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Renewable Sources of Energy in Pakistan

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This paper has been divided into three parts. Part I sets the background of energy for development and some features of the Pakistan situation. Part II shows the need for renewable sources and introduces their likely contribution in the near future (2,000 A.D.). In the third part, we examine the various renewable sources of energy to obtain estimates of their economics and give broad recommendations.

I

One of the most dramatic features of the technological revolution has been the rapidly increasing dependence of all human activities on energy, so much so that the modern way of life has been called the "Energy-Intensive Culture". Increased productivity per capita naturally requires more work and therefore higher energy inputs for each person. It is therefore understandable that higher per capita GDP should be associated with higher per capita energy consumption, which is often used as an indicator of development, cf. the initial linear part of Fig. 1. Of course there will be some individual variations, as seen in Fig. 1, due to various types of activity, but what is worrisome is the steep rise beyond the middle of the curve, perhaps indicating highly wasteful energy use.

The developed nations of the world consume four-fifths of the world's fossil fuels and electricity. In sharp contrast, the more or less neglected people of the developing countries of the world have an extremely difficult present and a bleak future, largely because they are poor in energy. This is borne out by the fact that countries at the lower end of energy consumption in Fig. 1 are lacking in large-scale industrialization and adequate food, housing, transportation, sanitation, and medicare and have low productivity in terms of agriculture, minerals and industrial commodities.

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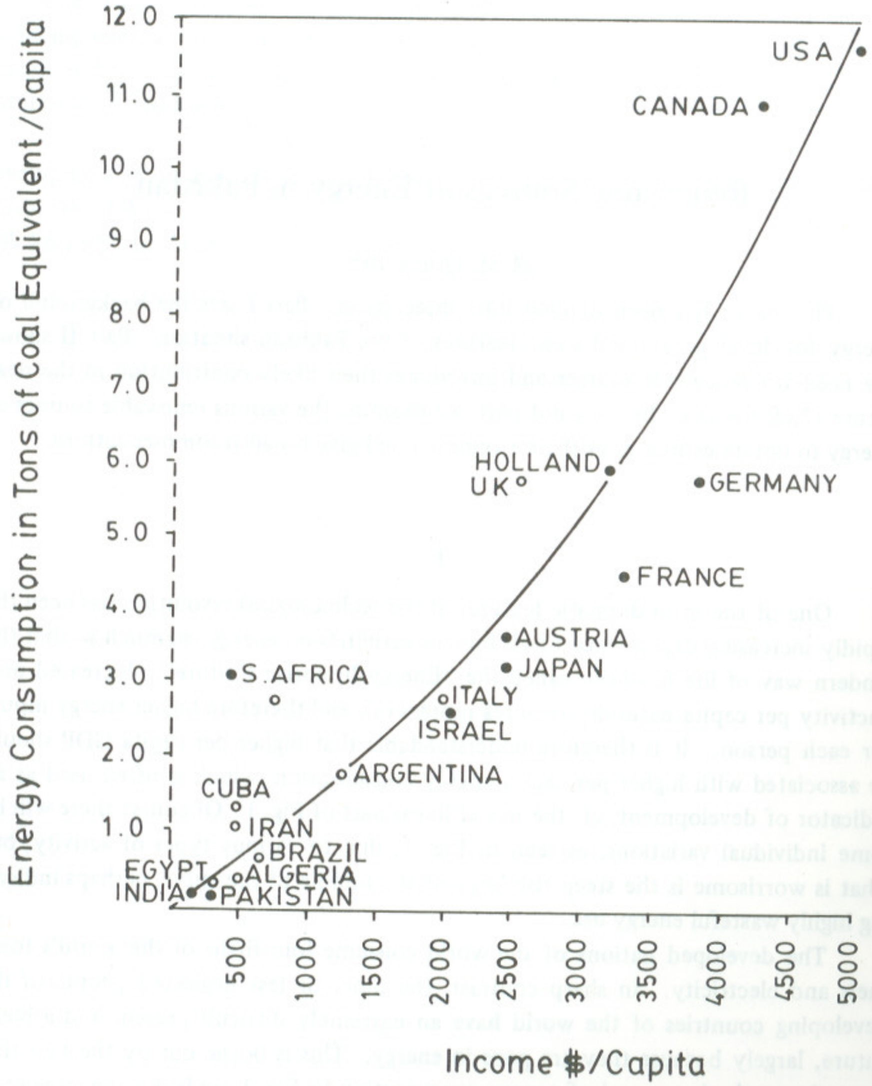

Fig. 1. Energy Consumption versus per capita Income for Various Countries (1972-DATA)

The energy picture of the world suffered a very drastic change towards the end of 1973 when the oil-producing countries decided to increase the price of crude oil by a factor of five from 2 dollars to 10 dollars per barrel. The economic development of developing countries has since then been greatly hampered by the ever-increasing prices of oil; see Fig. 2, which shows that whereas in 1960 the oil prices were well below the cost-of-living curve, they were well above it in the late Seventies.

Power inputs are needed for nearly all agricultural and industrial development. For the developing countries generally, the effect of higher oil prices has been to make it difficult and, in some cases, nearly impossible to overcome power shortages by importing cheap oil, as they did in the past. In the long term, the only real bottleneck preventing development is shortage of energy.

