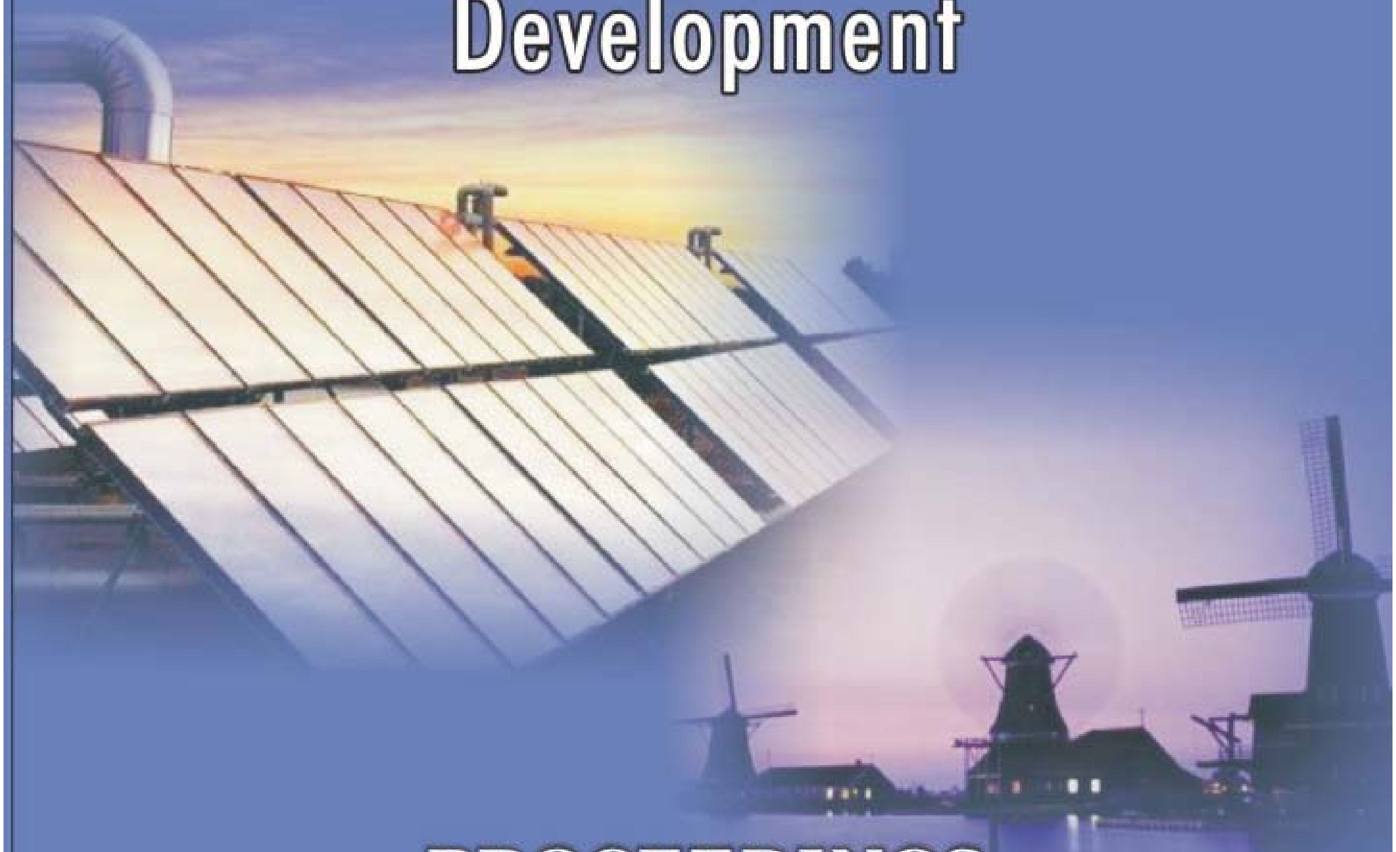
# Renewable-Energy Technologies and Sustainable Development



## PROCEEDINGS

Commission on Science and Technology for Sustainable Development in the South

4
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# Renewable-Energy Technologies and Sustainable Development

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February 2005

**Commission on Science and Technology for Sustainable Development in the South**

**COMSATS Headquarters**
4th Floor, Shahrah-e-Jamhuriat, Sector G-5/2, Islamabad.
Ph: (+92-51) 9214515-7, Fax: (+92-51) 9216539
URL: http://www.comsats.org.pk, Email: comsats@comsats.org.pk

**Renewable-Energy Technologies and Sustainable Development**

**Editors**

Dr. Hameed A. Khan
Prof. Dr. M. M. Qurashi
Engr. Tajammul Hussain
Mr. Irfan Hayee

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# Renewable-Energy Technologies and Sustainable Development

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# FOREWORD

Energy now plays an increasingly crucial role in the development and well-being of a nation. Energy has impact on lives, livelihoods, growth and progress, not only at a collective level but also at the individual, grassroots level. Given the circumstances of today, the source and nature of energy, the supply and environmental impacts of its supply and the utilization need to be addressed in a comprehensive and effective manner.

Renewable Energy resources and technologies have the potential to provide solutions to the long-standing problems being faced by the economy, the industry, the environment and the masses in the consumption of traditional sources of energy. It is only through devising such solutions that the development of nations can continue without hindrance, and so contribute towards sustainable developmental goals. Renewable Energy sources include wind energy, solar energy, geothermal energy, ocean energy and biomass energy, amongst others.

For energy-production in the developing countries, the expansion of existing energy resources and exploration of new sources is an important exercise to be considered, in order to ensure their future and sustain their development initiatives. It is indeed the developing countries that have to bear the maximum pressure of energy-scarcities. For this reason, Renewable Energy has been designated as one of the thrust areas where COMSATS has focused its efforts for advocacy and help member countries in pursuing their national Renewable Energy agendas.

The International Meeting on Renewable Energy for Sustainable Development was a part of the Commission's efforts to emphasize that without efforts to continuously improve and upgrade the nature and use of energy and creating nature-based solutions to the problems created by synthetic and man-made energy sources, the objectives of sustainable development would not be attainable. The Pakistan Council of Renewable Energy Technologies (PCRET) and the Global Change Impact Studies Center (GCISC) were co-organizers of the event whose technical support and expertise proved to be indispensable.

The meeting reviewed the current and future renewable-energy technologies for production and distribution and their role in the economy. The meeting examined issues involved in the development and deployment of secure, sustainable and accessible renewable energies for the third world. The forum also deliberated upon appropriate and effective strategies in this regard.

The meeting was attended by 10 international experts from Germany, China, Syria, Egypt and Jordan and a total of 26 papers were delivered in the two days. Overall, 21 national and international organizations were represented. The proceedings contain the content of the presentations made at the meeting along with the recommendations that were put forth to the forum. The Commission is grateful to the authors for their valuable contribution.

In the end, I would like to acknowledge the efforts of the subject-experts, authors, organizing committee and the support team whose hard work was reflected in the success of the meeting.

I would also like to thank Dr. Ishtiaq A. Qazi, Director General, PCRET and Dr. Arshad M. Khan, Executive Director, GCISC for without their keen collaboration and guiding role, the objectives of the meeting could not have been achieved. My sincere appreciation also for Dr. M. M. Qureshi, Ms. Merium Khan, Mr. Irfan Hayee and Mr. Imran Chaudhry from COMSATS whose dedication made the publication of these proceedings possible.

**(Dr. Hameed Ahmed Khan, H.I., S.I.)**
Executive Director

# WONDER LIGHT – LET OUR POOR HAVE IT!

**Q. Isa Daudpota**
*Centre for Innovative Technology,*
*COMSTECH, Islamabad, Pakistan*

**Abstract**

*About two billion people in remote areas of developing nations have no electric lighting, a commodity industrialized nations take for granted. Poor lighting in homes hinders children's learning, affects family-health and limits opportunities for a better life. Electrical engineer Dave Irvine-Halliday realized that a single one-watt white-light emitting diode supplies enough light for a child to read by. A simple but revolutionary technology, supplied to homes by his Light-Up-The-World Foundation, can light an entire rural village with less energy than that used by a single, conventional, 100-Watt light bulb. This technology ought to be considered by Pakistan, OIC countries and those in the South.*

**Introduction**

The best applied science results in the solution of a common problem that people have either overlooked or felt it couldn't be solved easily. There is a lesson in this for those who seek out research problems in Pakistan. Our researchers often fail to identify doable problems because they are trained to mainly solve problems that interest others (usually their foreign Ph.D. supervisors) rather than ones that affect their own society.

The majority of our people who live in villages suffer due to lack of water, poor health-care provision, lack of communication infrastructure and efficient energy-sources. The challenge for our scientists and engineers is to identify clever, economically viable answers to such issues. Many clever solutions are already there -- people in other countries have found them and succeeded in putting them into action. These need to be brought here and adapted in a manner that makes them sustainable under our conditions. For this to succeed, inputs from a range of experts from business, management, developmental sectors and entrepreneurs is often needed.

**Reading Light for Children**

At times an outsider with a clearer vision and a great knowledge of technologies can help in solving our problems. This is what happened when in 1997 the Scottish-Canadian electrical engineering professor Dr. Dave Irvine-Halliday spent a sabbatical in Nepal. While trekking in the mountains he looked into an unlit school room and asked himself if you could help. The question has already transformed his life and is likely to improve the lives of millions more.

Only one seventeenth of the 4 million households in Nepal have a reliable power supply. It is a poor country, with average annual income around $200, and it is unlikely that these people could all be connected to the electrical grid. He faced the problem of providing the majority of people adequate and reliable lighting, so that their dark hours could be used constructively. This would allow children and housewives to study or work, small businesses to continue work and move away from fossil fuels for providing light. The latter is expensive and also pollutes the homes with smoke. Using solar photovoltaic panels, with storage batteries, for powering incandescent bulbs or compact economical fluorescent light has been tried, but these bulbs utilize more power necessitating installation of high capacity solar panels, which are still expensive.

The incandescent bulb is a mere heater that gives off only 5% of its energy as light; the remaining 95% vanishes as heat. All over the globe, tens of giga-watts of electricity are only producing heat, so that we can get a tiny bit of light. What is worse is that this generation of power produces hundreds of million of tons of carbon dioxide that goes into the atmosphere.

In the US alone, electricity production costs $60 billion a year. About 20% of it is used for artificial lighting, comprised mainly of incandescent and fluorescent lamps. Of the $12 billion used for lighting, $11.4 billion is wasted! Enter solid-state lighting (SSL) devices that promise to replace conventional sources and provide significant financial savings. Estimates are that in the US, expenditure for lighting will be reduced by $100 billion over the period 2000-2020. By 2020, electricity used for lighting may be cut down by 50%, sparing the atmosphere 28 million tonnes of carbon emissions annually. It is this technology that Halliday latched onto.

The key development in this transformation was the invention of the Gallium Nitride (GaN) light-emitting diode (LED), which made it possible to get white-light from a semiconductor. It has been more than seven years since a then-little-known researcher Shuji Nakamura, at Nichia Corp, in the backwaters of Japan, stunned the optical engineers by reliability producing blues, greens, and purples out of GaN. The production of this high-frequency light will greatly enhance the capacity of CDs, hard-disks and other devices that require the reading of data from a surface using coherent light. Blue-light can also be converted efficiently to white-light that is used for illumination.

There are several ways to get white-light out of an LED. The most common puts a blue LED chip beneath a film of Yttrium-Aluminum Garnet (YAG) phosphor. The phosphor gives off yellow light when struck by the blue light; the mixture of blue and yellow appears white. The transformation of the blue has also been done using organic compounds in a LED made from layers of organic material.

In 1998, after a fruitless year of trying to develop a white LED (WLED), he was browsing the Web when he discovered that Nichia had solved the problem of getting white light. Switching to Nichia's 0.1 watt LED made him realize that light even from such a frugal source would be very useful. He developed a multi-diode lamp to light up Nepalese homes through the newly formed *Light-Up-the-World Foundation*, an organization which has in the past year or two been the recipient of an array of awards for innovation and development. (*See www.rolexawards.com for example*).

**Economies of White LEDs (WLED) for Developing Countries**

Some order-of-magnitude estimates from Nepal made by Irvine-Halliday are presented. They show the attractiveness of this technology for large parts of our country without connection to the grid.

For the 4 million households countrywide without light in Nepal, supply of even a 25 watt incandescent bulb or an 8 watt compact fluorescent light to each require 100 MW and 32 MW, respectively. This alone will cost significantly, but when you factor in the environmental cost of such centralized power-generating facility, it seems well beyond what the poor country can afford.

Torches are an important feature of life in the developing world. These use up batteries at a high rate, with the total life of a D cell around 3 hours total, or an operational life of a few weeks. These are normally dumped, causing the ground and water-bodies to be polluted by mercury and other chemicals. WLEDs used instead of bulbs can extend the life tenfold to 30 hours. If rechargeable batteries are introduced, the numbers of discarded cells can be further reduced. Pedal generators, solar voltaic and tiny hydro generator have been shown as viable sources for charging batteries that are used for WLEDs.

Economies of scale will only strengthen the case for such lighting. If cost of production can be reduced, with steady increase in spread and demand for such lighting, it would become possible for households to buy home-lighting systems without subsidy.

Consider 1-watt lamps that costs $1.50 (this price is possible when scale-up happens) being used to service the 2 billion people currently without light after sundown. If we assume that there are 5 to 6 persons in each home then the number of homes lit by WLED is about 400 million. Assume that two lamps of 1 watt each are used in each home, the total number of lamps will be 800 million. These figures are conservative, as even poor families would want to buy more lamps once the price falls.

Right now the price of a system for a single home with associated generating equipment and storage system, if required, varies from $40 to $60, depending largely upon the type of generating system chosen and the local distribution system used. For large projects, even now, it is expected that this price tag will immediately come down by 30% even with moderate reduction in cost of WLED. (*For more info see www.lutw.org*).

**Future Prospects for WLED Globally**

Now for a taste of what is happening in the fast-moving world of WLED based on the assessment of Sandia Labs, where a lot of research is proceeding. WLED have already begun to replace incandescent bulbs in many applications, particularly those requiring durability, compactness, cool operation and/or directionality (e.g., traffic, automotive, display, and architectural directed-area lighting). Moreover, further major improvements are believed to be achievable. Electrical-to-optical energy-conversion efficiencies over 50% have been achieved in infrared light emitting devices. If similar efficiencies were achieved in visible light emitting devices, the result would be a 200 lm/W white-light source two times more efficient than fluorescent lamps, and ten times more efficient than incandescent lamps.

*This new white-light source would change the way we live:*

- Worldwide electricity consumption due to lighting could be decreased by more than 50%, and total consumption of electricity could be decreased by more than 10%.
- Carbon emissions, and new capital infrastructure associated with electricity generation, would decrease proportionately, also by more than 10%.
- The human visual experience would be enhanced, through digital control over the color and spatial distribution of lights. And along the way, compact visible and UV light sources, useful for detection of bio-agents, will be developed.
- Yet, to realize this future, enormous challenges lie ahead. These challenges include:
  - An improved understanding of the physics of AlGaInP and AlGaInN materials and nanostructures
  - Improved optoelectronic devices for high photon-generation and extraction efficiency
  - Improved wavelength-conversion color-mixing technologies for generation of white light
  - Improved packaging technologies for high power
  - New lighting fixtures and systems, based on the unique ways in which people can interact with solid-state lighting
  - Development of the science and technology foundation for high-volume low-cost manufacturing.

**Introduction of WLEDs in Pakistan and OIC**

The web is a wonderful tool for bringing us interesting and important ideas. The early demonstration in a developing country of WLEDs was by Dave Irvine-Halliday who discovering them on the web. And I discovered his work also using this same tool. He is very keen to see this idea of lighting for the poor spread to Pakistan fast. As I write, I have learnt that LUTW has a chapter in Pakistan – it started in last November. LUTW (Pakistan) chapter has produced a video of Mubarak village (500 homes), which is only a couple of hours from Karachi, where they intend to launch their first project.

This project needs the blessings of several ministries, including that of the environment and science. The current thrust to implement several large renewable-energy projects in Pakistan by the newly formed *Alternative Energy Development Board* (housed in the Prime Minister's Secretariat, and hence signifying the importance being given to it) shows that the time for this is ripe. For the WLEDs to be easily accepted by people, social marketing and participation by communities is essential. The NGO-sector's role will be critical in its success.

The Center for Innovative Technologies, where I work, can provide the focal point for spreading the word to technologists and decision makers in 57 countries of OIC. Lighting up the homes of nearly a billion people who live in these countries is a goal worth adopting!

**References & Notes**


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- Qazi Isa Daudpota is the Project Leader of COMSTECH's new Center for Innovative Technology in Islamabad. He was the founder project director of SDNP, which pioneered and popularized the internet in Pakistan. His current research interests are water purification, information theory and the study of large systems.

# ANALYSIS OF ECONOMICS OF INVESTMENT IN A WIND-FARM SYSTEM

**Fahd Ali and A. H. Nayyar**

*Sustainable Development Policy Institute*
*#UN Boulevard, Diplomatic Enclave,*
*P.O. Box 2342, Islamabad, Pakistan*

**Abstract**

*With the constant increase in the cost of generating electricity through conventional means, there is a growing need to look for other sources of energy. Renewable energy resources with their zero-emission features provide us with a good alternative. Of all the renewable energy resources, wind has proved to be the most promising one, chiefly due to its cost effectiveness and ability to provide grid-quality power. In Pakistan, the concept of using renewable energy for power generation is not new. However, the lack of support from the Government proved to be a major hurdle in developing Renewable Energy resources. Nevertheless, only recently the Government of Pakistan has taken concrete steps to develop renewable energy resources, one of which is a wind-mapping/charting program being carried out in the coastal areas of Balauchistan and Sindh. The wind-mapping program would eventually determine the wind-power potential of Pakistan and sizes of the wind-farm systems to be set up here. This study aims to estimate the cost of generating electricity using wind-energy and a suitable tariff-rate that may be set to attract foreign/local investment in this sector. This study also lays out policy-recommendations that may help to attract investment to develop wind farm systems.*

## 1. Introduction

With the increase in the cost of generating electricity through conventional means, there is a growing need to look for other sources of energy. The increase in demand of electricity in future would also strain the conventional method of generating electricity i.e. using fossil fuels. Around 70% power-demand is fulfilled using fossil fuels. However, these fossil-fuel resources are not expected to last beyond 30 years. This has certainly sparked the interest of the Government to find and develop other resources of energy. The desire to look for other affordable resources of energy has also been influenced by the environmental concerns. The facts that large hydel-power dams cause irrevocable ecological damages and thermal power stations, in the end, would only add more to the environmental cost of generating electricity, have also influenced the desire for sustainable developmental projects in power-generation sector. Hydel and Thermal power-projects are generally long-term projects, having gestation periods of at least 5-15 years. Therefore, in order to meet the power requirement of the country there is a need to explore projects that have a short gestation period.

