Annual Capital Charges*	($) :	62.4	233.3	148.2	256.9	1,270.5	217.8	145.2
4.	Annual Fuel Costs	($) :	442.6	75.0	44.2	–	–	–	–
5.	Annual Operation & Maintenance Costs	($) :	41.7	41.7	66.7	30.0	33.3	27.0	18.0
6.	Total Annual Costs (3) + (4) + (5).	($) :	546.7	340.0	259.1	286.9	1303.8	244.8	163.2
7.	Annual Load Factor	(%) :	50	50	50	50	50	50	50
8.	Cost of Energy Generated	($/KWh) :	0.125	0.078	0.059	0.066	0.298	0.0559	0.0373
		(Rs./KWh) :	2.12	1.32	1.00	1.11	5.06	0.95	0.63

* @ 12% annual interest rate and a plant residual value of 10%.

Exchange Rate: 1 U.S. $ = 17.00 PAK RUPEES.

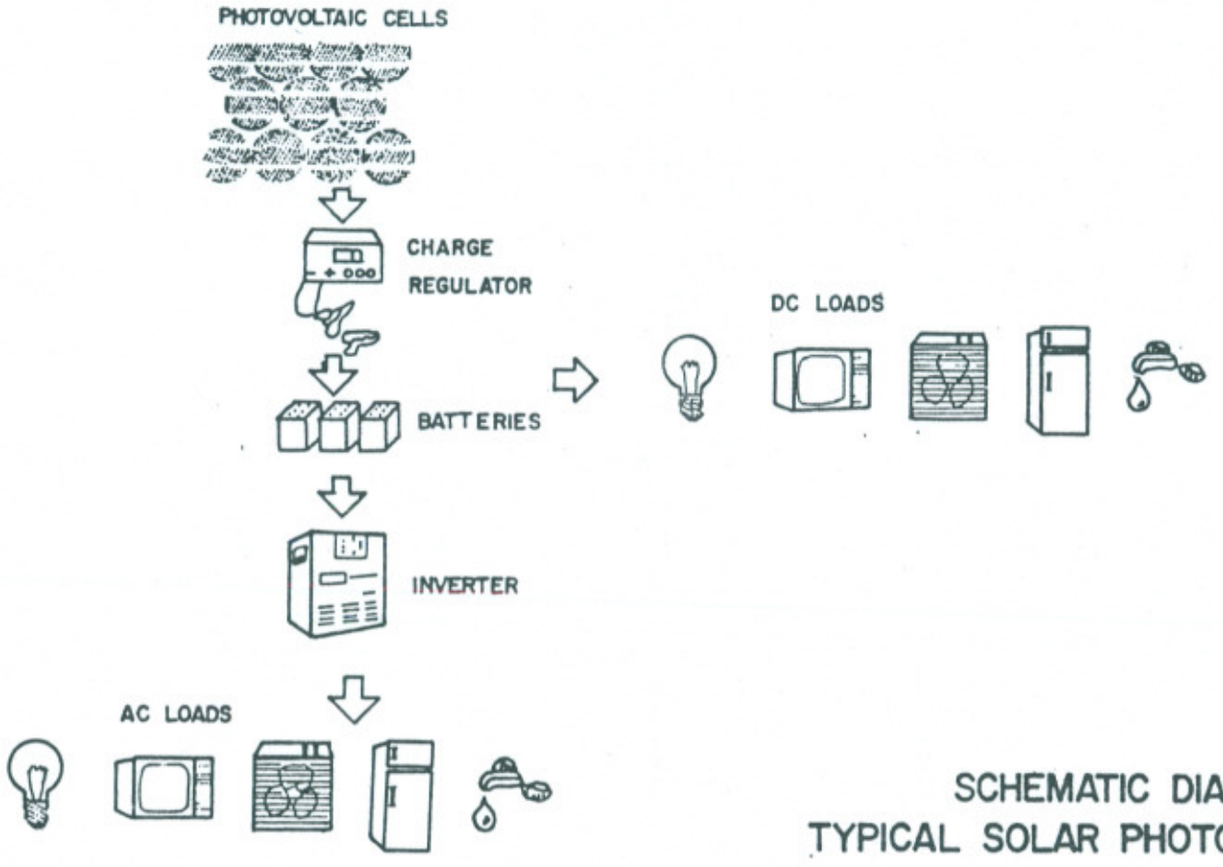


TYPICAL SYSTEM SCHEMATIC DIAGRAM

Steam Generator/Drier

Fig: 1

MUSHTAQ AHMAD BHATTI



SCHEMATIC DIAGRAM FOR A
TYPICAL SOLAR PHOTOVOLTAIC SYSTEM

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FIG - 2