Estimates of probable cumulative world energy consumption are shown graphically in Fig. 3, where the upper and lower curves are for the two extreme cases [5, p. 186] of the so-called "High Scenario" and the "Low Scenario". Both indicate a total depletion of these fossil fuels by the middle of the 21st century A.D.

There are two main strategies being considered at the moment: (a) The first alternative, the so-called *Hard Path,* is based on the theory of 'demand accommodation', while (b) the other option – the 'Soft Path' – involves radical change at the earliest opportunity. This has two aspects, viz. 'substitution' and 'shift'. Examination of Fig. 3 shows that as oil drops off, the use of coal-based synthetic fuels would rise sharply. This is essentially a case of fuel substitution. Secondly, as far as possible, there would be a shift away from consumption of energy from non-renewable sources, such as coal and firewood, to increasing use of wind power, tidal power, and biogas, solar and geothermal energy. This shift has to be of a magnitude that will fully take care of all the increases in future consumption from non-renewable sources. (This is the 'shift' aspect.)

The total energy consumption may still remain at the present levels or may even continue to grow; but the gap should be filled by other sources, namely nuclear power and renewable sources of energy, like hydro, biomass, solar and wind energy.

Ideally, the developing countries should themselves take the necessary steps However, at the moment they have neither the motivation, nor the capital resources. In this setting, it is for the industrial world to come forth to help the Third World to slow down and change direction by developing renewable sources of appropriate energy technologies and their adoption. (The industrial world has the capital, sophisticated know-how and indeed the R & D resources for a Renewable Energy base for different Third World areas.) In this way, it would be possible to mobilize indigenous new and renewable energy sources hitherto poorly utilized; solar energy; wind; geothermal energy, biomass and liquid fuels manufactured from biomass-ethanol, methanol, vegetable oils; tide & wave energy; ocean and thermal energy.

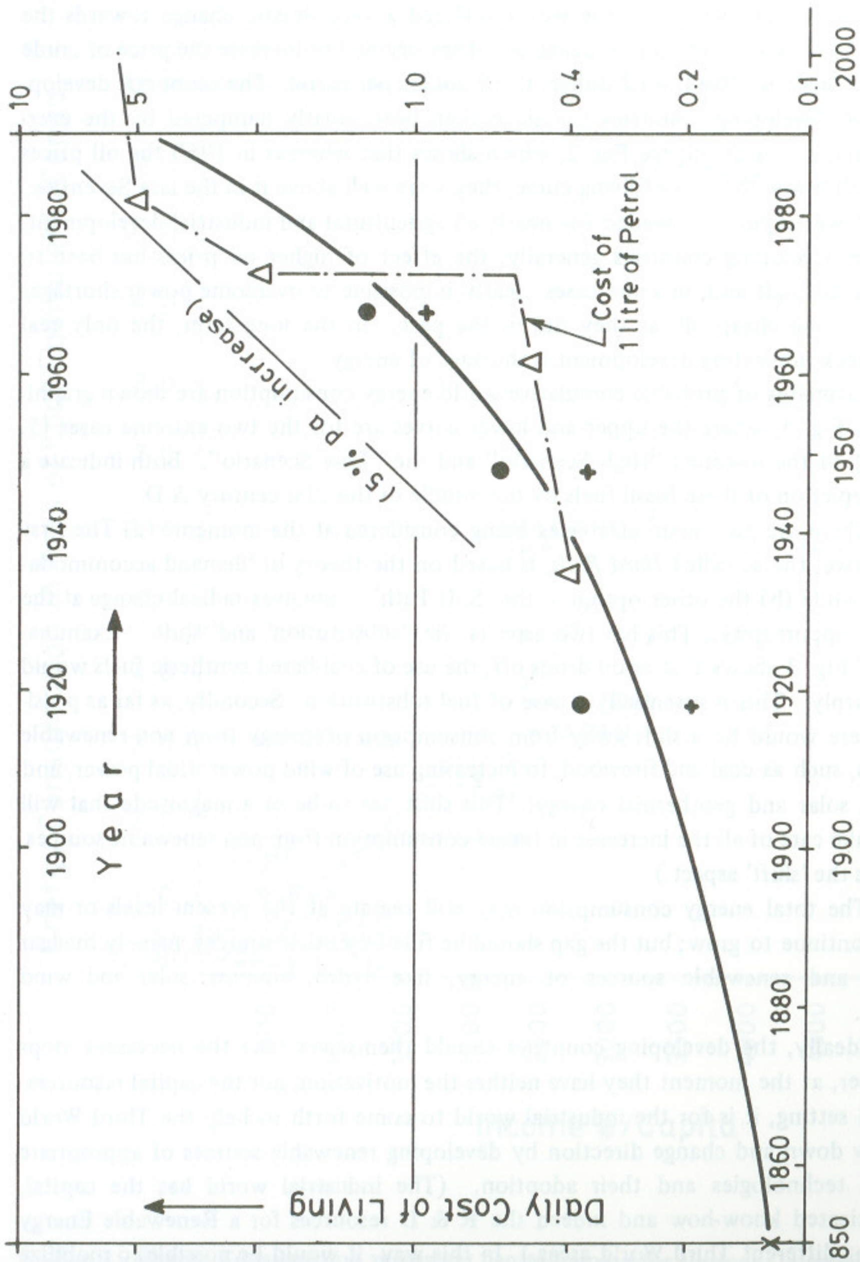
Daily Cost of Living
Year
(5% pa incrrease)
Cost of
1 litre of Petrol
10
5
1.0
0.4
0.2
0.1
1850
1860
1880
1900
1920
1940
1950
1960
1980
2000