However, before formulating policies to attract investments it would be useful if the wind-power potential of Pakistan can be estimated. Preliminary studies show that almost all of the wind-power potential lies in the coastal regions of the country. Therefore, Pakistan Meteorological Department (PMD) has started a wind resource assessment program in the coastal regions of Sindh and Balauchistan. This program was started in April 2002. The collected data from this program would be used to make wind-maps/charts for the region. Normally, this wind-charting/mapping is done after collecting data for at least one or two years. This is done only to make the data more reliable and accurate. The selection of a suitable turbine-size greatly depends on the average annual wind-speed. This would also help to determine the true magnitude of wind-power potential in the coastal regions. Any inaccuracy in the data can prove to be costly.

The electricity demand would sharply increase in the province of Balauchistan with the development of Gawadar and Pasni ports. The contract for developing the Gawadar port has already been awarded to a Chinese firm. There is a 17 MW diesel-based power-generation plant situated in Gawadar. A small grid to serve the local area also accompanies it. However, the existing resources would not meet the increase in the electricity-demand resulting from the development of Gawadar port. WAPDA has already discarded the idea of connecting Gawadar and its adjacent areas to the national grid, as it would be too costly for it. Therefore, eventually the Government of Pakistan would have to either establish a thermal power station in the vicinity, or look for alternative resources. Wind power is therefore a healthy option to explore.

Pakistan has no capability of producing wind-turbines. So, when setting up this wind-power plant, most of the equipment would have to be imported. However, it may be argued over here that indigenous capability may be encouraged and the Provincial or the Federal governments should help to establish a local industry as well. The example of India may shed some more light on this issue. Wind turbines for power-generation in India were commercialized in early nineties. Since then India has moved from a few kilowatt-hours to a massive 1.5 GW (fourth largest in the world), the wind-power generating plants being situated mostly in the western coastal and southern part of the country. In due course of events, India developed its own wind-turbine industry and is now one of the prominent wind-turbine manufacturers of the world. However, this growth was achieved mainly due to the huge wind-power potential of a least 40 GW; India found it prudent to invest in indigenous development of wind turbines. A number of research and development institutes were established in this area, resulting now in a massive wind-turbine industry. This is eventually going to make exploitation of further wind-resources much more economical than elsewhere.

In principle, Pakistan ought to be thinking along similar lines, and planning to establish capabilities for indigenous technologies. However, this is an expensive proposition, given that the total wind-power resource is not likely to exceed 1 to 2 GW. For such low-level resources, it may be economical to import technology and invite direct foreign investment. In the light of this information, it may be argued that establishing a local industry would probably not be a wise move. Manufacturing industries usually have large gestation periods. Furthermore, manufacturing turbines would not be the only requirement; a related support-industry would also have to be established. By the time we would be able to produce everything at an internationally competitive cost, the wind-energy potential of the country would have been exhausted and this industry may then become a burden on our economy.

## 2. Methodology

The various factors that go into calculating the economics of an investment are identified and defined in this section. These will apply to an investment in the energy project also.

### *2.1 Discounted values*

The value of an asset changes with time, because of (i) the opportunity-cost of the capital, (ii) inflation and (iii) the increase in prices without any change in the quality or quantity of the goods.

Over time, the rate of inflation (*h*) and the average real increase in capital goods' prices (*e*) enhance the value of investment, while the discount-rate ($k_n$) reduces it. We define a discount factor (Γ)

$$\frac{1 \quad e \quad 1 \quad h}{1 \quad k_n} \qquad \text{... Eq. (2.1)}$$

Where ($k_n$) is the discount rate, also called the opportunity cost of capital, and is defined as the best rate of profit that can be earned on an alternative investment; (h) is the rate of inflation; and e is the annual increase in prices of goods.

The total discounted capital investment-cost (I) is evaluated from the formula,

$$I \quad \sum_{t \; 1 \; P}^{0} I_t \quad ^{t} \qquad \text{... Eq. (2.2)}$$

Where ($I_t$) is the total annual investment costs at the end of year (t), and (P) is the period of construction of the project. It may be noted that the base year is taken from the commencement of production of energy.

The discounted value (*E)* of the total energy produced in n years is given by

$$E \quad \sum_{t \; 1}^{n} E_{annual} \quad ( \;_{e})^{t} \qquad \text{... Eq. (2.3)}$$

where ($E_{annual}$) is the value of the electricity produced every year, and

$$_{e} \quad \frac{1 \quad e_e \quad 1 \quad h}{1 \quad k_n} \qquad \text{... Eq. (2.4)}$$

is different from Γ in Eq.(2.1) in containing $e_e$ as the annual real increase in the price of energy.

The production incurs operational and management costs that are also to be discounted over the period of operation. The discounted value of the operational and maintenance cost after n years of operation is:

$$O = \sum_{t=1}^{n} O_{annual} \, (\Gamma_o)^t \qquad \text{... Eq. (2.5)}$$

Where ($O_{annual}$) is the annual operational and maintenance cost, and

$$\Gamma_o = \frac{(1+e_o)(1+h)}{1+k_n} \qquad \text{... Eq. (2.6)}$$

Now contains $e_o$ as the annual real increase in the operations and maintenance costs.

One important economic parameter is the pay-back time ($T_{PB}$) of the initial investment in an energy project. This is usually defined as the ratio of the initial capital-investment (*I*) to the net income (difference between the value of the energy produced in the first year of operation, $E_1$, and the sum of the expenditure on operation and maintenance in the first year, $O_1$, as well as on the input fuel, $F_1$);

$$T_{PB} = \frac{I}{E_1 - O_1 - F_1} \text{ Years} \qquad \text{... Eq. (2.7)}$$

A plant after a certain period of operation has a salvage value of its capital investment. This is usually estimated at the start of the project, and then gets discounted similar to other economic parameters. The discounted salvage value after n years of operation is evaluated by the formula

$$S = S_n \left( \frac{1+h}{1+k_n} \right)^n \qquad \text{... Eq. (2.8)}$$

where ($S_n$) is the salvage or resale value of the plant in the year "n" as estimated in the zero year dollars.

### *2.2 Depreciation cost*

A plant gets depreciated in value with use. Often an accelerated depreciation is allowed as an incentive for investment. For a depreciation expense ($D_t$) in year (t) and a depreciation period of (d) years, the discounted depreciation is

$$D = \sum_{t=1}^{d} D_t \frac{1}{(1+k_n)^t} \qquad \text{... Eq. (2.9)}$$

### *2.3 Replacement cost*

With time, many components of the plant would need replacement. For a replacement cost ($R_t$) in year $t$ ($t<n$) in zero year dollars, the replacement cost gets depreciated by the following formula

$$R \qquad {}_{t} \; R_t \; \frac{1 \quad h}{1 \quad k_n}^{\,t} \qquad \text{... Eq. (2.10)}$$

***2.4 Net Present-Value (NPV)***

After tax NPV, which represents the discounted cash-flow over the lifetime of a plant, can in general be stated as

$$NPV \quad (1 \quad T) \quad (E \quad S) \quad (F \quad O \quad R) \quad T \; D \quad I \qquad \text{... Eq. (2.11)}$$

The expenses on the project are subtracted and the revenues from the projects and the salvage value are added, weighted suitably by the marginal tax rate T. All the quantities are discounted as defined above.

***2.5 Levelized Cost***

Levelized cost is the total cash flows of a project divided by the discounted energy produced over the lifetime of a project. Levelized cost of electricity from a particular source is a very important factor in determining the financial viability of utilization of that source. Various benchmarks of levelized costs have been set to evaluate investments in particular sectors.

Levelized cost $C_L$ is calculated from

$$C_L \quad \frac{I \quad O \quad R \quad F}{E_1 \; {}_{t\;1}^{\;n} \; \frac{1}{1 \quad k_n}^{\,t}} \quad [\$/\text{Kwh}], \qquad \text{... Eq. (2.12)}$$

where $E_I$ is the annual energy produced.

***2.6 Objectives of the Analysis***

In case the unit price of energy is given, the levelized costs of energy-production from investments in two or more energy-technologies are evaluated, to determine which of the technologies would offer a more attractive investment. For an individual investment, the basic principle for determining suitability is that the Net Present Value be positive. In principle, any positive NPV assures a profitable business.

On the other hand, if the unit price of energy from an investment is not already fixed, because of which one cannot evaluate the value E of the energy produced, or levelized cost or NPV, the principle of positive NPV provides a convenient way to determine price of energy. We take as cost of energy-production the value that makes the net present value zero, and the unit price of energy as that which includes a reasonable markup on the cost. Thus, if x cents per kWh of energy renders NPV zero, then x is the cost of energy production. And if 20% is regarded as a reasonable markup rate then 1.2x will be the price, which the producer will charge the buyer for each kWh sold. This is the principle that will be used below to find the reasonable unit-price of energy. In the scheme of calculations here, therefore, evaluation of levelized costs does not remain meaningful.

### *2.7 Value of Parameters*

Discount-rate ($k_n$): For most public and private sector analysis, one uses a 10% discount rate, but some private investors sometimes have a more pessimistic approach and they use 15-20% discount rates to evaluate the return on their investment. In this analysis we shall use a 10% discount rate, which is probably the best interest-rate one can obtain from a bank.

Rate of inflation (h): For most public-sector investments in Pakistan, the inflation rate considered is 3-4%. In general, however, the average rate of inflation over the last five years, as documented in the Government of Pakistan's economic surveys, has been 6.8%. To keep our estimations more favourable to an investor, we shall take this value of the inflation rate.

Real rate of increase in prices of capital goods (e): The average real rate of increase in the prices of manufactured goods and building material over the last five years, as listed in the Economic Survey, has been 3.7%.

Real rate of increase in the operations and management costs ($e_o$): We shall take this to be the same as the average rate of inflation, that is, 6.8%.

## 3 A 10-Megawatt Electricity Generating Wind-Farm

The world has seen a continuous decline in the installed capital-cost of a wind farm in the past two decades. The installed capital cost has decreased from 2-3 US $/W to around 1 US$/W, as shown in Figure-1. The installation cost came down chiefly because of the advancement in technology. This reduction in cost has made wind-

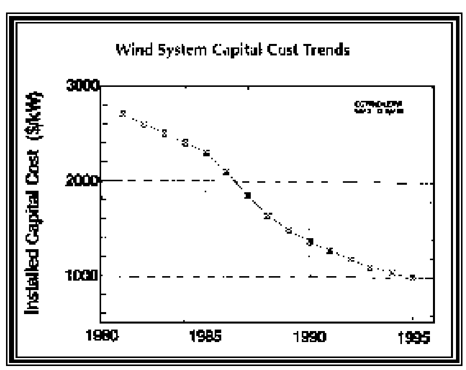


**Figure-1: Wind-System Capital-Cost Trends**

energy competitive with the conventional electricity, thus bringing down the generation cost to 4-5 cents/unit.

As was mentioned in Section-1, the GOP would probably have to invite foreign investors to build wind-farms in the coastal regions of Pakistan. However, as said earlier, before formulating policies or inviting investors for investing in wind-energy sector it would be prudent to find out the economics of such investments in order to see if enough incentives exist for potential investors. A far more important thing to find out would be the tariff rates that would make the investment profitable. This is important, in view of the disastrous experience Pakistan has faced in allowing extraordinary concessions to the IPP's of thermal power plants. This is a necessary exercise, as it would help us to determine the cost of wind-generated electric power. The cost calculated could then be used to determine a tariff rate for this project, which would make the investments profitable over the farm's lifetime, 20 years in this case. Whether a wind-power plant is developed by a foreign or a local investor, a suitable tariff-rate that can be paid by the consumer has to be established. Pakistan has suffered immensely because of the agreement with the Independent Power Projects. The high tariff-rate promised to them not only caused problems for WAPDA and KESC but the high electricity tariff affected consumers the most.

For our analysis, we therefore have assumed that, in the beginning, setting up a 10 MW wind-farm would be considered appropriate by an investor. We would now see the various cost factors that go into building a 10 MW wind farm. Naturally, this wind farm would be built in Balauchistan, where most of our wind-energy resources lie.

As mentioned earlier, installation-costs have come down to one $/watt world over. However, for our analysis we are assuming that the installation cost would be as high as US $1.5/watt. We are assuming this because we believe that a significant portion of this cost would go into the provision of basic infrastructure, like building roads, transmission cables, etc, something which far flung areas like Gawadar and Pasni lack all together. We therefore think that our installation-cost assumption is not unfounded.

### *3.1 Discounted Cost of Investment*

With 1.5 US $/watt, the initial capital required for a 10 MW wind farm is 15 million US Dollars. The total cost of construction, calculated using equation 2.2, when the investment is taken to equally divided over each year of the installation period of five years is

***I = US $ 15.31 million***

Therefore, as far as investor is concerned, the cost of building a 10 MW wind power plant will be US$15.31 million.

### *3.2 Total Value of Electricity Produced by Wind-Turbines*

The total number of electricity units, E1 produced in a year by a 10 MW wind farm is given by the following formula;

$$E_1 \quad P \quad F \quad H \ (in\ kWh)$$

where *P* is the plant size in *kW*, *F* is the capacity factor and *H* is the number of hours in a year (8760). Here P = *10,000 kW* (*or 10 MW*) and *F = 0.30*. Total number of units comes out to be

$$2.628 \quad 10^7\ kWh \quad or \quad 26.28\ GWh$$

***3.3 Total Discounted Operational and Maintenance Cost***

The operational and maintenance cost of a wind power plant has been estimated at 1 cents/kWh. Therefore, the annual operational and maintenance costs, is estimated at 0.26 million US dollars. The discounted O&M costs over the lifetime of the plant, as calculated from equation 2.5, is therefore

***O = US $ 7.86 million***

***3.4 Discounted Salvage Value***

We now try to estimate the salvage value of the farm after 20 years of operation. Wind farms generally have very little salvage value. This is primarily because of the fact that the farm's equipment is used up in its lifetime. At the end what is left to salvage, chiefly consists of the land purchased for construction and wind-towers erected for mounting turbines. We are assuming that after 20 years of operation 5% of the initial investment would be salvaged. So, using equation 2.8, the Salvage Value is estimated to be

***S = US $ 0.31 million***

***3.5 Discounted Depreciation Cost***

Although plant equipment usually depreciates gradually during the life of the plant, we assume that all the initial would depreciate in first 10 years of operation. This also forms a standard investment-incentive all over the world. We further assume that this depreciation occurs uniformly in ten years. That is, the depreciation every year is I/10. Equation 2.9 gives us the discounted depreciation over ten years.

***D = US $ 9.22 million***

***3.6 Discounted Replacement Cost***

Wind-farm equipment may require replacements every few years. However, the level of replacement depends on the details of design. Generally, major overhaul of the wind-turbine are required every 5, 10 or 15 years. These major overhauls include replacements of various parts, like gears, seals and various other moving parts. However, situations may arise where other parts have to be replaced without any prior planning. Such infrequent replacements may occur whenever a blade gets broken or rusts away due to extreme humid climate of the coastal regions. Nevertheless, whatever kind of replacement expense occurs, it requires, on the part of investor, a yearly accrual of a fixed amount to meet such expenses. This amount is then discounted to give us replacement expenses over the lifetime of the farm. We assume that a charge of 0.04 cents/kWh is sufficient to meet such expenses. Equation 2.10 gives the discounted value of replacement cost over plant's lifetime.

***R = US $0.16 million***

### *3.7 Net Present-Value, Cost of Electricity Generation, Electricity Tariff and Payback Time*

We are now in a position to calculate the cost of (wind) electricity-generation and electricity tariff. As mentioned earlier in section 2, for an individual investment, the basic principle for determining suitability is that the Net Present-Value be positive. In principle, any positive NPV assures a profitable business. Since, the unit price of electricity is not given here, therefore we cannot calculate NPV for this investment. However, we can estimate the lowest possible value of cost of electricity generation that would make NPV zero. The electricity tariff is then calculated by fixing suitable value of markup on that cost. For example if x cents/unit makes NPV zero, and 20% is a reasonable value of markup then electricity tariff is simply 1.2x.We now try to find out the cost of generation by equating NPV, equation 2.11, to zero. This gives

$$c \quad \frac{I \quad T\;D \quad (1 \quad T)(O \quad R \quad S)}{(1 \quad T)\;E_1 \quad _{t\;1}^{\;n} \quad e^{t}} \qquad \text{... Eq. (3.1)}$$

where $E_1$ is the number of electricity units than the wind-farm can generate in a year. Substituting the values in the above equation yields a cost of 4.54 cents/kWh. With a markup of 20%, the electricity tariff comes out to be 5.44 cents/kWh. The total revenue that the wind farm would generate in its lifetime of 20 years would be 30.75 million US dollars. NPV for this investment comes out to be 0.82 million US dollars. The investor will have the investment returned in 13.1 years. Table-1 below shows the same results

**Table-1: Summary of the Calculated Quantities for a 10-MW Electricity-Generation Wind-Farm**

| Quantity | Calculated value |
|---|---|
| Discount value of the investment | 15.31 million US dollars |
| Discounted operation and maintenance cost | 7.86 million US dollars |
| Discounted depreciation cost | 9.22 million US dollars |
| Discounted replacement cost | 0.16 million US dollars |
| Salvage value | 0.31 million US dollars |
| Cost of production of a unit of electricity | 4.54 cents |
| Sale price of a unit of electricity | 5.44 cents |
| Total discounted revenue over 20 years | 30.75 million US dollars |
| Net present value | 0.82 million US dollars |
| Payback period | 13.1 years |

in a tabular form.

## 4. Sensitivity Analysis

The cost and tariff for wind electricity calculated in the previous section is dependant on various factors. It would be interesting to see how the cost varies as one of these factors varies while everything else remains constant. The cost in Section-3 is dependant on the following factors:

i. Discount-rate
ii. Inflation-rate
iii. Tax-rate
iv. Real rate of increase in prices of electricity
v. Depreciation-rate

### *4.1 Discount-Rate*

Discount rate is an important factor for projects where large investment is required. High discount-rates make loans expensive, while low discount-rates making loans cheaper, encourage investors to take loans. Figure-2 below shows the relationship of cost of electricity-generation with discount rate. The government has recently lowered the discount rate from 10% to 7.5%. The figure clearly shows that if the reduced discount-rate is taken into account, cost of generation comes down to 4.00 cents/kWh.

### *4.2 Inflation-Rate*

The relation ship between inflation and the cost of electricity generation is negative. The higher the inflation rate lower is the cost. This is because higher inflation-rate also inflates the revenues, thus bringing down the cost. The

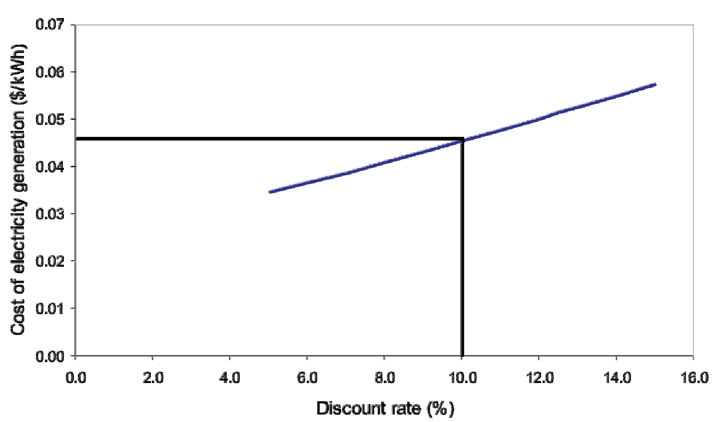


**Figure-2: Cost of Electricity-Generation versus the Discount-Rate**

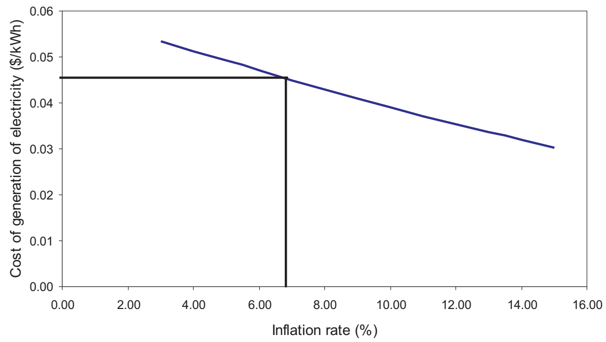


**Figure-3: Cost of Electricity-Generation versus Inflation-Rate**

relationship is shown in the Figure-3 with the inflation (6.8%) used in these calculations.

### *4.3 Tax-Rate*

The relationship of generation cost with the tax rate is exponential, with positive slope. However, the curve remains fairly flat up to 40%. In these calculations, we have used the highest tax rate levied on a business in this country. However, as shown in the graph lowering this tax rate does not reduce the cost dramatically. Figure-4 shows this pictorially.

### *4.4 Real increase in Prices of Electricity*

The increase in electricity prices depends upon various factors. Among them, an important one is the input fuel price. NEPRA, the electric-power regulatory authority, reviews electricity-rates quarterly and adjusts them to prevailing furnace-oil prices. Every year, 40% of the electricity generated comes from furnace-oil based plants. The Economic Survey of Pakistan lists out the changes in prices of fuel lighting and lubricants in its statistical appendix for the past ten

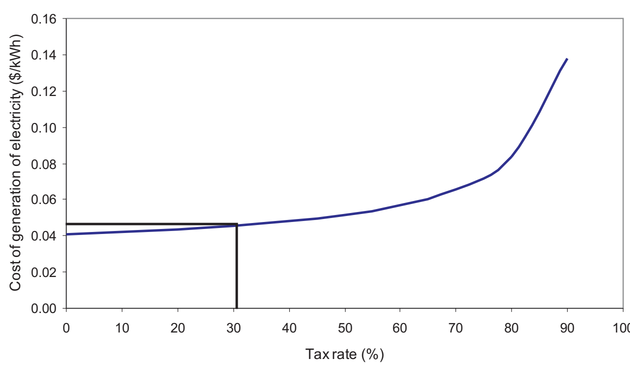


**Figure-4: Cost of Electricity-Generation versus Tax-Rate**

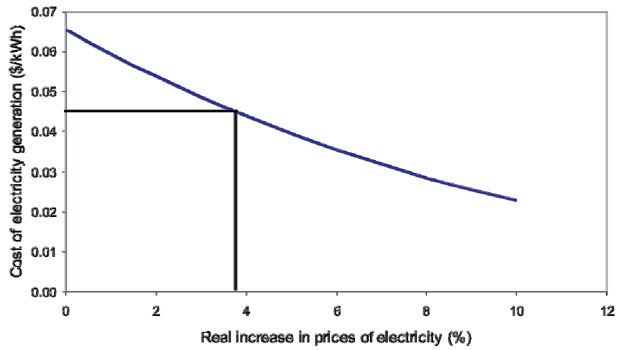


**Figure-5: Dependence of Generation-Cost on Real Increase in Prices of Electricity**

years. The percentage average of this price-change is 11.4%. However, the electricity generated by a wind-farm does not need input fuel. Therefore, using 11.4% as the average yearly increase in the prices of electricity to calculate cost and tariff will give misleading results. Instead, we believe that for a non-thermal source of electricity, this yearly increase should be equal to the real increase in prices of capital goods every year. Obviously, a large increase in real prices of electricity would generate more revenues. This would reduce the unit price of electricity. This relationship is also shown in graphical form in Figure-5.

### *4.5 Accelerated Depreciation*

Finally, we now consider the effect of accelerated depreciation on the cost of electricity generation. Interestingly, accelerating depreciation does not affect the cost that much. This relationship is clearly shown in Figure-6. For the shortest duration of two years, the cost only comes down to 4.25 cents/unit from4.54 cents/unit. Clearly, the reduction is not significant. However, coupled with other incentives a short depreciation-period can yield favourable results.

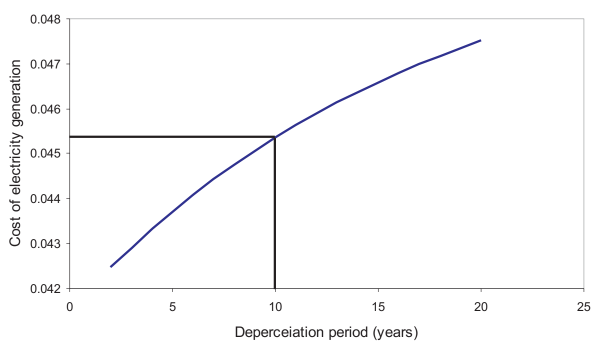


**Figure-6: Generation-Cost of Electricity versus Depreciation-Period**

### *4.6 Ten-year Averages*

The calculations performed in Section-3 used certain parameters like inflation, real increase in the price of electricity, real increase in the cost of capital goods, and the real increase in prices of operation and maintenance cost. These values, as mentioned earlier in this paper, have been estimated by taking an average of the change in the values of these parameters for the past five years. Interestingly, the results change to quite an extent if we average the change in these parameters over a period of ten years. Thus, the value of inflation, h, becomes 9.41%, real rate of increase in prices of capital goods, e, is 7.16%, real rate of increase in the operations and maintenance costs, $e_o$, is 9.41%, and the real rate of increase in price of electricity is equivalent to e at 7.16%.

The results with these new values are tabulated in Table-2. A comparison with earlier results has also been provided.

Clearly, the cost of electricity generation reduces by 1.26 cents/unit or 28% when we use new values. This happens, in spite of the fact that overall cost of the project rises (note the increase in discounted values of investment, operation and maintenance, and replacement). However, this increase is offset by a considerable increase in the revenue from the farm over its lifetime. The only apparent disadvantage in this is the payback time, which jumps from 13 to 23 years exceeding even the lifetime, 20 years, of the project.

## 5 Conclusions and Policy Recommendations

The exponential growth in utilization of wind-power has not solely been brought by advancement in technology. A key factor in the growth was the various incentives governments offered to investors. It should however, be noted that no one incentive can bring considerable private investment in this sector. The incentive should consist of a mixture of factors that we considered in Section-4 for our sensitivity analysis. The

**Table-2: A Comparison of the Values, When Inflation and other Parameters are Averaged for Five and Ten-Years for a 10-MW Wind-Farm**

(Million US$)

| | 5 years | 10 years |
|---|---|---|
| Discount value of the investment | 15.31 | 18.24 |
| Discounted operation and maintenance cost | 7.86 | 14.35 |
| Discounted depreciation cost | 9.22 | 9.22 |
| Discounted replacement cost | 0.16 | 0.20 |
| Salvage value | 0.31 | 0.64 |
| Cost of production of a unit of electricity | 4.54 cents | 3.28 cents |
| Sale price of a unit of electricity | 5.44 cents | 3.94 cents |
| Total discounted revenue over 20 years | 30.75 | 43.21 |
| Net present value | 0.82 | 2.28 |
| Payback period | 13.1 years | 23.6 year |

sensitivity analysis in Section-4 clearly shows that decreasing the (i) discount rate, (ii) tax rate, and (iii) the depreciation period would lower the generation cost as well. It is interesting to note that accelerated depreciation in case of India had the greatest effect. This meant that if a company showed its income, at the year-end, as investment in wind-farming then it could get away by paying no taxes at all. Obviously, a company actually had to invest in wind farming as well. Similarly, in the state of Minnesota in the US, this incentive improved the investors tax-position. The tax automatically comes down as depreciation is accelerated. A 100% accelerated depreciation in the fist year of investment means that the investor will not pay any tax on its capital equipment for the lifetime of the project. Lowering the discount rates or offering special discount-rates on investment in this sector can also play a crucial role. Low discount rates actually make the loans cheaper, thus increasing investor's profit-margin during the lifetime of the project. If we assume a 100% accelerated depreciation in the first year of investment, zero tax rates and a 5% discount rate for wind-farm investors, the cost of electricity generation comes down to 3.18 cents/unit a decrease of about 30% from our original figures. If this holds true, then wind energy has a potential of becoming competitive with conventional energy-resources in Pakistan. The generation-cost can further be decreased if we rely on indigenous technology as much as possible. Pakistan has a local capability of manufacturing electrical generators, wind-masts/poles can also be constructed locally; however, turbine blades would have to be imported. Emphasis should be laid on training people in maintenance of wind farms to cut long-term maintenance costs.

Overall, wind farming has potential of both becoming competitive with conventional energy-resources and taking off in Pakistan. However, this would greatly depend on the way GOP plans and executes commercialization of wind-power potential in Pakistan.

# ENERGY AUDIT: POTENTIAL OF ENERGY-CONSERVATION IN JORDANIAN CERAMIC INDUSTRY

**Haitham Adas & Ammar Al-Taher**
*National Energy Research Center*
*P.O. Box 1945 Amman 11941, Jordan*

**Abstract**

*This paper represents the findings of the preliminary energy-audits performed by the Rational Use of Energy Division at the National Energy Research Center (NERC), as well as the findings of a detailed energy-audit carried out in the largest Ceramic plant in Jordan (Jordan Ceramic industries).These studies were preceded by a survey of the ceramic factories in Jordan. The survey was carried out in 1997. The performed preliminary energy-audits showed that an average saving-potential in most of theses plants is about 25 % of the total energy-bills in these plants, which constitutes a considerable portion of the total production-cost. This fact was verified through the detailed energy-audit performed by NERC team for the largest Ceramic Plant in Jordan in June 2003, which showed an energy-saving potential of about 30 %. This saving can be achieved by some no-cost or low-cost measures, in addition to some measures that need reasonable investments with an average pay-back period of about two years. This detailed energy-audit covered electrical systems, refrigeration systems, compressed-air systems, and kilns. The results of the detailed energy-audit can be disseminated to other Ceramic plant, because of the similarity in the production process between these plants and the plant where the detailed energy-audit was carried out.*

## 1. Introduction

The primary energy consumption in Jordan in the year 2002 was 5.299 million ton oil-equivalent (MTOE), representing an annual growth of 2.89 % relative to the year 2001, while the final energy-consumption in Jordan in the year 2002 was 3.811 million ton oil-equivalent. The cost of the consumed energy in 2002 is 610 million JD, which represents 14 % of the imports of Jordan. (1JD = 1.43 US dollar).

In the year 2002, the Jordanian industrial sector consumed 0.846 million ton oil-equivalent, which represents 22 % of the final energy. The electricity consumption in 2002 was 2,193 GWh in the industrial sector. Small and medium industries consumed 47.7 % of this amount, which is about 1,046.1 GWh, while the rest of this energy is consumed by the large local industries; such as Jordan Cement Company, Potash, Phosphate, Oil refinery, Jordan Magnesium Company, Bromine company, Queen Alia Airport and National Broadcasting station [1].

However, to a lesser extent, Ceramic industry in Jordan can be considered as one of the most energy intensive industries. In the present paper, a brief summary of the most important aspects regarding a sample of three Jordanian Ceramic-plants profiles, energy profiles and energy-saving projects emerging from the preliminary energy-audits performed by the National Energy Research Center (NERC) for these plants will be presented. In addition, the findings and the recommendations of a detailed energy-audit performed by NERC team for the largest Ceramic plant will be presented.

## 2. Ceramic Industry in Jordan

A wide range of products are manufactured by the Ceramic Industry in Jordan. Glazed and unglazed floor tiles, wall tiles, sanitary ware and potteries are examples of the products of this industry. The technologies used in Ceramic industry in Jordan vary from relatively primitive technologies, in some of the small plants, to the state of the art in others.

There are many small Ceramic plants in Jordan, in which small potteries are made either manually or using simple technologies. On the other hand, there are six large Ceramic plants in Jordan, in which ceramic tiles as well as sanitary wares are produced. These largest three are: Jordan Ceramic industries Company, Arab Ceramic Industries Company, International Ceramic Industries, and Al-Mas Ceramic Company.

Raw material used in all these plants similar; the raw material consists of clay, quartz, feldspar, dolomite, gums, etc. Also, the basic process of manufacturing in these plants is also similar. This process consists of: raw-material preparation, grinding and mixing, shaping or pressing to produce greenware, drying, glazing, firing in kilns, inspection and testing and packing and dispatching.

Local studies made by National Energy Research center in Ceramic industry, on a sample of the largest ten plants, revealed that the initial investment in these plants is about 21 Million JD, the total number of employees is about 1400, the percentage of energy-cost relative to the total energy-cost in these plants is about 25 %.

## 3. Sample of Plant-Profiles, Energy-Profiles & Energy-Saving Projects

The plant profiles, energy profiles, and summary of the energy-saving recommendations for Arab Ceramic Industries Company, International Ceramic Industries Company, and Ibrahim Mousily Company will be presented herein.

### *3.1 Arab Ceramic Industries Company*

#### *3.1.1 Plant-Profile*

The plant is situated in Sahab Industrial Estate in the southern part of Amman. It is one of the oldest Ceramic plants in Jordan. The plant has the ability to produce a variety of Ceramic products like floor and wall tiles, and sanitary ware.

*3.1.2 Energy-Profile*

The annual total energy-bill in Arab Ceramic Industries Company was about 120,000 JD according to data taken in 1996. In addition to the electrical energy used to drive the huge number of electrical motors in the plant, thermal energy is supplied by LPG which is used in the ceramic firing kilns.

In November 1996, NERC has performed a preliminary energy-audit that covered all the energy-using utilities in the plant; such as electrical system, lighting system, electrical motors, spray dryers, kilns, electric ovens, compressed air system and hot air furnaces

The study revealed that about 28 % of total energy-bill can be saved through implementing the recommendations and the proposed projects.

The following Table-1 summarizes the main energy-saving proposed projects.

**Table-1: Main Energy Saving Projects Proposed for Arab Ceramic Industries Company**

| No | |
|---|---|
| **1** | **Electrical Systems:**<br>- Loading pattern of transformers<br>- Power factor correction |
| **2** | **Electric motors**<br>- Reshuffling of undersized motors -Star mode operation of underloaded motors<br>- Installation of soft starters for variable load motors<br>- Application of high-efficiency motors<br>- Application of electronic variable-speed drives in place of mechanical variable-speed drives. |
| **3** | **Spray Dryers**<br>- Efficiency evaluation for identifying opportunities for energy-saving. |
| **4** | **Sanitary ware kilns**<br>- Waste heat recovery from exhaust flue gases |
| **5** | **Tiles Kilns**<br>- Carrying out heat-balance of the kilns, by indirect heat-loss method to identify energy-saving potential.<br>- Improving excess air level in burners.<br>- Upgrading of the insulation in the firing zone, by using more energy- efficient insulation. |
| **6** | **Hot water Generators**<br>- Improving the efficiency of the hot water by tuning up the combustion.<br>- Improving the operational procedures to save energy.<br>- Application of solar water-heaters. |

### *3.2 International Ceramic Industries Company:*

*3.2.1 Plant-Profile*

The plant is located in the city of Mafraq. It started production in 1995. The design capacity of the plant is 1,400,000 m2 of tiles. The actual capacity in 2000 was 1,440,000 m2 of tiles. The plant produces floor and wall tiles. Also, Granite is produced in the plant. The plant works 312 days, 24 hours/day continuously during the whole year.

*3.2.2 Energy-Profile*

In addition to electrical energy that is used extensively in the plant, Kerosene is used as a source of thermal energy in kilns and dryers. There are two 1000 kVA electrical transformers in the plant.