Fig. 2

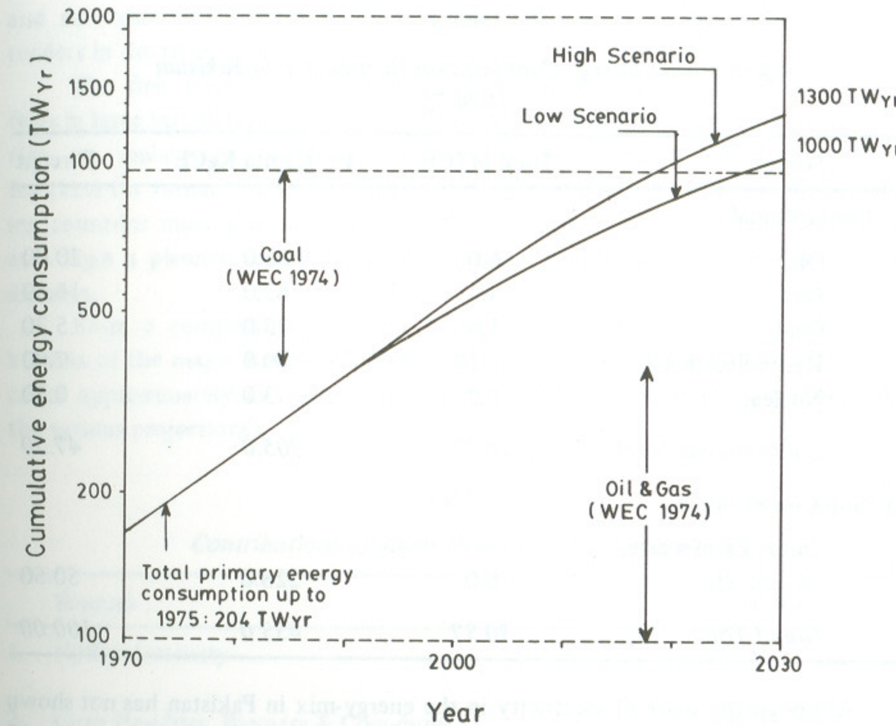
Cumulative energy consumption (TWYr)
High Scenario
Low Scenario
1300 TWYr
1000 TWYr
Coal
(WEC 1974)
Oil & Gas
(WEC 1974)
Total primary energy
consumption up to
1975 : 204 TWYr
2000
1500
1000
500
200
100
1970
2000
2030
Year

Fig. 3

The Pakistan Situation

The energy pattern in Pakistan has undergone a change since the advent of natural gas: utilization of coal, which was nearly 40 percent or more prior to the use of Sui natural gas, has gone down to less than 5 percent of the total energy consumption of conventional fuels (Table 1 for 1974-75).

Table 1

Source-wise Energy Consumption Distribution in Pakistan 1974-75

Source	Total MTCE	Per Capita KgCE	Percent
(i) Conventional			
Oil	6.0	86.0	20.00
Gas	4.4	63.0	14.50
Coal	1.6	23.0	5.30
Hydroelectricity	2.17	30.0	7.00
Nuclear	0.2	3.0	0.70
Conventional Total:	*14.37*	*205.0*	*47.50*
(ii) Non-Conventional			
Dung, Farm waste, wood, etc.	16.0	228.0	50.50
Grand Total:	*30.37*	*433.0*	*100.00*

Although the share of electricity in the energy-mix in Pakistan has not shown any significant change over the last 16 years, the overall growth rate over the last 28 years in electricity consumption has been calculated at 15.9 percent per annum, while the growth rate between 1965 and 1976 was a little over 9 percent per annum, i.e. doubling every 8 years.

Today, the WAPDA generating system consists of a mix of hydel and thermal power stations, the total capacity of which is 4,000 MW, of which hydel represents 63 percent of the total. (This of course excludes the 132-MW KANUPP Power Reactor at Karachi.) The increase in total installed capacity represents an increase of 32 times in the past 23 years: power demand in the year 1960 was 131 MW and today it is more than 3,163 MW. Nevertheless, the overall energy situation is not a heppy one. Pakistan's a bleak position can be visualized from the fact that its per capita energy consumption at present is about 5 million BTU per annum, i.e. less than 0.3 tons of coal equivalent, a value only 1/10th of the world average at 2.0 TCE.

II

Even to achieve rather modest growth targets during the next 20 years, Pakistan would have to produce 25,000 MW of energy. This target will remain short by at least 10,000 MW, even when proven reserves of fossil fuels and about 6,000 MW of additional potential of hydro are pressed into service. It is this yawning gap that has got to be filled in, and efforts need to be intensified to introduce various renewable and non-renewable sources of energy; coal and nuclear energy being strong contenders in the latter category.

The first steps are of course *conservation,* i.e. more efficient use of fossil fuels in large installations as well as vehicles, and the careful use of ***inter-fuel substitution,*** e.g. replacement of oil by coal-based synthetic fuels or use of more suitable fractions for furnace oil and internal combustion engines. Nevertheless, the developing countries must plan now for a transition to a lesser dependence on fossil fuels, and begin a planned introduction of renewable energy sources over the next two decades.