**Table-2: Main Projects for Saving Energy, Proposed for International Ceramic Industries Company**

| No | |
|---|---|
| **1** | **Electrical Systems:**<br>Energy saving in the areas of:<br>- Incoming voltage condition and distribution losses<br>- Maximum-demand management, including diesel-generator utilization.<br>- Electric bill analysis.<br>- Submetering |
| **2** | **Electric Motors**<br>Studying the loading pattern of motors, to identify the following energy-conservation opportunities:<br>- Reshuffling of motors (between overloaded and under-loaded).<br>- Star mode operation of under-loaded motors.<br>- Installation of soft starters for variable load motors.<br>- Application of high-efficiency motors.<br>- Application of Adjustable Speed Drives.<br>- Proper sizing of motors |
| **4** | **Kiln and Spray Dryer:**<br>Energy-saving measures that involve operation, combustion, loading pattern, insulation and waste heat recovery . |
| **5** | **Compressed Air System**<br>- Energy saving through studying the compressed-air system, to find the most suitable operational mode of the compressed-air system. Compressed-air generation, distribution and utilization. Also, energy-saving through compressed-air leakage survey, using ultrasonic leak- detection technology, and accordingly locating leakage points. |
| **6** | **Lighting system**<br>- Measurement of lux level.<br>- Study of operational improvements for energy-savings.<br>- The use of energy - efficient retrofits |

Based on the data taken for the year 2000, the thermal-energy cost constitutes about 70 % of the total monthly energy-bill, while the remaining 30 % goes for electrical energy consumption.

The Preliminary study for this plant was performed in November 2000. This study indicated that the potential of energy-saving in the plant is 22%. The Table-2 summarizes the main energy-saving proposed projects.

**Table-3: Main Energy Saving Projects Proposed for Ibrahim Mousily and Partners' Company**

| No | |
|---|---|
| **1** | **Electrical Systems:**<br>Energy saving in the areas of: - incoming voltage-condition and distribution losses<br>- Power-factor management. |
| **2** | **Electric motors**<br>Studying the loading pattern of motors, to identify the following energy-conservation opportunities:<br>- Reshuffling of motors (between overloaded and under-loaded).<br>- Star mode operation of under-loaded motors.<br>- Installation of soft starters for variable load motors.<br>- Application of high-efficiency motors.<br>- Application of Adjustable Speed Drives.<br>- Proper sizing of motors |
| **3** | **Kilns**<br>Energy-saving measures that involve operation, combustion, loading pattern, insulation and waste-heat recovery. |
| **4** | **Compressed Air System**<br>- Assessment of capacity by free air delivery test.<br>- Assessment of leakage by no-load leakage test and ultrasonic leak detection.<br>- Determination of optimum pressure setting.<br>- Resizing necessary pipes that are thought to be inadequately sized.<br>- Energy-saving through studying the compressed-air system to find the most suitable operational mode of the compressed-air system. Compressed-air generation, distribution and utilization. Also, energy-saving through compressed-air leakage survey, using ultrasonic leak-detection technology, and accordingly locating leakage points. |
| **5** | **Lighting system**<br>- Measurement of lux level.<br>- Study of operational improvements for energy-savings.<br>- The use of energy - efficient retrofits |

### *3.3 Ibrahim Mousily and Partners:*

*3.3.1 Plant-Profile*

The plant is located in Alkustul area in Amman. The plant was established in 1994.The plant produces various types of sanitary-ware, based on Italian designs and decorations. The production rate in 1996 was 3000 sets of first-grade sanitary wares.

The plant has the following manufacturing equipment: Mixers, molding hall, two shuttle kilns operated by LPG for the first firing stage, electrical kiln for the second stage.

*3.3.2 Energy -Profile*

In addition to LPG used in shuttle kilns and electrical energy used allover the plant, Diesel is used extensively in the hot-air generators. The annual total energy-bill in 1996 was 51,782 JD; about 20 % of it is paid for the electrical energy, 22 % of it is paid for Diesel, and the remaining 58 % is paid for the LPG

The Preliminary study for this plant was performed in August 1997. This study indicated that the potential of energy-saving in the plant is 25%.

## 4. Detailed Energy Audit for the largest Ceramic Plant in Jordan

*4.1 Plant-Profile*

A detailed energy audit was performed by (NERC) for one of the largest Ceramic plants in Jordan in 2003. The purpose of this study was to assist this plant in reducing the energy-bill, to disseminate the results to other similar local Ceramic plants and to be used as a tool in improving the energy-efficiency in these plants. The purpose of the present paper is also to disseminate the results of the detailed energy-audit, in order to benefit all relevant parties.

The ceramic plant under detailed audit produces a wide range of glazed and unglazed tiles, as well as a variety of sanitary wares. The plant comprises two plants; one was built in 1993 and the other was built in 1997. The 1993 plant comprises two sanitary-ware kilns and one single-firing tile-kilns, while the 1997 factory has a system of two tile-kilns; first tiles are fired in the biscuit-firing kiln, and these tiles are fired again in the glazed-tiles kiln. This system is called a double firing system. The fuel used in all these kilns is kerosene, excluding the very old German kiln in which Diesel is still used.

*4.2 Methodology Used*

The energy-saving measures proposed in this detailed audit were mainly from [3,4,5,6] developed by NERC team, in addition to [10,11].

In order to assess the energy-conservation opportunities in the plant, energy-conservation auditing specialists from the National Energy Research Center

**Table-4: Summary of the Specific Energy-Consumption in the Plant**

| Total Sanitary Energy cost JD | Total 93 Energy Cost JD | Total 97 Energy Cost JD | Sanitary Specific Energy Consum-ption cost/JD/ton | 93 Specific Energy consum-ption cost JD/M$^2$ | 97 Specific Energy Consumption cost JD/M$^2$ |
|---|---|---|---|---|---|
| 32973 | 16849 | 51960 | 113 | 0.62 | 0.78 |
| 25056 | 21724 | 48473 | 120 | 0.48 | 0.54 |
| 25627 | 28017 | 54529 | 124 | 0.43 | 0.53 |
| 32042 | 30938 | 60539 | 119 | 0.44 | 0.68 |
| 32059 | 27826 | 54806 | 112 | 0.38 | 0.69 |
| 32887 | 29803 | 57420 | 133 | 0.36 | 0.64 |
| 30423 | 29876 | 58159 | 116 | 0.38 | 0.53 |
| 31969 | 24620 | 54093 | 109 | 0.36 | 0.79 |
| 32562 | 31793 | 53594 | 107 | 0.44 | 1.21 |
| 32699 | 32913 | 63627 | 107 | 0.40 | 0.61 |
| 31630 | 28075 | 56295 | 114 | 0.39 | 0.53 |

(NERC) started a detailed audit and the physical inspection of the plant's operations and facilities in June 2003. All relevant utilities were inspected. Reviews of the available production and energy-documentation were carried out, and detailed measurements, data logging, and analyses were performed during the detailed energy audit.

*4.3 Energy-Consumption Profile*

The above figure shows that in the 1993 Sanitary-ware plant, the energy related to

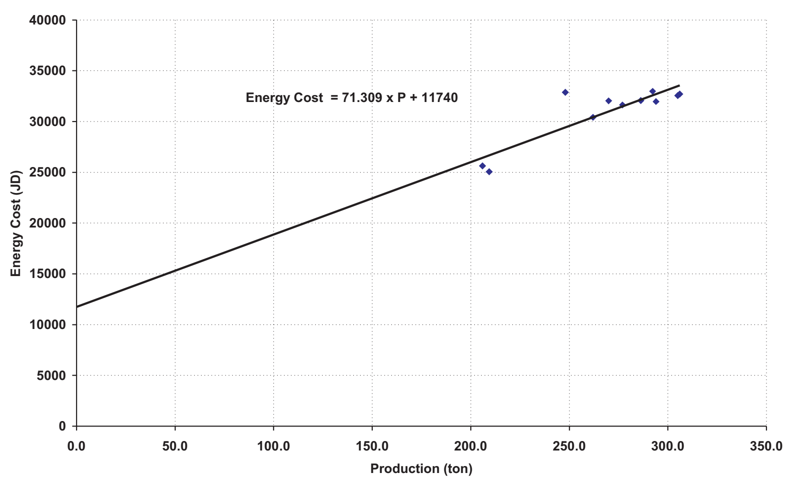


**Figure-1: The Production Versus Energy-Cost in the Sanitary factory [2]**

production was analyzed, and it was found that this value is 71.3 JD/Ton, while the energy not related to production was estimated to be 11,740 JD monthly.

The energy not related to production represents the electricity and fuel used for various purposes, which are not related to production; such as lighting, producing compressed-air and compressed-air leakage, running office equipment and air conditioners for office cooling, powering machine-tools in the workshop, running pumps, unnecessary idling of production- equipment and operation of the kilns with no production, as well as unnecessarily prolonged preheating of kilns prior to production start.

It was suggested to minimize the energy not related to production, by using high-efficiency lighting, turning off machines that are not in use, especially on the glazing line, reducing compressed-air leakage, and minimizing the idling periods for kilns and spray dryers.

The specific energy-consumption is represented by the cost of energy used to produce one ton of products. The specific energy consumption in the 1993 and 1997 plants was analyzed.

It was found the as the production quantity increases, the specific energy-consumption is considerably reduced. All values of energy related to production, energy not related to production as well as specific energy consumption were calculated for all factories.

It is estimated that for the sanitary factory, the specific energy-consumption, as a function of monthly production, is currently represented by the following equation:

$C = e/P + m$ [2]
where:
$e$ = monthly energy-cost not related to production (JD) = 11740 JD
$P$ = monthly production in tons
$m$ = Related energy to production per ton of product (JD/ton) = 71.3 JD/Ton

When production is very high, $e / p$ becomes very small and the value of C approaches m. But, when production becomes low, then (e), which is the energy not related to production, becomes very important and C increases rapidly.

A point lying below the line represents improved efficiency-management in energy-use. Over a period, the proposed established energy-committee should be trying to bring the specific energy-consumption curve lower and lower.

The point to grasp is that specific consumption C varies with production. By learning to use and manage energy more efficiently, this can lower the curve, so that when production is increased again, they will be using less energy and will be more competitive.

The following figure shows the specific energy- consumption for the Sanitary factory.

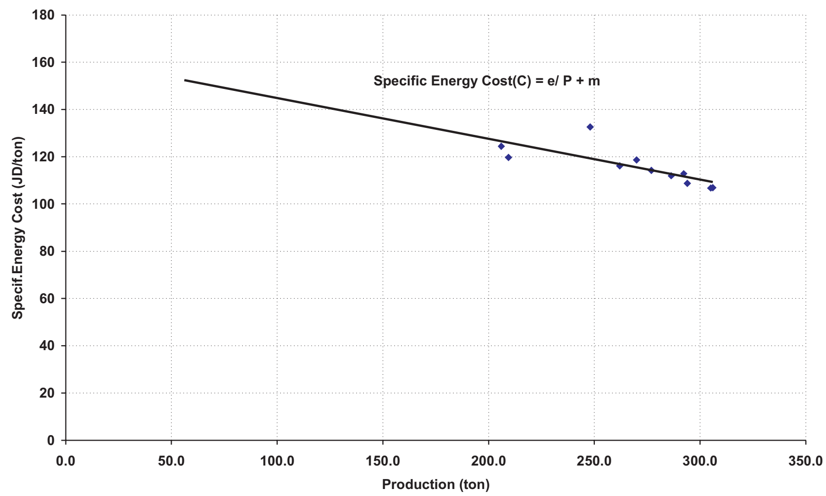


**Figure-2: Specific Energy-Consumption in the Sanitary Factory[2]**

The same previous discussion applies to the 93 factory. Figure-3 shows the monthly production (P) in $m^2$ versus monthly total energy cost in JD (E) in the 93 factory for the year 2002, while Figure-4 shows the specific energy consumption for this plant.

Also, the same analysis applies to the 97 factory. Figures 5 and 6 represent the energy-cost versus production and specific energy cost for 97 factory.

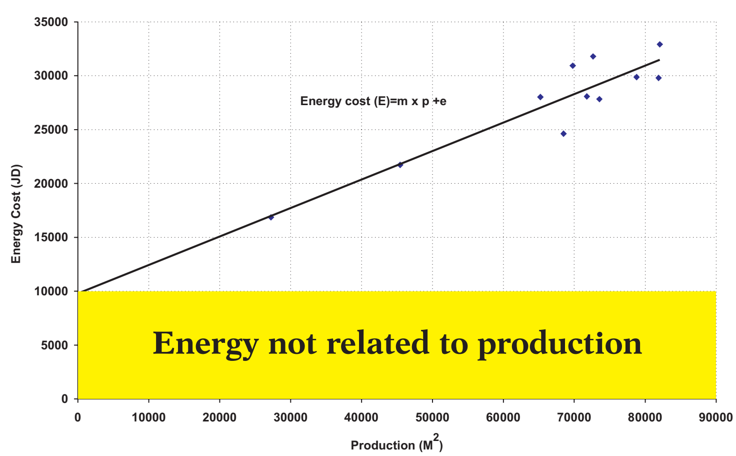


**Figure-3: Production Versus Energy-Cost in the 93 Factory [2]**

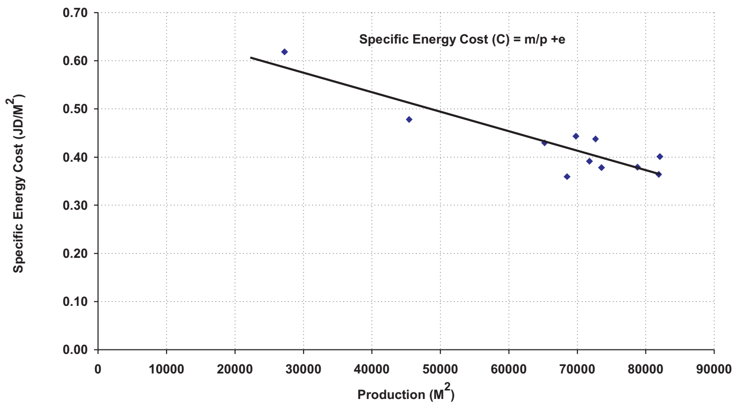


**Figure-4: Specific Energy-Consumption in the 93 Factory [2]**

*4.4 Investigated Facilities*

The facilities investigated included: the electrical systems, Diesel generators, refrigeration system, compressed air system, and kilns.

*4.4.1 Electrical System:*

In the electrical system, electricity is received from the electric company through the 11 kV lines. The company has five transformers 11/0.4 kV each. The company consumes 320,000 JD annually of electricity. The average kWh purchased from JEPCO (Jordanian Electric Power Compnay) is 0.038 JD/kWh (including the peak penalty). The electric tariff for the company is 0.035 JD /kWh for day consumption (7:00   23:00), and 0.023 JD/kWh for night consumption (23:00   7:00) and 3.05 JD/kW is paid as peak penalty.

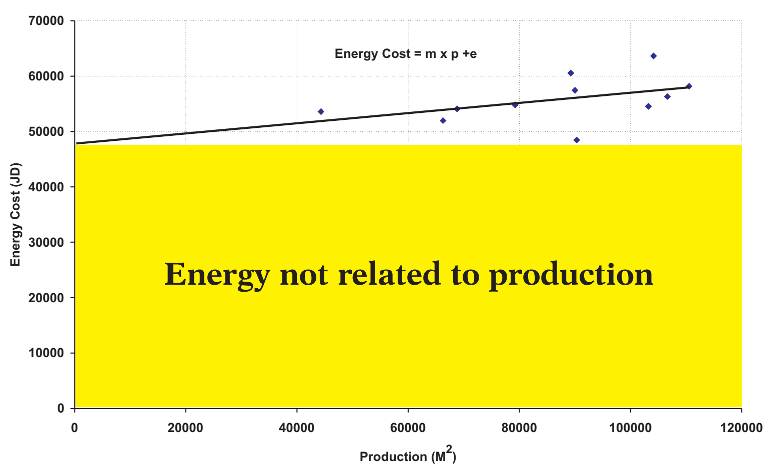


**Figure - 5: Production versus Energy-Cost in the 97 Factory [2]**

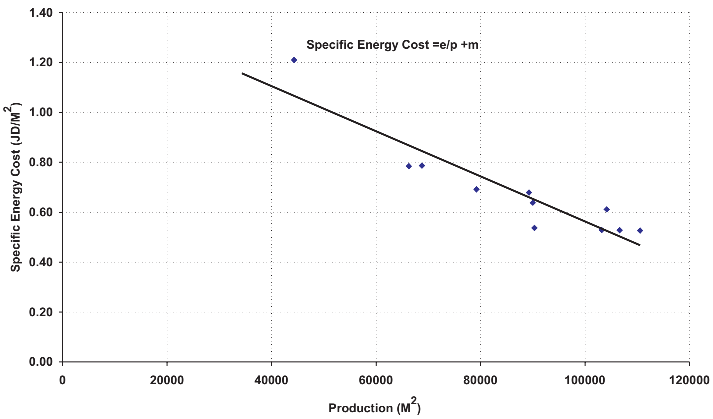


**Figure-6: Specific Energy-Consumption in the 97 Factory [2]**

The following figure shows the monthly electrical consumption in the plant through the years 2001 to 2003.

***i. Spray Dryer***

The spray dryer for the 93 factory operates from 7:00 AM until 9:30 PM, four days a week. It is shut down Monday, Thursday, and Friday. It is suggested that the dryer is shut down at seven o'clock (During the peak period). If there is a shortage in production-material, then the dryer will be operated on one of the off-days to make up for the shortage. The spray dryer consumes around 52.6 kW, as shown in figure 2.9 below. If this recommendation is implemented, the company will save 1926 JD annually.

***ii. De-dusting (93 Plant)***

A 55 kW motor is used to remove dust from the mills and dryers area, and is being controlled from the German dryer-control panel. The plant personnel do not agree on the running hours of the motor, but they think it should be running from 8AM to 3PM. The motor has no indication to tell if it was on or off, and is left running practically all the time. A timer should be installed to control the operation of this motor. The average consumption of the motor was measured and found to be 13.5 kW It is estimated that 35,640 kWh can be saved annually (assuming 8 hours off-time only), which translates into 1,354 JD annually. Another 494 JD can be saved by reducing the peak-demand penalty.