From a comparative study of two different sets of projections, the contributions of the major Renewable Energy Sources to the total in 2,000 A.D. may be taken approximately as follows (the ranges given after ± represent the variations in the various projections):

Table 2

Contributions of Major Renewable Energy Sources

Sources	Contribution
1. Hydroelectricity	20% ± 10%
2. Crop Residues, Biomass & Cow-dung	8% ± 2%
3. Wind	7% ± 1%
4. Direct Solar Energy	6% ± 2%
5. Geothermal	5% ± 1%
6. Ocean Energy	2% ± 1%

It is seen that *hydroelectricity* would contribute almost as much as all the others put together in 2,000 A.D. and that geothermal and ocean energy would be relatively minor contributors. In the case of Pakistan, it is quite possible that the relative importance of items Nos. 2 and 4, i.e. Wind Energy and Direct Solar Energy, may be interchanged, because wind energy is usable mainly near coastal areas. Of course, the above tables do not include nuclear energy, which is in some ways a renewable source, i.e. in case of fusion energy and breeder reactors. Nuclear energy presently contributes about 4 percent of the world's energy consumption and is expected to contribute about 12 percent in the 1990s, when over 500 nuclear power reactors would possibly be in operation [9].

The fundamental issue involved in the efficient use of non-conventional energy sources is to bring about the integration of socio-economic changes with technological innovations, which should be essentially simple and easy to understand and easy to operate (and maintain) by the agrarian population, most of which is either illiterate or semi-literate.

III

With the above general picture of renewable energy resources for developing countries, we can now attempt some estimates of the economics of the more important renewables, with special reference to the situation in Pakistan. Reliable data are not available in all cases, and their projections even to the year 2,000 A.D. are fraught with numerous uncertainties. Nevertheless, it is not difficult to see that the first four, namely hydroelectricity, biomass, wind and direct solar energy deserve immediate attention. Accordingly, we give substantial data on these four, followed by a brief account of the position of geothermal and ocean energy. As already noted earlier, the world-wide projections show that of all the renewables taken together, 20–30 percent contribution in 2,000 A.D. would come from hydroelectricity. The position in Pakistan is described below for the four most significant renewables, viz. hydro, biomass, solar energy and wind energy.

a. Hydropower

(i) The edge of Hydroelectricity over the others has today increased somewhat rapidly as a result of increased costs of fossil fuels [1;3], as shown in Table 3.

Table 3

Comparison of Present and 1970 Costs of Electricity Generation by various methods (paisas/kWh) – paisa ≃ 1.3 mil = 0.13 cent.

Years	Hydel	Gas-fired	Coal-fired	Diesel	Nuclear
1970	0.9	4.1	5.2	10.2	(7)
1980–82	3	30	150	170	(~60)

Thus, the overall cost of generation averages around 30 paisas/kWh. The transmission, distribution and overheads add nearly another 25 paisas/kWh to the above, thus bringing the average cost of electricity supply to about 55 paisas (i.e. nearly 40 mils/kWh) in the cities and towns.

(ii) *Mini-Hydels:* Small power houses of 50–500KW capacity are of great significance for towns in the far-away hilly areas of the country where it would not be easy or economical to take the National Electricity Grid, but where sizeable streams or rivulets provide hydel potential of up to 1 Megawatt (1,000 kW) at each site. The generation costs with these so-called "mini-hydel" plants are, of course, greater than those indicated in Table 3 by a factor of 3 to 5, because of increased capital costs per kW installed [3], but this is more or less offset *by* the relatively lower costs of transmission lines etc. in the case of units of 50 to 200 kW, provided the organization is run on an efficient co-operative basis.

(iii) Another attractive concept is that of *"micro-hydel" units* of 1 to 20kW put up on a self-help, co-operative basis in far-flung villages [8] of Pakistan, the cost reduction being achieved by using a simple locally manufactured (Banki) turbine and local resources for its installation, construction of power-channel penstock and transmission/distribution lines. The capital costs run around Rs. 2,000 to 10,000 per kW installed and the analysis for a typical 12.5 kW generator put up in 1977 at Lillowni on the Indus Valley highway shows that the net cost of electricity supplied was Rs. 0.45 i.e. 40 mils per kWh. Hundreds of suitable sites are available and await the installation of micro-hydel units.

b. Biomass

Biogas: A family-sized unit based on 3 to 5 animals (i.e. 50 to 80 Kg of wet dung/day) costs between Rs. 4,000 and Rs. 8,000, depending on design and location [8]. The waste from only half of the 60 million animals (cows, buffaloes and goats/sheep) in Pakistan, could provide 600 million cu. ft. of biogas/day, giving 400 thousand million BTU/day, i.e. 150×10^{12} BTU/annum, i.e. 8 million tons coal equivalent, or approximately one-half of the total consumption of non-commercial fuels in Pakistan today.

The family size plant gives us about 70 cu. ft. of biogas containing 60 percent of methane, which corresponds to 2 Kg coal, normally costing Rs. 3, or Rs. 5 in the form of Kerosene today. At this rate, the initial investment can be recovered in three to four years. Two difficulties in popularizing biogas technology are (i) capital, and (ii) the messy nature of the inputs.

Ethanol by Fermentation: This is already being done in Brazil and some European countries. The energy balance of the fermentation processes is such that we can achieve a conversion of 70 to 80 percent of the available energy [6;7], and the product can thus sell at half the price of petrol. However, in many developing countries, the primary input, viz. sugarcane or corn, has a competing use as food.

c. Solar Energy

(i) *Solar Cells (Photo-voltaic generation of electricity)*

This high-technology, high capital-investment industry is currently unsuited for manufacture in most of the developing countries. Prototype generators are now available in various capacities up to 10 kW and are undergoing field tests in a number of situations, many with the co-operation of UN agencies. The main problem is one of cost which currently is $ 2,500, i.e. Rs. 35,000 per kW. The price of a conventional silicon-cell is still falling, as the production increases, but has *not* yet reached the level ($ 300/kWe) where such generators can be regarded as economic; in comparison with other sources; see Fig. 4. Another problem is storage in order to tide over the periods when the sun does not shine.

It is seen that in terms of cost/kWh, the solar array at 300 mils/kWh currently compares with the diesel unit operating 60 percent of the time [7], and this small-scale diesel generation is 3 to 5 times as costly as ordinary electricity from the grid of large-scale generation. There has to be a good deal more R&D as well as testing, except for small power requirements of 1 to 2 KW in isolated locations, or for very special uses, such as communication.

(ii) *Solar Collectors*

An alternative method of utilizing solar energy is by directly trapping it with solar collectors. These are of various types and have many uses, such as water-heating, room-heating and cooling, water distillation, water-pumping and cooking.

Water-Heating: A typical solar water-heater is composed of 4 solar collectors with 250 litre storage [2]. The materials cost of the unit is about Rs. 5,000 and the labour cost is about Rs. 1,000. With a life of 10 years, the thermal energy provided would cost about Rs. 0.30/kWh, which can compete favourably with electric or oil-fired water-heaters.

Room Cooling/Heating: For cooling 3 rooms (4.25 x 4.25 x 3 m) for 6–8 hours in summer, $80m^2$ area of solar collectors with double glass are required. Heating in winter can be provided whole time, using these collectors with a hot-water storage system. The cost of solar collector is about Rs. 80,000/for $80m^2$ @ $1000/m^2$, which is expensive but would pay for itself in reduced energy bills over the life of the house.

Water-Distillation: A typical solar still may have an area of 10–15 m^2 for 15–60 litres. The cost of the unit is about Rs. 6,000 and, for an assumed life of 15

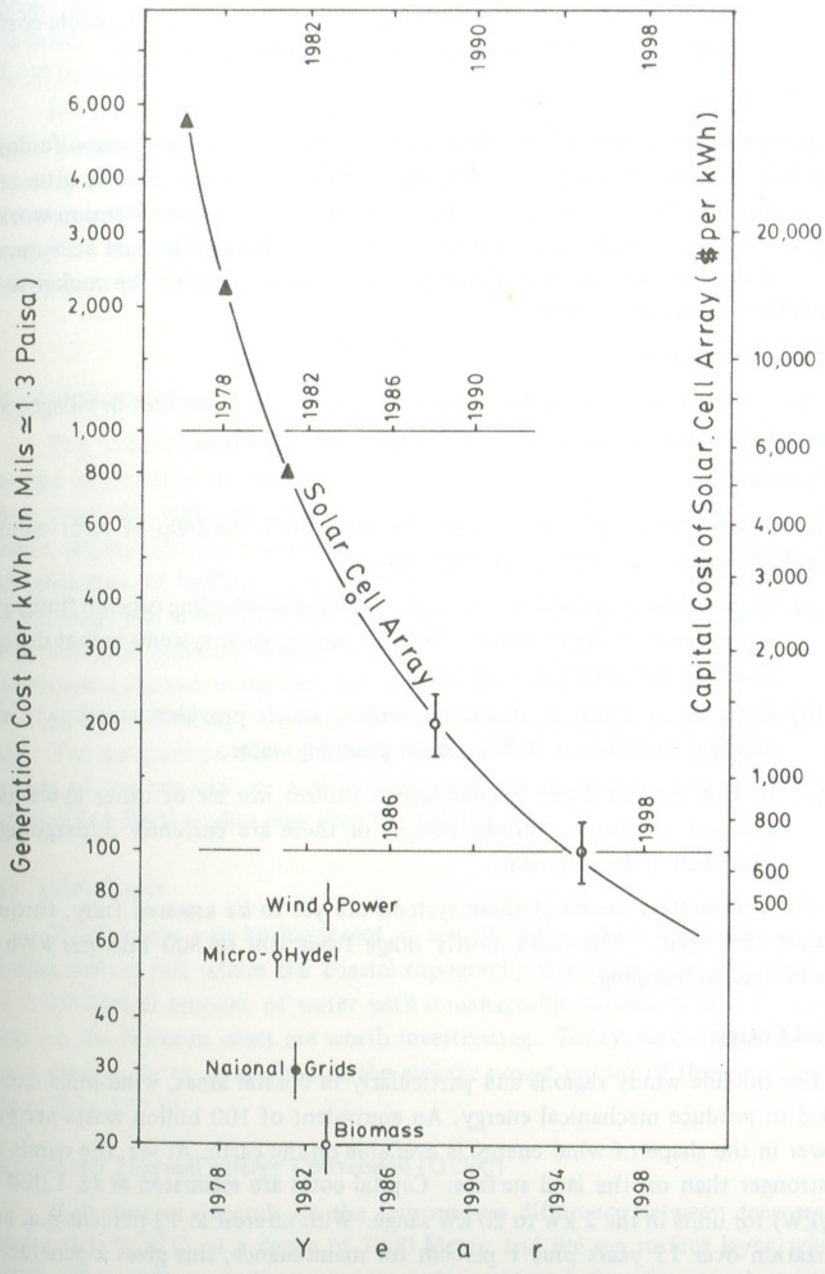

Fig. 4

years, the cost of distilled water works out to Rs. 0.034 per litre or Rs. 0.140 per gallon, which offers a good solution to provide potable water at a reasonable cost in remote or coastal areas where drinking water is not readily available [2].