After further investigation, it was concluded that the motor can be eliminated and a duct can be run to the deducting system in the preparation area (cost of around 2000 JD). This will reduce the annual consumption by another 31,185 kWh and save the company 1,185 JD (shutting off the motor in the 7 hours it is supposed to be in operation during the day). This will bring the total savings to 3033 JD/yr.

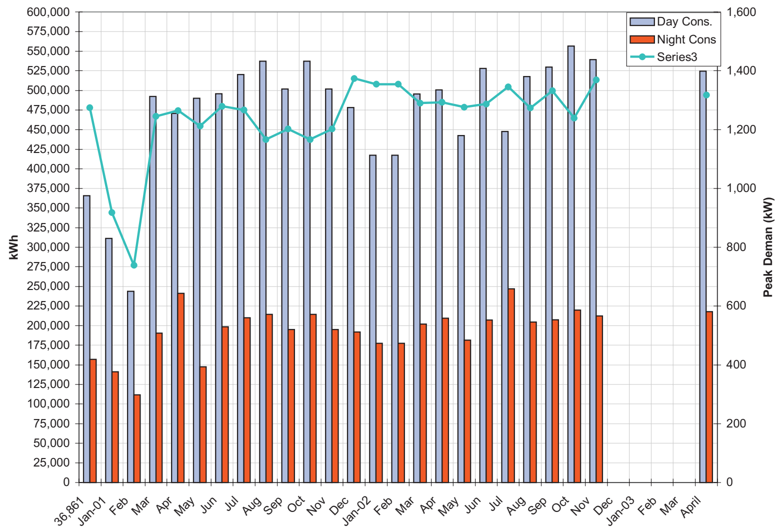


**Figure - 7: Monthly Electricity-Consumption 2001-2003**

***iii. Well Pump***
A 37 kW pump is used to fill up the water-reservoir from the underground well. The measured load on the pump motor was around 29.6 kW. The pump is operated manually and without any control. It is suggested that a timer be used to prevent starting the well-pump during the peak period. This will save the company around 1,083 JD annually

***iv. Electronic Ballast***
The plant utilizes some 1776 36-Watt and 26 18-Watt fluorescent tubes for lighting throughout plants and offices. All of the fixtures utilize the conventional magnetic ballast, which consumes around 15 watt each. All conventional ballasts should be replaced with electronic ballast, which consumes about 3 Watt each. Beside the energy saving in the ballast, the fluorescent tube will consume less energy when used in conjunction with the electronic ballast. It is estimated that a total of 20 Watt /tube for the 36-Watt tubes and 18 Watt/tube for the 18 Watt tubes will be saved by using the electronic ballast. Assuming 8 hours operation for the management building, and the sanitary plant and part of the tile-plant and 16 hours for the tile-factory, the company will save 103,139 kWh annually (based on 330 working days annually). This will translate into 3919 JD/yr.

***v. High Efficiency Motors***
It was suggested to replace many of the existing motors with high-efficiency motors in the plant, the expected energy saving resulting from this measure is 191,085 kWh/yr, with a cost saving of 7261JD/year. The Cost of implementation is

8762.5 JD, which means a pay-back period of about 1.2 years.

The overall annual saving in the electrical systems amounts to 17,200 Jordanian Dinars (JD).

*4.4.2 Refrigeration System:*
*i. Facility Description:* The existing refrigeration system in the factory comprises 2 chillers with a capacity of 27 tons and 10 tons for the 93-plant and 97-plant, respectively. The chillers are air-cooled systems. Each chiller has two reciprocating semi-hermetically sealed compressors and uses refrigerant R-22 in the primary cycle. The capacity of the compressors is controlled in steps by cylinder unloading, with corresponding steps in the chilled-water flow-temperature. These systems serve the tile presses utilities through the shell-and-tube heat exchanger.

Tons of refrigeration (TR) was determined indirectly for the chillers, by measuring the chilled- water flow-rate and measuring the chilled water and return-water temperature. A Panametrics Transport PT868 ultrasonic flow-meter was mounted to the return chilled-water pipe, to measure the water flow rate, where the chilled water and return water temperature were measured using Testo 454 Data-logger with surface-temperature sensor. The power consumptions were measured using Floke Power Analyzer

*ii. Observations:* The estimations above show that the COP values were of 2 and 1.2 for chiller (93) and chiller (97); respectively. The recommended value of COP for chillers is usually more than 3.0.

The specific energy consumption (or commonly called chiller efficiency) was 1.76 kW/TR and 3.0 kW/TR for chiller (93) and chiller (97) respectively.

The recommended value of chiller efficiency is less than 1.0 kW/ton. The low value of COP and high kW/ton of chiller (93) are probably due to old manufacturing criteria. It was shown that the time-duration of running chiller (97) supply pump was 1/3rd of the whole running time of the tile press. This short time of pump operation indicates that the chiller power is oversized, which causes chiller-efficiency to be low.

The study recommended installing new chillers instead of the existing ones, due to the low coefficient of performance in these chillers. Moreover, since there are many chimneys in the plant due to the kilns, it was suggested to make use of this waste-heat in installing an absorption chiller. The annual savings in the refrigeration system is about 5,370 JD.

*4.4.3 Compressed Air-System:* In the compressed air system, the free-air delivery for all compressors was measured, as well as the specific power consumption. The study recommended the operation of the most efficient compressors. The annual saving amounts to 700 JD.

*4.4.4 Kilns:*

*Kilns Description:* There are three kilns in the 93-plant; two of them are for sanitary-ware firing, they are the German and the Italian kiln, and the third one is for ceramic tiles firing.

The fuel used in the Italian sanitary-ware kiln and tiles kiln is Kerosene, while the fuel used in the German kiln is Diesel.

In the 97-plant there are two tiles kiln; one is for biscuit (body) firing, while the other is for the glazed tiles that are fired in the first kiln. The two 97-plant kilns are fueled by Kerosene.

The five kilns constitute the major fuel cost in Jordan Ceramic Industries Company.

The Kilns showed the largest opportunities for energy-saving. The recommendations showed that the speed of the kiln cars in two sanitary-ware kilns should be increased. The calculations were based on a proposed mathematical relation between the kiln-efficiency and the fuel- consumption at various speeds of kiln cars.

Uniform firing is essential to ensure rapid firing. Uniform temperature ensures stable product- quality and improved yield.

Although not widely known, the faster the kiln-car pushing speed, the less fuel will be consumed in the tunnel-kiln; this will contribute to the energy conservation in the plant.

In order to calculate the saving resulting from faster firing, the following analysis is made:

Previous data from past records about the average fuel-consumption at two different car- speeds was employed:

First Speed (S1): 1 car per 50 minutes. This means that the current speed is (24X60)/50 = 28.8 cars/day.

Average Fuel-consumption at this speed (F1) = 3160 Liters of Kerosene/day.

Second Speed (S2): 1 car per 48 minutes. This means that the current speed is (24X60)/48 =30 cars/day.

Average Fuel consumption at this speed (F2) = 3200 Liters of Kerosene/day.

Assuming that the kiln efficiency is $\eta$. Therefore, the fuel required to fire the products of 28.8 cars daily is given by: Fuel consumption X kiln efficiency.

This is equal to F1X $\eta$. The remaining portion of the input fuel energy is spent in maintaining the kiln temperature. This energy is equal to (1- $\eta$) X F1. This value should be constant at any speed of the kiln cars. Now, if the kiln is operated at a new different speed (S2). The expected new fuel required to heat products at speed2 is: Fuel consumption at speed 2= Fuel consumption at speed 1 X (Speed 2/Speed 1). In Symbols; Heat required to fire products at speed 2 = (F1X $\eta$) X (S2/S1). Therefore, the total heat spent at speed 2 is the sum of the heat spent in firing the products+ the heat required to maintain the kiln temperature (which is constant). Therefore:

$$F2 = (1-\eta) X F1 + (F1 X \eta) X (S2/S1) \qquad .... (A)$$

In this equation. , F1=3160 Liters of Kerosene/day = 131.66 Liters/hour, F2=3200 Liters of Kerosene/day = 133.36 Liters/hour. S1= 28.8 cars/day, S2= 30 cars/day. If this equation is solved for the kiln efficiency ($\eta$), the calculated value of the kiln efficiency is 31 %.

The above analysis is made based on [7].
Now, to calculate the fuel consumption per car, the following analysis is carried out.

a) Kiln works at 28.8 cars/day:
(131.66 Liters/hour X 24 Hours/day)/(28.8 cars/day) = 109.7 Liters /car.

b) Kiln works at 30 cars/day
(133.36 Liters/hour X 24 Hours/day) /(30 cars/day) = 106.6 Liters/car.

Thus, an increase in the car speed from 28.8 cars/day to 30 cars/day will increase the Kerosene consumption by about 1.3 %. But, in terms of the per-car value, the value change from 28.8 cars/day to 30 cars/day shows that an average energy saving of about 3 % is achievable. Thus, less fuel consumption will result in less cost.

Therefore, if the kiln-speed is increased say to 35 cars/day, then the above-mentioned equation (A) can be solved for F2 (the fuel consumption that corresponds to this new speed). i.e., the values substituted in this equation are as follows: F1 = 131.66 Liter/hour, S1= 28.8 cars/day, S2 (proposed) = 35 cars/day, Kiln efficiency ($\eta$). Then the result of the calculation will give F2= 140.44 Liters/hour, which is equal to 3370 Liters/day. Therefore, the per-car consumption will be:
(3370 Liters/day)/ (35 cars/day) = 96.8 Liters/car.

If we recall that the per-car consumption at the current speed (S1= 28.8car/day) is

109.7 Liters/day, this means that a saving of 12 % resulted only because of speed increase. This means that the annual energy-cost saving resulting from this measure is: 0.12 X annual amount of saved kerosene =0.12 X 1071400 Liters = 128568 Liters. Therefore, the cost saving is 0.13 JD/Liter X 128568 Liters = 16700 JD. There is no investment needed for this measure, therefore the payback period of this measure is immediate.

This calculation show clearly that firing this kiln at a faster rate will definitely result in a considerable saving of energy. This can be achieved, if the production follows a carefully-planned long term scheme, which is based on the coordination between all relevant production-departments and the available production-resources in this kiln.

Also, in one of these sanitary kilns, it was recommended to replace some parts of the kiln cars with low thermal-mass (LTM) material [8,9]. It was also recommended to make use of the wasted hot air in the cooling-fans to supply it to the combustion-air fan for the burners. Tuning up of the combustion was a common recommendation for all kilns. In one of the very old sanitary-ware kilns, it was recommended to replace the kiln by a more efficient kiln. All recommendations that dealt with kilns showed a potential annual saving of 139,000 JD.

The detailed energy-audit, in general, showed that about 204,000 JD could be saved annually. This amount represents about 30 % of the total energy bill and a 3326 Tons of $CO_2$ emissions reduction annually. The required investment is expected to pay for itself within two years.

## 5. Conclusions

The performed preliminary energy-audits showed that an average saving-potential in most of theses plants is about 25 % of the total energy-bills in these plants, which constitutes a considerable portion of the total production-cost.

This fact was verified through the detailed energy-audit performed by NERC team for the largest Ceramic Plant in Jordan, which showed an energy-saving potential of about 30 %, with an average pay-back period of about 2 years.

The results of the detailed energy-audit can be disseminated to other Ceramic plant, because of the similarity in the production-process between these plants and the plant where the detailed energy-audit was carried out.

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# ELECTRIFICATION OF REMOTE COASTAL AREAS THROUGH WIND-ENERGY

**Majid ul Hassan**
*Director (Projects)*
*Pakistan Council of Renewable Energy Technologies*
*Islamabad, Pakistan*

**Abstract**

*It has been estimated that with the present utilization of resources, the country will run out of oil and gas reserves in one and a half decade. There is, thus, a strong need to take measures to tap other resources of energy, which are abundantly available in Pakistan. The exploitation of these resources for production of electricity on local basis, under participatory system of development, would supplement energy being provided by WAPDA, at a much lower cost due to the avoidance of laying high-tension cables, transformers, and meters, etc., and the manpower required to maintain the system. Balochistan is a large but thinly populated province of Pakistan. The situation of electrification in Balochistan is serious, as a vast majority of the population is without access to electricity. Many villages and districts of Balochistan do not have centralized electricity-grid and there is no hope, in the near future, to have one because the extension of grid to such remote and scattered settlements is neither practical nor economically viable.*

*In Balochistan, out of a total number of 13,700 villages, WAPDA has merely electrified 3,154 villages due to the high cost involved in developing the necessary infrastructure. Not surprisingly, this situation is a source of discontentment among the people of the Province. Pakistan has a considerable potential of wind-energy in the coastal belt of Balochistan and Sindh, as well as in the desert areas of Punjab and Sindh, which if utilized effectively, can not only electrify all remote coastal villages, but the electricity so produced also can be fed to the national grid. This renewable source of energy has however, so far, not been utilized. Recently, fourteen small wind-turbines (300-500 watts) were procured and installed by PCRET under Sino-Pak S&T Protocol. Being encouraged by performance of these small wind- turbines, a further 120 wind-turbines (100 of 500 watts and 20 wind-turbines of 5kW each) are being installed. The small wind-turbines of 500 watts have been imported from China and that of 5kW from Spain. Efforts are also being made to initiate local manufacturing of 500 watts wind-turbines under ToT from China and (5-10) kW wind- turbines under ToT from some European countries.*

**Introduction**

Wind is an important source of energy. It has been estimated that 1% of the daily wind-energy available on Earth is equivalent to the present annual world total energy-consumption. The world's wind-energy resources are highly dispersed and prevalent mostly at sites where it is in the form of storms and hurricanes.

The world's wind resources are extremely large and well spread throughout six continents. The total available wind-resource in the world today that is technically recoverable is 53,000 TWh per year – about four times bigger than the world's entire electricity consumption in 1998. The International Energy Agency predicts that the world will double its electricity consumption by 2020, and new ways will have to be found to meet this increased demand. It is unlikely that wind will ever be a limiting factor in the development of this thriving energy-industry.

Wind-energy, the success story of the 1990s shows no sign of slowing down as we enter the new millennium. The most dynamic source of renewable power for many years running, this relatively young industry continues to expand rapidly, generating a new way of meeting the world's growing energy-needs, in addition to giving clean, green electricity. As one of the most advanced and commercially available renewable-energy technologies, wind is now becoming more price-competitive; given an increasing awareness of the need to reduce green-house gas emission and the equally important need for new sources of electricity, wind has a significant role to play in the future.

**Global Wind-Energy Generation**

By the end of 2002, total world cumulative wind-capacity was some 32,000 MW, which equates to just 0.4% of the world's electricity supply, so there is some way to go yet before wind can be said to have made a marked impression on a global energy-scale. Moreover, caution is necessary in interpreting even this figure since capacity does not equate to wind-power actually generated. Country-wise capacity of wind-energy generation is given in Table-I. The top five countries exploiting of wind-power are Germany, Spain, USA, Denmark and India. Germany at the top, with total installed capacity of 12,001 MW, generates 39% of the world's total wind-energy generation. Region-wise wind-energy generating capacity is depicted in Figure- I. Europe is at the top with 75% of the total world's generating capacity, which reflects strong commitment towards exploiting the wind-energy potential. The wind-power generating capacity of USA is 15% and that of rest of world is 10% only.

The relative decline in the wind-turbine industry of US from holding three quarters of the world market in 1990 to having 15% of it by the end of 2002, is because of the uncertainty over a Production Tax Credit (PTC) that has to be renewed every two years.

In contrast, Germany the world's wind "Superpower" has consistently required utilities to purchase electricity generated from renewable resources (Wind, Solar, Biomass, etc.), even at premium, since early 1990s. Now it has almost 40% of the world's installed capacity. Denmark has similarly encouraged exploitation of wind-resources and now meets over 10% of its energy requirement from this resource.

India, too, realizes the need for exploitation of wind-energy and has become the world's fifth largest market for wind-turbines, as well as the largest in the developing world.

**Wind the World's Fastest Growing Source of Energy**

Wind is a rather more variable resource than supplies of fossil fuels to conventional power-stations, so the average proportion of capacity actually utilized would be less for wind than for conventional power. Nevertheless, wind remains the world's fastest growing source of energy and the forecasts suggest a rosy outlook. The fact remains, however, that wind is just becoming competitive in cost per kilowatt hour (kWh) with conventional generation, so an element of subsidy is needed until the industry achieves a critical mass at which it can compete. Any uncertainty in terms of the financial support can affect future prospects of wind-energy.

**Cost Driver**

Cost of producing wind-energy at prime wind sites has fallen dramatically – for instance in the US from 38c/kWh in the early 1980s to 4 cents/kWh in 2001. A few long-term contracts were even signed at 3 cents/kWh (Figure-II).

Technological improvement and economies of scale have propelled this reduction. Large turbines are intrinsically more efficient than smaller ones, explaining the present growth of emphasis on turbines of 1MW plus. Units of 2.5 MW are becoming state-of-the-art, and, for the offshore wind-projects and low-wind onshore sectors, turbines as large as 5-6 MW are in prospect.

**Small Wind-Sector**

The wind-energy market is booming for the small wind sector as well, and companies involved in the manufacture of small-scale turbines report encouraging growth, an average of 30% per annum. With a projected market-potential of Euros 550 million by 2005, there is significant scope for further growth in this sector.

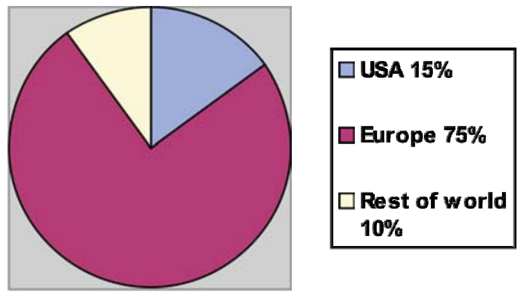
Utilizing the same technology as the larger commercial-scale machines, small wind-turbines range from battery chargers up to 225kW machines, although the majority of installations tend to be less than 30kW in capacity. Operating as either stand-alone systems or hybridized with other power sources, such as solar or diesel, this produces a robust technology, capable of unattended operation virtually anywhere in the world.