(iii) *Solar Cooking*

The problems at present are that in the cheaper designs the housewife doing the cooking is also exposed to the sun, and that cooking is not possible after sun-down or even late in the evening. Considerable development and extension work is needed to overcome these drawbacks before solar cookers gain general acceptance; also a cheap heat-storage material needs to be developed to enable the cooker to be used when the sun is not shining.

(iv) *Solar Dehydration*

These units have considerable application for drying vegetables in villages and fruit in remote areas, which can then be packaged for marketing.

(v) *Solar Pumping*

There are several systems for pumping water with the help of solar energy. Among these, three of the more important ones are:

(a) With a thermodynamic-cycle engine, using a low-boiling organic fluid, and large area of Solar Collectors. Notable among such systems is that developed from the designs by Giradier.

(b) Using Solar Cells, as described earlier, which provides a compact and handy power unit of 1KW or so for pumping water.

(c) With a Stirling Cycle engine, which utilizes hot air or other gases as a working substance. Various designs of these are currently undergoing a good deal of development.

The comparative merits of these systems are yet to be assessed fully, through large-scale field trials. The costs mostly range from 100 to 300 mils per kWh of energy utilized in pumping.

d. Wind Energy

For suitable windy regions and particularly in coastal areas, wind-mills can be installed to produce mechanical energy. An equivalent of 100 billion watts per year of power in the shape of wind energy is available on the earth. At sea, the winds are even stronger than on the land surface. Capital costs are estimated at ($ 1,000 to 2,000/kW) for units in the 2 kW to 20 kW range. With interest at 12 percent p.a. and amortization over 15 years plus 1 percent for maintenance, this gives a generation cost of 80 mils/kWh at 40 percent utilization factor [6;7].

Direct windmill pumping has been experimented within Pakistan by WAPDA and A.T.D.O. As one cannot always depend on wind power being constant, the need for oil-generated power as a stand-by should always be kept in mind. The wind-power plant, if properly operated, can still result in a substantial saving of fuel. A wind-mill pump for irrigating several acres of land can be installed at a cost of Rs. 50,000 or so.

In localities with annual average wind speeds of more than 8 to 10 m.p.h., wind power could often compete with the alternative methods of power generation if the question of storage could be solved. The best way currently to solve this difficulty is to employ the power produced for some useful work with an inherent storage capability, e.g. water-pumping, water-heating, refrigeration. Water churns can efficiently convert mechanical power directly into heat.

Some Other Sources

(a) Geothermal Energy

The utilization of geothermal energy, from hot springs & underground streams, for the production of electricity and the supply of domestic and industrial heat dates from the early years of the twentieth century. Unlike fossil-fuel or nuclear-power production, geothermal energy is not a technology that requires massive infrastructure of facilities and equipment or large amounts of energy inputs. The capital costs run around $ 500,000 per M.W. and the electricity costs 15 mils/kWh. Both the total quantity of gases in the fluid and the relative concentration of their constituents depend on the geochemistry of the underground reservoir.

A planned survey of the geothermal potential of the country should be carried out. The programme should include collection and tabulation of data on the hot springs of the country, as well as analysis of the fluids produced by these springs. Appropriate R&D studies may then be initiated.

(b) Tidal Power

Tidal power can be harnessed at specific sites, where the tidal amplitude is several metres and where the coastal topography is such as to allow impoundment of a substantial amount of water with a manageable volume of civil works. Some sites on the Pakistan coast are worth investigating. Today, wave energy is only used on a small scale to power buoys; the average power output of these systems ranges from 70 to 120 W.

(c) Ocean Thermal Energy Conversion (OTEC)

The process depends on the temperature difference between deep sea layers, where it is 7–8° C at a depth of 1000 Meter, and the sea surface layer, where it is 30° C. This difference in temperature is employed to generate electricity. The technology of OTEC is based on the ocean's functioning as both absorber and heat sink for solar radiation. Capital costs are high; but if energy costs are compared, OTEC compares favourably with oil and is only slightly above the cost of coal and nuclear power generation [4]. Energy cost was estimated two years ago at 30 to 43 mils/kWh for OTEC-generated electricity versus 28 mils for nuclear, 36 mils for coal and 90 mils for oil.

The National Institute of Oceanography plans to undertake a survey of likely sites for OTEC plants off the Pakistan coasts.

Conclusions and Broad Recommendations

One may here consider the "struggle for existence" of the various energy forms, as seen by Cesare Marchetti of I.I.A.S.A. (see Fig. 5) as a general indication of global trends in the various energy technologies over the span 1850 up to 2100 A.D. This shows quite distinctly that, in the recent past, the useful span of any one fossil energy form has been of the order of 250 years, with an outstanding popularity over 50 years or so. A similar pattern is emerging for nuclear energy (peaking around 2020 A.D.) and appears likely for the newer renewable energy technologies, shown by the double line in the right hand part of Fig. 5. Thus, there has to be a more or less continuous effort for development of new renewable forms of energy.