Long recognized as an ideal solution for remote or isolated locations, small wind-systems offer a huge potential benefit to countries in the developing world, where an absence of natural resources or a supporting electrical infrastructure makes a grid supply unlikely. Current estimates put the total number of people living beyond the grid at about two billion, and renewable technologies, such as wind, can make an important contribution to economic and social development in such countries.

**Table - I: Country-Wise Capacity of Wind-Energy Generation**

| Wind-Energy markets (by installed capacity in MW) | 2001 year-end total | 2002 additions | 2002 year-end total |
|---|---|---|---|
| **Country** | | | |
| USA | 4275 | 410 | 4685 |
| Canada | 98 | 40 | 238 |
| North America Total | 4473 | 450 | 4923 |
| Germany | 8754 | 3247 | 12001 |
| Spain | 3337 | 1493 | 4830 |
| Denmark* | 2489 | 497 | 2880 |
| Italy | 682 | 103 | 785 |
| Netherlands* | 486 | 217 | 688 |
| UK* | 474 | 87 | 552 |
| Sweden | 293 | 35 | 328 |
| Greece | 272 | 4 | 276 |
| Portugal | 131 | 63 | 194 |
| France | 93 | 52 | 145 |
| Austria | 94 | 45 | 139 |
| Ireland | 124 | 13 | 137 |
| Belgium | 32 | 12 | 44 |
| Finland | 39 | 2 | 41 |
| Luxembourg | 15 | 1 | 16 |
| EU Total | 17315 | 5871 | 23056 |
| Norway | 17 | 80 | 97 |
| Ukraine | 41 | 3 | 44 |
| Poland | 22 | 5 | 27 |
| Latvia | 2 | 22 | 24 |
| Turkey | 19 | 0 | 19 |
| Czech Republic | 6.8 | 0.2 | 7 |
| Russia | 7 | 0 | 7 |
| Switzerland | 5 | 0 | 5 |
| Hungary | 1 | 1 | 2 |
| Estonia | 1 | 1 | 2 |
| Romania | 1 | 0 | 1 |
| Other Europe Total | 123 | 112 | 235 |
| India | 1507 | 195 | 1702 |
| Japan | 275 | 140 | 415 |
| China | 400 | 68 | 468 |
| Australia | 72 | 32 | 104 |
| Egypt, Morocco, Costa Rica, Brazil, Argentina & others | 225 (est.) | - | 225 (est.) |
| Other Total | 2479 | 435 | 2914 |
| World Total | 24390 | 6868 | 31128 |

***Source:*** *(AWEA & EWEA)*




**World Total: 31,127 MW**

**Figure-I: Total of World's Wind-Power Generation by Region**

**Potential of Wind-Energy in Pakistan**

The coastal areas are dominated by sea breezes, which have a strong diurnal pattern. During the day, the land heats up and the air adjacent to it starts to rise. The sea breeze first starts in a narrow coastal zone but penetrates inland during the day, usually between 20-40 Km but in exceptional cases where the temperature gradient becomes very large such as the coastal area in Balochistan, upto 100 Km. The sea breeze starts in the afternoon reaching its maximum late in the afternoon. In the evening, when the temperature difference decreases, the sea breeze fades away.

Pakistan Metrological Department (PMD) had installed wind speed data recording towers in the coastal belt of Sindh and Balochistan. According to their report, the available wind-potential is strong enough to suite small stand-alone wind-energy conversion-systems as well wind-farms. Average annual wind speed of 14 sites, recorded at 10 meter and 30 meter tower heights, is given in Table II and III, respectively.

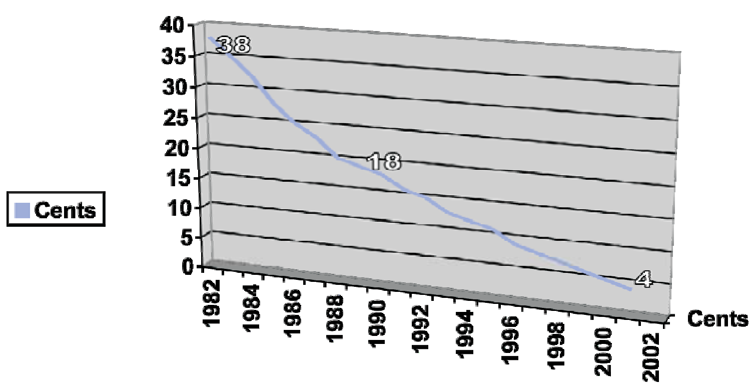



**Figure-II: Cost of Wind-Energy in U.S. (From 1982-2002)**

**Small Wind-Turbine (Stand-Alone Systems)**

In the coastal belt of Balochistan and Sindh and the Thar desert of Sindh, there are a number of remote isolated population pockets, which cannot be supplied electricity from the National Grid. For such remote and isolated locations, small, stand-alone wind-systems offer a huge potential benefit, where absence of natural resources or a supporting electrical infrastructure makes grid supply unlikely.

**Utilization of Wind-Energy in Pakistan**

In Pakistan, the potential of wind-power has so far not been utilized significantly. In the year 2002, fourteen small wind-turbines, 6 of 500 watts each & 8 of 300 watts each, were procured from China and installed by PCRET for demonstration purpose. Out of these 14 wind-turbines, 8 were installed in the coastal belt of Balochistan (3 at Dhorajee, 2 at Phore and 3 at Mata Mandar Hinglaj, Lesbella) and 6 wind-turbines were installed in the coastal areas of Sindh, (1 at Super Highway Karachi, 3 at Gujjo & 2 at Kharo Chan).

This demonstration project has been concluded successfully. Both PCRET and CAAMS have gained a lot of experience from this exercise. It has been observed that small wind-turbines are techno-economically viable for electrification of the remote population-pockets in the Coastal areas of Sindh and Balochistan. Kharo Chan and Phore can be stated as a symbol of the successful exploitation of wind-energy. It has certainly paved the way for successful implementation of PCRET on-going project for installing of 120 small wind-turbines.

Efforts are also underway to initiate local manufacture of 500 watts wind-turbines, under ToT from China and 5-10 kW wind-turbines, under ToT from some European countries.

**Box - 1: Specification of 500 Watts Wind-Turbine**

| | |
|---|---|
| Rotor diameter (m) | 2.5 |
| Blade material | Fiber Glass epoxy |
| Blade Number | 3 |
| Speed Regulation | Fold tail-vane (side wind) |
| Working wind speed (m/s) | 3 ~ 20 |
| Cut-in wind speed (m/s) | 3 |
| Rated wind speed (m/s) | 9 |
| Output Power (w) | 500 |
| Output voltage (v) | DC24/36, AC220 |
| Generator | 3 phase, AC, permanent - magnet |
| Mast height (m) | 5.5 ~ 7 |
| Weight (battery not included (Kg) | 125 |
| Battery bank voltage (v)/ capacity (Ah) | Dc24, 36/150~200 |

| Box - 2: Specification of 6000 Watts Wind-Turbine | |
|---|---|
| ROTOR | |
| Blade Number: | 3 |
| Diameter (m) | 4 |
| Material | Fiber glass / carbon |
| | |
| Electrical System | |
| Type: | Three phases permanent magnet alternator |
| Magnets: | Neodymium |
| Rated Power | 6,000 W |
| Voltage (V) | 48 / 300 V |
| | Regulator and full wave rectifier box, Volts, and Watts Display |

**Table-II: Wind Data - Average Annual Wind-Speed (m/s)**
**(10 Meters Tower Height)**

| Station / Months | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Max.No. of Hours** | | **744** | **672** | **744** | **720** | **744** | **720** | **744** | **744** | **720** | **744** | **720** | **744** | **8760** |
| Jati | 10m | 1.8 | 2.1 | 3.7 | 3.8 | 5.4 | 4.7 | 5.6 | 3.6 | 2.6 | 1.8 | 1.4 | 1.6 | **3.2** |
| | Noh | 744 | 672 | 744 | 718 | 605 | 705 | 369 | 504 | 720 | 744 | 720 | 744 | **7988.3** |
| Jiwani | 10m | 2.6 | 3.5 | 3.7 | 4.4 | 4.3 | 4.1 | 4.3 | 3.7 | 3.2 | 2.8 | 2.3 | 3 | 3.5 |
| | Noh | 740 | 671 | 744 | 720 | 742 | 719 | 743 | 744 | 719 | 743 | 720 | 743 | **8748.2** |
| Kati Bandar | 10m | 2.7 | 3.1 | 2.4 | 5.6 | 7.7 | 6.5 | 8.7 | 5.8 | 5.7 | 2.6 | 1.8 | 2.6 | **4.6** |
| | Noh | 744 | 671 | 728 | 717 | 742 | 716 | 744 | 681 | 720 | 740 | 720 | 743 | **8665.5** |
| Managi | 10m | 2 | 2.5 | 2.6 | 3.4 | 4.6 | 4 | 5 | 3.3 | 3.6 | 1.8 | 1.8 | 2 | **3.2** |
| | Noh | 743 | 672 | 715 | 720 | 742 | 719 | 744 | 744 | 665 | 744 | 713 | 462 | **8384.4** |
| Mirpur Sakro | 10m | 0.8 | 1.4 | 1.6 | 8.2 | 10.3 | 4.7 | 6.5 | 4.1 | 4.5 | 0.9 | 0.6 | 0.9 | **3.7** |
| | Noh | 744 | 672 | 728 | 717 | 742 | 720 | 744 | 743 | 720 | 728 | 720 | 744 | **726.6** |
| Noori Abad | 10m | 2.9 | 3.5 | 3.4 | 5.3 | 8 | 7.4 | 9.6 | 6.8 | 7 | 2.6 | 2.4 | 3.2 | **5.2** |
| | Noh | 744 | 671 | 727 | 719 | 742 | 720 | 744 | 743 | 719 | 744 | 720 | 744 | **728** |
| Ormara | 10m | 1.9 | 3 | 3.2 | 4.2 | 5.2 | 4.8 | 4.9 | 3.8 | 4.1 | 2.7 | 2 | 2.1 | **3.5** |
| | Noh | 744 | 672 | 718 | 720 | 742 | 720 | 680 | 744 | 718 | 744 | 720 | 743 | **722.1** |
| Shah Bandar | 10m | 2.8 | 3.1 | 3.7 | 4.9 | 7.2 | 6.4 | 7.6 | 6.3 | 5.3 | 2.9 | 2.2 | 2.6 | **4.6** |
| | Noh | 744 | 672 | 744 | 718 | 741 | 719 | 720 | 746 | 718 | 744 | 720 | 743 | **727.3** |
| Thano Bula Khan | 10m | 1.6 | 2.2 | 1.8 | 3.3 | 5.7 | 5.9 | 7.6 | 5.4 | 4.8 | 1.1 | 1.3 | 1.8 | **3.6** |
| | Noh | 744 | 671 | 728 | 688 | 742 | 719 | 744 | 742 | 720 | 739 | 720 | 743 | **725.1** |
| Basol | 10m | 2.2 | 2.9 | 3 | 3.3 | 4.7 | 4.4 | 5.1 | 3.7 | 3.6 | 2.2 | 2.6 | 2.6 | **3.4** |
| | Noh | 743 | 672 | 728 | 720 | 550 | 465 | 317 | 481 | 656 | 728 | 716 | 515 | **7293** |
| Gaddani | 10m | 3.4 | 3.5 | 3.8 | 4.3 | 6.3 | 7.2 | 5 | 5.1 | 5.3 | 1.1 | 2 | 3.4 | **4.2** |
| | Noh | 743 | 671 | 744 | 720 | 725 | 145 | 26 | 164 | 611 | 744 | 719 | 743 | **6456.3** |
| Gharo | 10m | 1.5 | 2 | 2.5 | 4.4 | 6.6 | 5.8 | 7.3 | 5.1 | 5.5 | 1.6 | 1.2 | 1.5 | **3.7** |
| | Noh | 744 | 672 | 731 | 717 | 741 | 719 | 744 | 743 | 720 | 743 | 720 | 744 | **8738.1** |
| Hawks Bay | 10m | 3 | 3.6 | 4.6 | 5.4 | 6.3 | 5.5 | 6.1 | 4.4 | 4.4 | 2.6 | 2.3 | 2.9 | **4.3** |
| | Noh | 743 | 672 | 718 | 718 | 743 | 720 | 477 | 663 | 719 | 744 | 720 | 744 | **8380.8** |
| Hyder abad | 10m | 2.2 | 2.4 | 2.5 | 4.1 | 6.5 | 6.6 | 8.3 | 5.8 | 5.8 | 1.8 | 1.7 | 2.3 | **4.2** |
| | Noh | 744 | 672 | 729 | 718 | 737 | 719 | 744 | 743 | 719 | 744 | 720 | 743 | **8732.5** |

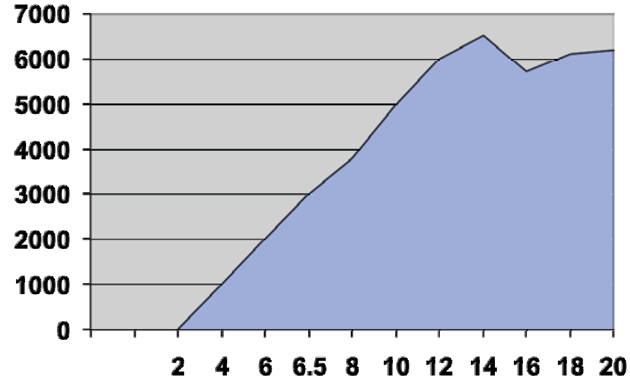



**Figure-III: Power-Curve of 6000 Watts Wind-Turbine**

**Table-III: Wind Data - Average Annual Wind-Speed (m/s)**
**(30 Meters Tower Height)**

| **Station / Months** | | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Annual** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Max.No. of Hours** | | **744** | **672** | **744** | **720** | **744** | **720** | **744** | **744** | **720** | **744** | **720** | **744** | **8760** |
| Jati | 30m | 4 | 4.3 | 5.1 | 5.9 | 8.1 | 7 | 8.5 | 6 | 4.7 | 3.7 | 3.5 | 3.8 | **5.4** |
| | Noh | 744 | 672 | 744 | 718 | 605 | 705 | 369 | 504 | 720 | 744 | 720 | 744 | **7988.3** |
| Jiwani | 30m | 3.4 | 4.5 | 4.7 | 5.5 | 5.2 | 4.8 | 5 | 4.5 | 3.9 | 3.7 | 3.4 | 4.1 | 4.4 |
| | Noh | 740 | 671 | 744 | 720 | 742 | 719 | 743 | 744 | 719 | 743 | 720 | 743 | **8748.2** |
| Kati Bandar | 30m | 3.9 | 5 | 5.3 | 7.6 | 10.5 | 8.2 | 10.5 | 7 | 7.1 | 4.3 | 3.5 | 3.9 | **6.4** |
| | Noh | 744 | 671 | 728 | 717 | 742 | 716 | 744 | 681 | 720 | 740 | 720 | 743 | **8665.5** |
| Managi | 30m | 3.1 | 3.7 | 3.8 | 4.6 | 5.6 | 5 | 6.3 | 4.3 | 4.9 | 2.9 | 3 | 3.4 | **4.2** |
| | Noh | 743 | 672 | 715 | 720 | 742 | 719 | 744 | 744 | 665 | 744 | 713 | 462 | **8384.4** |
| Mirpur | 30m | 3.3 | 3.8 | 3.9 | 12.7 | 14.7 | 6.7 | 9.2 | 6 | 6.4 | 3.2 | 2.8 | 3.4 | **6.4** |
| Sakro | Noh | 744 | 672 | 728 | 717 | 742 | 720 | 744 | 743 | 720 | 728 | 720 | 744 | **726.6** |
| Nooriabad | 30m | 4.3 | 4.6 | 4.5 | 6.8 | 9.4 | 8.5 | 11 | 7.7 | 7.9 | 3.5 | 3.6 | 4.5 | **6.4** |
| | Noh | 744 | 671 | 727 | 719 | 742 | 720 | 744 | 743 | 719 | 744 | 720 | 744 | **728** |
| Ormara | 30m | 3.2 | 4.1 | 4.2 | 5.3 | 6.1 | 5.6 | 4.6 | 4.4 | 5 | 3.6 | 3.1 | 3.5 | **4.5** |
| | Noh | 744 | 672 | 718 | 720 | 742 | 720 | 680 | 744 | 718 | 744 | 720 | 743 | **722.1** |
| Shah | 30m | 4.4 | 4.5 | 5.1 | 5.8 | 8.3 | 7.1 | 7.9 | 7 | 6 | 3.8 | 4 | 4.2 | **5.8** |
| Bandar | Noh | 744 | 672 | 744 | 718 | 741 | 719 | 720 | 746 | 718 | 744 | 720 | 743 | **727.3** |
| Thano Bula | 30m | 2.7 | 3.4 | 3 | 5 | 6.8 | 4.6 | 8.3 | 6 | 6.5 | 2.1 | 2.3 | 3 | **4.5** |
| Khan | Noh | 744 | 671 | 728 | 688 | 742 | 719 | 744 | 742 | 720 | 739 | 720 | 743 | **725.1** |
| Basol | 30m | 2.8 | 3.6 | 3.6 | 3.9 | 5.1 | 4.7 | 5.4 | 4.1 | 4 | 2.7 | 3.2 | 3.2 | **3.9** |
| | Noh | 743 | 672 | 728 | 720 | 550 | 465 | 317 | 481 | 656 | 728 | 716 | 515 | **7293** |
| Gaddani | 30m | 3.5 | 3.8 | 4 | 4.5 | 7.2 | 7.7 | 5.5 | 5.8 | 5.9 | 1.5 | 2.2 | 3.7 | **4.6** |
| | Noh | 743 | 671 | 744 | 720 | 725 | 145 | 26 | 164 | 611 | 744 | 719 | 743 | **6456.3** |
| Gharo | 30m | 3.4 | 4 | 4.8 | 6.6 | 9.2 | 7.9 | 9.9 | 6.9 | 7.6 | 3.7 | 3 | 3.4 | **5.9** |
| | Noh | 744 | 672 | 731 | 717 | 741 | 719 | 744 | 743 | 720 | 743 | 720 | 744 | **8738.1** |
| Hawks Bay | 30m | 3.6 | 4.3 | 5.9 | 6.3 | 7.4 | 6.2 | 6.9 | 5 | 5.3 | 3.2 | 2.8 | 3.6 | **5.1** |
| | Noh | 743 | 672 | 718 | 718 | 743 | 720 | 477 | 663 | 719 | 744 | 720 | 744 | **8380.8** |
| Hyderabad | 30m | 3.5 | 3.7 | 3.9 | 5.7 | 8.8 | 8.4 | 11.2 | 7.4 | 7.7 | 3.1 | 3.1 | 3.6 | **5.8** |
| | Noh | 744 | 672 | 729 | 718 | 737 | 719 | 744 | 743 | 719 | 744 | 720 | 743 | **8732.5** |

Performance Wind Speed
Cut in Wind Speed: 3.5 m/s
Rated Wind Speed: 12 m/s
Auto Break 14 m/s

**Table-IV: Wiring Dimensions for the Cable Coming Down From the Wind-Turbine to the Control-Box**

| Maximal Amps per phase | Maximal Amps per 3-phase | Minimum Recommended Length (mm) | | |
|---|---|---|---|---|
| | | Up to 30 m | Up to 60 m | Up to 90 m |
| 42 | 126 | 3 x 16 | 3 x 16 | 3 x 25 |
| 21 | 63 | 3 x 10 | 3 x 10 | 3 x 16 |
| 16 | 48 | 3 x 10 | 3 x 10 | 3 x 10 |
| 11 | 33 | 3 x 6 | 3 x 6 | 3 x 6 |
| 5 | 15 | 3 x 4 | 3 x 4 | 3 x 6 |

### Conclusion & Recommendations

- There is a considerable potential of wind-energy, which can be exploited for electrification of remote coastal villages.
- The encouragement of local wind-turbine manufacturing industry is essential for efficient utilization of wind-power.
- An effective policy-framework and fiscal incentives are required for the development, promotion and mass-dissemination of wind-energy technology to flourish in the country.
- Introduction of trade in "Green Certificates" like Europe's Renewable Energy Certification Scheme (RECS) can help the wind-energy technology in the country.
- An effective Renewable-Energy Policy is required to develop and implement setting up the renewable targets, having a streamlined planning and standardized regulations. Such a policy should also include tax-credit and other financial incentives.

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# RENEWABLE-ENERGY APPLICATIONS IN EGYPT

**Mohamed A. Hamad**
*National Research Centre*
*Dokki-Cairo, Egypt*

**Abstract**

*The paper illustrates the main activities carried out concerning development and application of renewable-energy technologies in Egypt. Main attention is devoted to biogas technology, solar and wind energy technologies. The main constraints for implementation of renewable-energy technologies in Egypt and the activities carried out for its release are highlighted. The coordination between the Islamic and other developing countries is highly needed, to achieve marked progress in implementation of renewable energy and sustainable development. Establishment of a network for renewable energy among the Islamic countries can play an active role in these aspects.*

**Introduction**

In order to attain sustainable development in the developing countries, development of renewable energies is highly needed, primarily, biomass constitutes a major energy resource for the rural population of Egypt. Thus, the household energy was dependent mainly on non-commercial energy as crop-residues, animal-dung and fuel-wood. Recently, the share of biomass energy decreased to high extent, as the habitants in rural areas switched to commercial energy, due to the low cost of the highly subsidized petroleum products and the urbanization in the rural areas. Research and Development (R&D) is carried out in Egypt for application of different renewable-energy sources.

**Biogas Technology**

Research and development are principally undertaken by the National Research Centre (NRC) and the Agricultural Research Center (ARC). Several universities have also started some research programs.

At present, there are around 500 field-demonstration units all over Egypt. The majority are of household size. A few large-scale plants are established in conjunction with livestock-raising operations. Most of the units are constructed by the NRC and ARC.

Many engineering developments have been locally introduced. NRC promotes application of a complete recycle system. In this system, the animal shed is modified, by covering the floor with concrete, using proper slopes to assist collection of urine, which is mixed with dung and used for feeding the digester. The latrine is directly connected to the digester. The grey water is collected and introduced into small collection and treatment unit, which consists of 3-4 chambers. One acts as settler, the

2nd as water-reservoir, for obtaining the water required for dilution of dung, while the third one is biofilter for degradation of organic matter. The residual water is used for plantation of some trees around the house. Egyptian-Chinese water pressure digester was selected for wide implementation. The digester is mostly half-sphere baffeled reactor.

However, the main activities in biogas technologies started during the year 1979 in Egypt, so the implementation still quite limited. These are mainly due to high subsidy in conventional energy products, lack of space in clustur villages, suitable for construction of the units and absence of organizations, which are responsible for construction of biogas units and their maintainance. However, the cost of the selected water-pressure digester is comparatively low, but is still high for most of the farmers.

Some research work is going on for the development of other more efficient designs, and to introduce the biogas system in the new reclaimed desert areas. The potential of biogas technology can be stretched by developing new designs that can alleviate the major prevailing local conditions.

Recently, Biogas technology is applied for treatment of municipal sewage sludge in El Gabal El Asfar wastewater treatment plant, Cairo, and also in some industries, such as sugar industry in Hawamdeiah, and starch factory in Alexandria.

**Biomass-Energy**

Agricultural residues, such as bagasse and rice hulls, are used as industrial fuels in sugar and rice mills, by direct combustion. Biomass wastes and residues, particularly stalks and dung-cakes are still used in rural areas. Dry wastes are burned directly in polluting and low-efficiency open-fire mud stoves. Modified biomass stoves and ovens of efficiencies higher than 30% were introduced by NRC.

A number of projects have been initiated to investigate the prospects of growing oil plants, such as Euphorbia and Hohoba in arid, semi arid and marginal lands. The major institutes involved in these types of activities include Ein Shams University, Desert Institute, American University in Cairo and NRC.

**Wind-Energy**

Some commercial projects are already operating in Egypt (Suez gulf) for production of electrical energy using wind-energy. Thus, with the cooperation of Ministry of Electricity with Government of Denmark, two stations were constructed, each of 30 Megawatt. The first one was operated during the year 2001, while the second one was operated in Dec. 2003.

Another project was undertaken with the cooperation of Germany. The project aims to produce 80 Megawatt. The first stage was operated in march 2001, to produce 33

Megawatt, while the 2nd and 3rd stages are estimated to come into operation during June 2004.

Thus, the share of wind energy for production of electrical energy will reach 140 Megawatt during the year 2004. The estimated petroleum equivalent is about 128,000 tons/ year. By the year 2010, it is planned to increase the energy-production to 800 Megawatt.

**Solar Energy**

***i) Photovoltaic Systems***

Photovoltaic systems are already used for small power requirements in different activities. These applications include production of electrical energy for water-pumping for irrigation and drinking water, water desalination, fisheries and illumination of some desert roads. No plant for production of photovaltaic cells is yet in place.

***ii) Water-Heating***

Water-heating is used for both household and industrial sectors. Application of solar heating is mainly in new towns, and also in a few houses in other towns. Generally, the application of solar heaters is still very low in Egypt, due to the difficulties in erection in a suitable place, and also due to high subsidy of commercial fuels. Some industrial water-heating systems are demonstrated in some plants. There are about eight plants dealing with manufacturing of solar water-heaters in Egypt.

***iii) Solar Thermal Electricity-Generation***

The parabolic trough is to be used to concentrate the solar radiation for heating the intermediate fluid to temperatures higher than 300°C, which can be used for production of electrical power. Ministry of Electrical Energy has started a project: *Bulk Renewable Energy Electricity Production Program*. The project deals with application of solar heating for production of electrical energy. The project will be undertaken in cooperation with Global Environment Facility (GEF). The capacity of the plant is about 126 Megawatt. The initial investment cost is about 120 m dollars. It is estimated that the plant will operate by the year 2007.

**Recommendations**

- Establishment of a network for renewable energy development between Islamic countries.
- Establishment of a development-fund to assist transfer of technology amongst members.
- Start a regular journal for renewable-energy news illustrating the activity between members, and development and demonstration of new projects.
- Financing cooperative research and demonstration-projects, to include participation of more than two countries, to assist propagation of new

technologies.

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# SUSTAINABLE SUPPLY OF FUEL-WOOD FOR THE RURAL AREAS OF PAKISTAN: FARM-FORESTRY AS A RENEWABLE-ENERGY SYSTEM

**Khalid Farooq Akbar**
*Department of Botany*
*Government College Sahiwal, Pakistan*

**Abstract**

*"It costs as much to heat the pot as to fill it." This old African proverb illustrates the energy-problems faced by majority of the world, who live in the villages and urban slums of developing countries, such as Pakistan. For a majority of them, the real energy-crisis is a daily scramble to find wood to cook meals and nearly 90% of their domestic energy-demands are derived from wood. This essential resource, however, is threatened.*

*The developing world is facing crisis of a critical shortage of firewood as serious as the petroleum-crisis. The shortage of firewood is resulting its soaring prices; a growing economic burden on rural poor; the wasteful burning of animal dung; and an ecologically disastrous and potentially irreversible spread of treeless landscapes.*

**Introduction**

Our growing population is also drawing attention towards the growing needs for having more fuel-wood production, to alleviate the energy-crisis. It requires immediate and effective steps for restoration of our forests to optimum level and increasing their area. In cultivated areas of Pakistan, where most of our rural population lives, the chances of increasing the forest area are limited because the entire cultivated area has already been covered under different crops. The only possible alternate left to us is to expand the cultivation vertically instead of horizontally, through integrated farm-forestry systems. Farm forestry is a sustainable land-management system particularly for arid, cultivated areas of Pakistan. In farm-forestry, Multipurpose Tree Species (MPTS) are grown with agricultural crops, which increase the production of wood and wood based products, and improve bio-physical and socio-economic environment of rural areas. Some main benefits of agro-forestry are:

- Ensuring sustainable fuel-wood availability;
- Increased fodder and timber production;
- Increased income for farmers and better land productivity;
- Improvement in soil-fertility;
- Ecological benefits such as control of wind-erosion by wind-breaks and conservation of species; and
- Provision of non-wood products, such as medicines, gums, etc.

Despite its enormous potential, farm-forestry has failed to achieve large-scale acceptance among our farmers. Some of the main constraints in this regard are long gestation- period of trees, poor productivity/yield, low economic return for many past farm-forestry plantations, poor extension services and continuously fragmenting of small agricultural land holdings. To achieve self-sufficiency and sustainability in fuel-wood production, farm-forestry should be planned and developed on following lines:

*Selection of Tree Species:* As farmers have many choices of land-use, including agriculture, dairy farming, shifting to long gestation-tree crops will only be preferred by farmers if such species ensure substantial increase in their incomes compared to traditional crops. Therefore, selection of appropriate tree-species assumes vital significance. In the past, many farm-forestry schemes have failed due to careless selection of tree-species. The choice of the tree-species for fuel-wood production should have following characteristics:

- The growth requirements of the selected species must match the local agro-ecological conditions;
- Fast growing to give high yields of fuel-wood at short-rotation;
- Ease of establishment and need for little maintenance;
- Multi-purpose Tree-Species (MTPS), which can provide non-wood products, such as fodder, medicines etc, and
- Provision of economic returns, particularly on short-term basis and long term basis.

**Research and Development Inputs**

Agro-forestry should be supported with adequate research and development activities to grow farm plantations up to optimum levels. Our land- resources are already limited and depleting rapidly. It is, therefore, necessary that land-productivity be improved through intensive but sustainable production of fuel-wood trees. The following priority areas for research in farm-forestry are proposed:

- Production of genetically improved tree-species with fast growth-rates and increased resistance to pests and diseases;
- Introduction of improved silvicultural practices for better fuel-wood yields, and conservation of water, soil and biodiversity;
- Management of tree and crop competition in farm-forestry systems; and
- In addition to modern knowledge, we must respect traditional wisdom and time-tested local experience of our farmers. This wealth of traditional knowledge should be compiled, tested and improved on scientific lines.

**Improvement of Extension Services**

At present, forest-management and extension-activities are under the control of Forest Department, which has authoritarian approach. Its efforts are strongly focussed on timber-production and protecting the forests through policing. Other aspects of forestry, such as, fuel wood and fodder are not or barely managed. Following constraints are acting as stumbling blocks in popularisation of farm-forestry in Pakistan.

- Inter-departmental conflicts;
- Socio-cultural problems; and
- Socio-economic barriers.

To address the problem, following recommendations are suggested.

**Involvement of Farmers**

The current method of top-down approach, in which extension-workers are assigned with a target to be achieved within a fixed time-frame has lost its effectiveness. These targets are fixed in terms of number of beneficiaries to be covered or the seedlings to be raised and distributed. Such an approach has only resulted in creating a wide gap between the extension- workers and the farmers. To reverse this trend, a sustainable participatory farm-forestry development approach should be formulated and implemented.

**Economic Incentives**

Economic incentives are generally in the form of direct financial regards to farmers, who accept and adopt modern farm-forestry techniques. Commercial banks should offer credit facilities for farm-forestry on long-term basis, and there should be provision of minimum support price. Government should regularly review the marketing, pricing of intermediate and final products.

**Integrated Farm-Forestry Extension-System**

At present, there are various departments and agencies, which have different and conflicting views and policies about the development of farm-forestry. To ensure smooth and effective flow of farm- forestry technology to the farmers, all departments dealing with rural areas (agriculture, forest, local government, banks) should make concerted efforts to establish an integrated and strong delivery infrastructure, to create a conducive environment for the large-scale adoption of farm-forestry on long term basis.

**Conclusions**

Farm-forestry offers a renewable and sustainable energy-production system, particularly for the rural masses of Pakistan. Providing incentives for farm-forestry can solve the problem of energy crisis. In addition, it provides important benefits, such as soil-conservation, increased employment-opportunities, economic benefits and creation of a dynamic rural environment. In any development strategy, to address the energy-problems of rural areas, the needs of the local population and conservation of nature should be assigned the highest priority. Through these measures, we can lead Pakistan on the path of self-sufficiency in fuel-wood and other forest products simultaneously contributing to environmental amelioration, conservation of our ecological resources and cultural heritage.

# RURAL ELECTRIFICATION THROUGH PV AND HYBRID SYSTEMS IN PAKISTAN

**M. N. Zakir, K. Khetran, I. A. Qazi and P. Akhter**
*Pakistan Council of Renewable Energy Technologies*
*Islamabad, Pakistan*

**Abstract**

*Grid-based rural electrification has benefited about 800 million people over the last decade; about 1.5 billion people, however, still have no access to electricity. The current scenario is expected to remain unchanged if we continue to rely on the conventional electrification methods. This is due to the high cost of grid-extension to rural areas with a very small load. Solar energy is one of the most promising sources of electricity-generation through solar cells and photovoltaics, and being decentralized in character, is suitable for remote-area applications. During the last decade, there has been a significant increase in the use of PV all over the world. A growth-rate of 15-30% per year is estimated worldwide. In Pakistan also, the use of PV for rural electrification has started. We are focusing here on the current development in the use of PV and hybrid technology for the socio-economic uplift of the remote areas.*

**Introduction**

It is an established fact that world is being depleted of the fossil-fuels very rapidly and environmental threat is also a considerable factor in the present modern energy-regime. In addition to this, Pakistan is investing a large amount of its precious foreign exchange on the import of Oil, for the generation of electricity. Primary energy-supplies in the county registered a growth of 4.8% over the last year and amounted to 44.5 million tones of oil-equivalent during 2000-01 (1). Therefore, it is high time to focus on the available Renewable Energy Resources for the generation of electricity in the country.

Fortunately, Pakistan is blessed with high values of solar insolation and long sunshine-hours. Solar-energy is widely distributed and abundantly available throughout the country, with the exception of some northern areas. The mean global irradiance falling on horizontal surface is about 200-250 W/$m^2$ in a day in Pakistan. This amounts to about 1,500-3,000 sunshine-hours and 1.9-2.3 MWh/$m^2$ in a year (2). Daily global radiation up to 6 KWhrs/$m^2$/day for 24 consecutive days (80%) is available in this area. Such a data is ideal for PV and other solar-energy applications.

In spite of the abundant availability of solar energy, a PV system, in itself, cannot meet the power requirement over a day-night period (3). Stand-alone diesel generator sets, while being relatively inexpensive to purchase, are generally expensive to operate and maintain, especially at low load-levels (4). PV and diesel have, however, complementary characteristics; capital cost of PV is high as compared to diesel; operating cost of PV is low as compared to diesel; maintenance requirements of PV are less as compared to diesel; diesel-energy is available all the time, whereas availability of PV is greatly dependent on solar-radiation (5). In the (PV/Diesel) hybrid system attention is also focused on the deficit energy to be generated from the back-up diesel-generator (in addition to PV + battery), to meet a specific annual electrical energy-demand. The diesel back-up system is operated during periods when PV fails to satisfy the load and when the storage-battery is depleted (6).

In addition to PV/Diesel, the PV/wind, or a combination of both for power-generation, is also becoming more and more attractive. An optimum match design is very important for PV/wind hybrid system, which can guarantee battery-bank working at the optimum conditions, the battery-bank's life can be prolonged to the maximum and cost of energy-production decreased to the minimum (7).

Balochistan is the largest but very thinly populated province of Pakistan, having 19,000 villages, out of which 90% villages are yet to be electrified (8). Therefore, it has a huge potential to be worked upon.

**Barriers to Rural Electrification**

Most of the rural areas have no electrical grid-lines and the load-demand of rural population is low & dispersed. At present, the 11 KV, 132 KV and 220 KV lines may have expenditure of 0.2 million, 3.0 million and 5 to 7.5 million rupees/km respectively. As such, it is not economically feasible to extend the grid lines, due to high cost with low energy-demand & less number of beneficiaries, due to scattered nature of localities.