To sum up the situation in Pakistan, the country would need to produce 25,000 M.W. in the year 2,000 A.D., as against a probable available total of 6,000 M.W. from fossil fuels and 9,000 M.W. from hydel. So, the target would remain short by about 10,000 M.W. and this gap has to be filled in with renewable energy sources, among which the most significant are mini- and micro-hydel, biomass, wind energy, and direct solar-energy conversion, because these technologies are at a stage where they can be more or less readily exploited in Pakistan.

The economics of the more promising technologies relative to the existing power resources in Pakistan, e.g. national grid, are given below in mils/kWh, where 1 mil = $ 0.001, i.e. 1.3 paisa:

1.	Micro-hydel units	60	±	10 mils/kWh	
2.	Wind Power	80	±	10 "	
3.	Biomass	About 20		" "	i.e. 3,300 BTU
4.	(a) Solar Collectors	30	–	100 " "	
	(b) Solar Cells Array	300	±	100 " "	
	Compare with National Grid.........			30–40 mil/kWh	

This shows that programmes for at least the first three should be undertaken in all seriousness, while the fourth be kept under constant review. The use of biomass and direct solar energy is particularly important in view of its significance for rural areas.

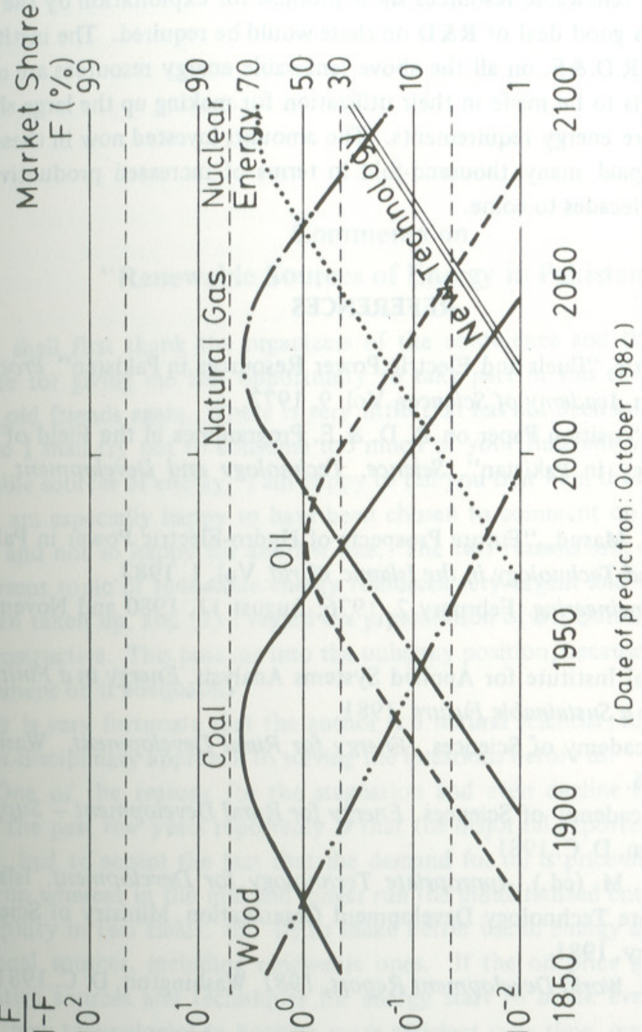

Fig. 5

Three other renewable resources show promise for exploitation by the turn of the century, but a good deal of R&D on these would be required. The institutional arrangements for R.D.&E. on all the above renewable energy resources are essential if rapid headway is to be made in their utilization for making up the large short-fall in Pakistan's future energy requirements. The amounts invested now in these activities would be repaid many thousand-fold in terms of increased productivity and prosperity in the decades to come.

REFERENCES

1. Ahmad, Nazir. "Fuels and Electric Power Resources in Pakistan". *Proceedings of Pakistan Academy of Sciences.* Vol. 9. 1972.
2. Aslam, M. "Position Paper on R. D. & E. Programmes in the Field of Renewable Energy in Pakistan". *Science, Technology and Development.* Vol. 2, No. 4.
3. Butt, M. H. Masud, "Future Prospects of Hydro-Electric Power in Pakistan". *Science and Technology in the Islamic World.* Vol. 1. 1983.
4. *Chemical Engineering.* February 2, 1976; August 11, 1980 and November 16, 1981.
5. International Institute for Applied Systems Analysis. *Energy in a Finite World – Paths to a Sustainable Future.* 1981.
6. National Academy of Sciences. *Energy for Rural Development.* Washington, D. C. 1976.
7. National Academy of Sciences. *Energy for Rural Development – Supplement.* Washington, D. C. 1981.
8. Qurashi, M. M (ed.). *Appropriate Technology for Development.* Islamabad: Appropriate Technology Development Organization, Ministry of Science and Technology. 1981.
9. World Bank. *World Development Report, 1981.* Washington, D. C. 1981.

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Comments on "Renewable Sources of Energy in Pakistan"

I shall first thank the organizers of the conference and the Director of the Institute for giving me this opportunity to take part in this conference and to be among old friends again. There is very little that has not been said during these few days; so I shall try not to consume too much of your time and your – hopefully – renewable sources of energy. I am happy to tell you that I am the last speaker.

I am especially happy to have been chosen to comment on this paper for one reason and not so happy for another one. The two reasons are: (1) I always found the present topic of renewable energy resources very urgent and I am happy that it has been taken up, and (2) I regard the presentation of Dr. Qurashi very informative and constructive. This puts me into the unhappy position, because I may not be able to comment on it adequately.

It is very fortunate that the author is a natural scientist; for this may lead to an inter-disciplinary approach to solving the questions before us.

One of the reasons for the stagnation and even decline of world oil prices during the past few years reportedly is that the major oil exporters, especially Saudi Arabia, had to accept the fact that the demand for oil is price-inelastic only in the short run whereas in the mid and longer run the industrialized countries have proved their ability in two fields, viz. (i) to make better use of energy and (ii) to mobilize additional sources, including renewable ones. If the oil price goes up too much, alternative sources and techniques for energy start to break even. Since one can expect new technologies to become more efficient over time, market shares may be lost for oil, even in a situation of falling oil prices. Therefore, high price policies bear economic risks for the oil exporters not only because of a world recession, but also because of induced technological change.

The new policy to keep the oil price in a limited range has paid out so far. In the West, especially in Germany, coal is again piling up and the construction of nuclear power plants has been shelved, not to speak of R & D (research and development) funds for developing renewable energy sources, which were highly regarded for a short while and again have been left as an obscure playing ground for ecologists and anti-nuclear activists.

For low-income countries, we obviously can observe a similar development. Pakistan does not seem to be an exception, if we only think of conventional, finite resources. The plans to set up a conventional thermal power plant based on Lakhra coal are on and off the table, depending on the latest development in the international energy market.

I have been following these plans almost since the inception of the Appropriate Technology Corporation Development Organization in the mid '70s, and I am not surprised to find actions for utilizing renewable energy sources being slow.

Dr. Qurashi's message is very clear:

1. We shall need more energy for the country's development.
2. The non-renewable energy sources will not be sufficient world-wide or in Pakistan.
3. We have to concentrate on alternative, i.e. renewable, sources, namely:
   - Hydroelectricity;
   - Biomass, biogas (I would also include fuel wood);
   - Solar energy; and
   - Wind energy.

Other likely renewable sources are:

(a) geothermal;
(b) ocean; and
(c) nuclear fusion.

There is no time here to go into details of Dr. Qurashi's assessment of estimating the potential and the likely cost of different alternatives. However, I also arrived at similar figures as Dr. Qurashi. Given the present state of information, they can only give a very rough idea of the magnitudes.

I would like to add a few general remarks. In a historic perspective, in the field of renewable energy sources, we definitively have to expect different technical coefficients, so we do not know to what extent we can make use of cross-country and inter-temporal analyses. We know that the industrialized countries use more energy per capita than the low-income countries and we do know that the industrialized countries have increasing energy consumption with increasing production. But we also know that their production grew during the recent time, while their energy consumption was receding, and we do know that new technologies will be less energy-intensive. I shall cite two examples: micro-computers and bio-chemistry.

Energy demand is a function of economic growth, and economic growth depends on energy supply. Fixed coefficients should be meaningful only for short-term projections. So any long-term extrapolations may just indicate the direction and speed of the energy demand to be expected. But as I tried to spell out and as Dr. Qurashi has shown, the energy problem has been shelved rather than solved, and renewable energy sources may soon be required urgently to fill the gap.

At present, there is little breathing time, and Pakistan could use it to intensify its research in this field, with equal emphasis on what is technically and economically feasible, as a combined effort of natural scientists and economists. It could be regarded as an obligation, an opportunity, and a challenge – as an obligation because the world energy market might change for the worse without forewarning; as an opportunity because low oil prices give same breathing time; and as a challenge since the industrial countries are not using this breathing time too well, giving low-income but technologically advancing countries, like Pakistan, a good chance to catch up technologically. In the 19th century it was the combination of inventors and businessmen, both often with little formal education, which brought the breakthrough in energy. Today things have become more complicated, and scientists, may be even economists, are required for further innovations.

I shall skip discussing technical details, which might be too tiring after so many papers, and leave these to the general discussion. Anyway, I would subscribe to Dr. Qurashi's elaborations, maybe with the only major exception that I would include fuel wood into biomass, which is Pakistan's prime traditional and renewable energy source. Energy balances have to be calculated for intensive foresting, including fertilizing of just growing shrubs and trees, utilized for heating, cooking in private households as well as in home and small-scale industry.

In this connection watershed management plays an important role because it helps to raise water-holding capacity of mountain forests, thus reducing the need for storage basins and rescuing fertile valleys from being used as storage basins for hydel energy production.

Whereas some information is available on the hydel power potential, most basic information on wind energy is missing, especially the seasonality and reliability of minimum wind velocities and the net benefit for excess wind energy fed into the national grid.

Another point is that renewable sources of energy are commonly discussed with respect to heating purposes or generation of electricity. Dr. Qurashi rightly mentions utilizing wind for milling and pumping of water.

The known reserves of finite energy in Pakistan can be estimated to be about 24×10^{15} Kilo Joule (K_j). At the given level of consumption, this would be sufficient for 43 years, even without using the hydroelectric potential.

Finally, I thank Dr. Qurashi with whom I had a series of very inspiring discussions on energy matters during the conference, and I am sure that he will be prepared to share his knowledge as a scientist with economists, who will carry on this study on renewable sources.

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