In these circumstances solar-energy is more promising for electrifying most parts of Balochistan. Hybrid power-generation systems are also attractive, particularly in the coastal regions, due to high potential of wind. But here again, the barrier is the capital cost, which is not affordable for an individual, unless subsidized by the government or by any other agency.

**Solar Station Bughat, Tehsil Dukki, Loralai, Balochistan**

This 40 KWp solar-station was partially installed by Directorate General of New & Renewable Energy Resources (DGNRER), Ministry of Petroleum and Natural Resources in 1989, but never become fully functional. The solar-station was handed over to Water and Power Development Authority (WAPDA) after rollback of DGNRER. While still non-functional, it was then handed-over to Pakistan Council of Renewable Energy Technologies (PCRET) in 2002. Most of the solar panels were found in good condition, but the batteries had become useless due to aging effect and non-utilization. After detailed survey and discussions with local residents, it was established that the central distribution-system (common system) is not viable to be functional, due to peculiar social set-up of the tribal community. It was decided to distribute the solar-panels to individual families, who would buy the batteries, invertors and balance of the system on their own.

PCRET provided the technical assistance and training to the end-users for setting-up and utilization of stand-alone PV systems. About fifty individual PV systems ranging from 300 to 1,000 watts were installed on the mud homes, including a 2 kW system on the mosque and madarsa.

**Baiker, Tehsil Phalough, Dera Bugti, Balochistan**

This solar station was also installed by the Directorate General of Energy Resources, Ministry of Petroleum & Natural Resources, in 1987, and handed-over to WAPDA and then to PCRET, in 2002.

The system was of 5 KWp capacity; it was used to provide power to village mosque, school, and dispensary and to two houses. Again the solar station was out of function for 3-4 years, due to aging of batteries & faults in the inverter. PCRET made it functional by replacement of the 15 KWhr battery-bank and 1 KW inverter, while another inverter of 2 kW and 22 kwhr batteries are being added, on site.

**Installation of Wind/Solar/Diesel Hybrid Systems**

Presently, for the first time in the country Wind/Solar/Diesel hybrid systems have also been installed for rural electrification. The funding was available from the New Zealand Official Development Assistance (NZODA), through *Empower Consultants*, New Zealand, while PCRET provided the assistance from the Govt. of Pakistan's side for importing the equipments, training of end-users and the installation of the systems. The two sites were chosen, based on the suitability of social and geographical locations; one was the village Chib Kalamati, located at about 30 Km northwest of Gawadar and the another one was Durgai a village in Zardaloo valley, district Sibbi, 50 Km north east of Quetta. In January 2001, monitoring towers were installed at both sites to collect the reliable wind & solar energy data, to be used in appropriate designing of the systems. The data was recorded for about one year.

**Solar/Diesel Hybrid System, Gawadar, Balochistan**

Based on the metrological data, a combination of solar and diesel-generator system was chosen for the village Chib Kalamati. A control room, battery room, generator room and the office were set-up. Two branches of under-ground wiring of 1,000 meter and 800 meter in length were laid down to provide the power to the twenty houses, including a school and a mosque.

The system was installed in June 2003 and comprised 4 KW solar panels, with a back-up of 10 KW diesel-generator and a 10 KW inverter with 95 KWhr battery-bank.

**Wind/Solar/Diesel Hybrid System, Durgai, Sibbi, Balochistan**

Durgai is a village, located in Zardaloo valley, surrounded by the mountains, just behind Ziarat, but administratively located in district Sibbi. Fortunately, the area is rich in water springs and, due to specific topography of the land, it has a tremendous amount of wind throughout the year. Not surprisingly, the main power-generation source here was chosen to be wind.

The system was installed in September 2003, comprising 7.5 kilowatts wind- turbine, 500 watts solar panels, with a back-up of 10 KW diesel-generator and 125 KWhr battery-bank. Due to the area being mountainous, overhead power-distribution lines were installed. The power was provided to about 20 houses, including the mosque, school and dispensary.

The specific feature of the above two systems is that the systems were handed over to the local community, who would be responsible for the subsequent repair and maintenance, and long-term battery replacement. This would be accomplished by charging the electricity bills from the end-users by their own local organization.

**Ongoing Projects**

Pakistan Council of Renewable Energy Technologies is applying its efforts to promote the appropriate unconventional energy resources in the country. A pilot project for the rural electrification, using solar energy, is underway by PCRET, under the funding of Ministry of Science and Technology. By 2006, four remote villages of Balochistan will be electrified through Photovoltaics under this project. A project of rural electrification through wind-energy in the coastal areas of Pakistan is already being executed.

**Conclusion**

Pakistan has a high potential for the utilization of renewable-energy sources, especially solar and wind.  Barriers in widespread application are the high capital-cost, lack of awareness, in general, and the lack of political will, in particular. If rural electrification is accorded the right priority, with fixed targets, there is no reason why a reasonable portion of the country's power-generation could not be done from PV and the appropriate unconventional resources.

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# PROSPECTS OF RENEWABLE-ENERGY SOURCES IN PAKISTAN

**Nayyer Alam Zaigham**
*Professor & Director*
*Institute of Environmental Studies, University of Karachi, Karachi, Pakistan*
**Zeeshan Alam Nayyer**
*Lecturer*
*Department of Applied Physics, University of Karachi*
*Karachi, Pakistan*

**Abstract**

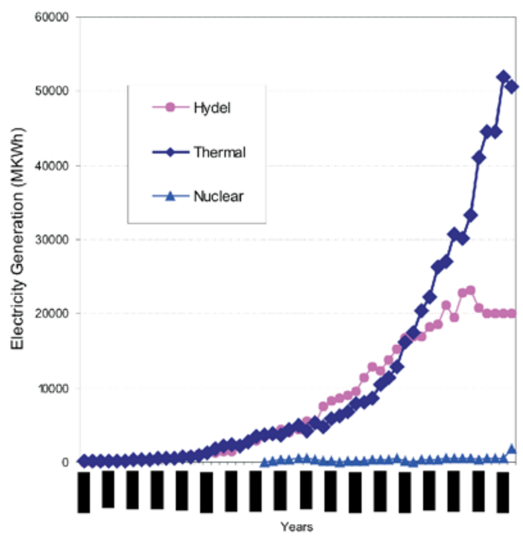
*Pakistan, despite the enormous potential of its energy resources, remains energy- deficient and has to rely heavily on imports to satisfy its needs. Moreover, a very large part of the rural areas does not have the electrification facilities, because they are either too remote and/or too expensive to connect to the national grid. Pakistan obtains its energy-requirements from a variety of traditional and commercial sources. Share of various primary energy-sources in energy-supply mix remained during last few years as oil: 43.5%, gas: 41.5%, LPG: 0.3%, coal: 4.5%, hydro-electricity: 9.2%, and nuclear electricity: 1.1%. The electric-power generation included 71.9% thermal, 25.2% hydel and 2.9% nuclear. While there is no prospect for Pakistan to reach self-sufficiency in hydrocarbons, a good option is the exploitation and utilization of the huge coal-reserves of Thar and the other renewable energy sources. Pakistan has wide spectrum of high-potential renewable energy sources, conventional as well as non-conventional, which have not been adequately explored, exploited and developed. Thus, the primary energy-supplies today are not enough to meet even the present demand. So, Pakistan, like other developing countries of the region, is facing a serious challenge of energy deficit.*

*The development of the renewable energy sources can play an important role in meeting this challenge. Present observations, based on reviewing the geological setup, geographical position, climatological cycles and the agricultural/industrial/ urbanization activities, reveal that there are bright prospects for the exploitation of various renewable-energy sources, which include mega & macro/micro-hydel, biomass, biogas, wind, solar, co-generation, city and other solid wastes, utilization of low-head canal levels, sea wave & tide and geothermal energies etc. Technologically, all these renewable-energy sources are viable and consequently suited to efforts for poverty-alleviation and cleaner environment in Pakistan. The country can be benefited by harnessing these options of energy-generation as substitute energy in areas where sources exist. As Pakistan is an agricultural country and major part of its population lives in the rural areas, the electricity generated by renewable sources will also improve rural life, thereby reducing the urban migration that is taxing the ability of cities to cope with their own environmental problems.*

## Introduction

As the availability of adequate supplies of energy is a pre-requisite to generate economic activities, the energy-sector plays a vital role in ensuring all-round development and growth of economy of a nation. Energy is considered as one of the four major drivers of growth in strategic planning of Pakistan Government (FD, 2001). The other three drivers are agriculture, small & medium enterprises, and information technology. Since the inception of Pakistan, the primary-power supplies from the conventional energy-sources were (and are still today) not enough to meet the country's demand (Figure-1). Pakistan, despite the enormous potential of its indigenous energy- resources, remains energy-deficient and has to rely heavily on imports of the petroleum products to satisfy its present day need.

Efforts have also been made to exploit the existing conventional energy-resources to build a strong indigenous exploration and production base. In spite of all these efforts, the results achieved so far are not cost-effective, nor helpful in reduction of import-dependence, promotion of self-reliance through accelerated exploitation of conventional energy-resources with minimum environmental degradation. Though the thermal power-generating capacity has increased rapidly during the last few years, due to foreign investment in Independent Power Producers (IPPs), but at the same time, it has caused increased air-pollution and GHG emissions, with the result of degradation of health and eco-systems.




**Source:** *Federal Bureau of Statistics Division, 1998; and Energy Year Book, 2001, HDIP*

**Figure - 1: Generation of Electricity from 1948 to 2001 by Hydel, Thermal (oil, natural gas, coal) and Nuclear Sources in million Kwh**

The conventional energy sources, i.e. fossil fuels (such as coal and petroleum and biofuels like wood), mega-hydels, and nuclear plants have remained the energy-sources of choice of the world for long. Now, there has been a growing recognition, for more than one reason, of the dangers inherent in continuing with the model of economic development based on these sources, particularly the excessive consumption of fossil-fuels. One reason is that the reserves of fossil-fuels are not unlimited and, at the present rate of consumption, they would not last very long. The world community today uses up in one minute what it took the earth a millennium to create. It is prophesied that at this rate, well before the end of the new millennium, the world will run out of conventional energy-sources. Moreover, it has been conclusively proved that climate change, which has been resulting in global warming, is mainly caused by greenhouse-gas emissions from energy-generating systems based on fossil fuels. Yet another aspect that has come into sharp focus is that the developing countries can ill afford to depend excessively upon petroleum imports, marked as they are by volatile price-fluctuations. Moreover, indiscriminate use of fuel-wood leads to deforestation, with consequent environmental hazards, and inefficient burning of fuel-wood leads to an increase in indoor air-pollution and consequent health-hazards, especially for women and children. Similarly, the other conventional sources of energy-generation have their adverse impacts on environment.

It is in this context that there has been a growing world-opinion in favour of looking at alternatives to conventional sources that would ensure eco-friendly sustainable development, on the one hand, and energy security on the other. This paper describes the prospects for the availability of renewable-energy sources in Pakistan, with the view of the geological set up of the country.

**Renewable-Energy Sources of Pakistan**

Pakistan has a wide spectrum and high potential of renewable-energy sources, conventional and non-conventional as well, which have not been adequately explored, exploited or developed. As a result, the primary energy supplies today are not enough to meet even the present demand. Moreover, a very large part of the rural areas does not have the electrification-facilities, because they are either too remote and/or too expensive to connect to the national grid. So, Pakistan, like other developing countries of the region, is facing a serious challenge of energy-deficit. The development of the renewable energy sources can play an important role in meeting this challenge.

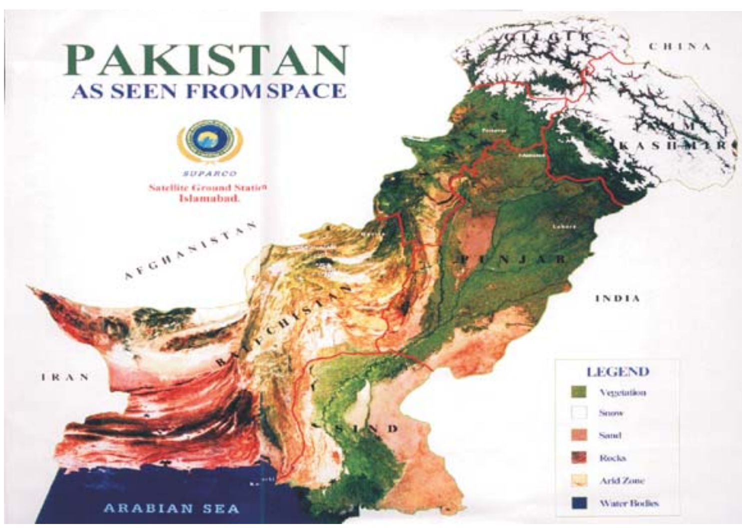
As Figure-2 shows, Pakistan stretches from 24°N to 37°N latitudes and from 61°E to 76°E longitudes. The total land area of Pakistan is about 800,000 $km^2$. The northeast to southwest extent of the country is about 1,700 km, and its east-west width is approximately 1,000 km. The geology and geography of Pakistan varies from lofty mountains of Himalayas, Karakorum, Hindukush and Pamirs in the north, to the fascinating coastline of the Arabian Sea in the south. In between, the northern and southern extreme ends of the country, notable and unique bented north-south oriented mountain ranges exist centrally bounded by the fertile plains of 3000-long River Indus and western part of the famous Thar Desert on eastern side, and by the Chagai volcanic arc, vast tectonic depression of Kharan, and the westward swinging mountain ranges of Makran flysch basin.

In the north and west, nearly 60 % of the land area is mountainous terrain and incised tableland topography. The remaining area consists of alluvial plains of the Indus River-System and the Thar & Cholistan Deserts. The offshore Exclusive Economic Zone covers over 231,674 km$^2$ in the Arabian Sea. In Pakistan, cropped and forest lands cover an area of about 23 million hectares and 4 million hectares, respectively.

Considering the geological setup, geographical position, climatological cycles and the agricultural activities, various renewable resources are technologically viable and have bright prospects for commercial exploitation in Pakistan, which include Solar (PV, thermal), Water (mega & macro-micro-hydel, and sea wave & tide), Wind. Wastes (City solid waste, waste from local chicken-farms, forestry waste, wood waste from furniture factories, agricultural waste, hospital waste and animal slurry from farms), geothermal and others. Pakistan can be benefited from these as substitute energy in areas where these renewable energy sources exist.

**Potential of Water-Energy**

Hydropower source of energy is very well known in Pakistan, and there is ever growing experience in this sector to develop the hydropower potential indigenously in the country. The hydro-potential was estimated at about 50,000 MW, out of which about




**Source:** *SUPARCO, 2002*

**Figure - 2: Geological & Geomorphic Division of Pakistan**

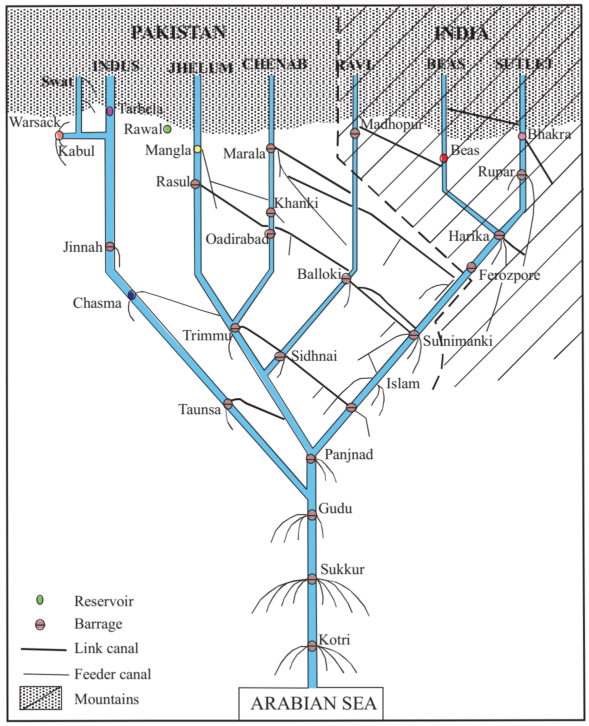



**Figure - 3:** **Schematic Presentation of one of the Largest Irrigation Systems of the World Developed mainly based on Water Divergence from Indus River and its Tributaries, which Comprises Several Major and Small, Barrages, Headworks, Link Canals, Canal Commands and Thousands of Watercourses**

**Table - 1: Proposed Sites and their Discharge, Fall and Power Potential (Hassan, 2002)**

| S# | Name of Channel | Location | Discharge in $Feet^3$/ Second | Fall in feet | Power potential in MW |
|---|---|---|---|---|---|
| 1. | Baloki-Sulamanki Link-1 | RD106250 | 12500 | 10.64 | 10.00 |
| 2. | Baloki-Sulamanki Link-2 | RD33430 | 9000 | 17.86 | 10.72 |
| 3. | Chanab-Jhelum Link (Tail) | RD316622 | 13527 | 41.70 | 40.00 |
| 4. | Upper Chanab | RD0 | 16500 | 8.83 | 9.70 |
| 5. | TP Link Canal (DG Khan) | Rd183000 | 12000 | 3.00 | 12.28 |

4,800 MW has been developed over the past 50 years through mega-hydel plants and the remaining has yet to be exploited (Kazi, 1999). The northern areas of the country are rich with hydropower resources. In the northern areas of Pakistan, the results of the hydrological surveys revealed that there are numerous small streams and waterfalls, with strong and violent flow, having sufficient potential for electricity-generation through micro-hydroelectric power plants. The recoverable potential in micro-hydropower (MHP) units upto 100 kW is roughly estimated to be 300 MW on perennial water-falls in northern Pakistan (Hassan, 2002). In the country, WAPDA, PCRET, and other public and private-sector organizations, like Azad Jammu & Kashmir (AJK) Electric Board, Sarhad Small Hydrelectric Organization, the Northern Areas Public Works Department and the Aga Khan Rural Support Programme, are investing for the development of the hydroelectric plants of various generating capacities, i.e., very large hydro plants, small hydro plants, and micro hydro plants, since people are well aware and have become familiar with the relevant technology.

Besides, there is an immense potential for exploiting water-falls in the canal network, particularly in Punjab, where low-head with high discharge exists on many canals. One of the largest irrigation systems of the world has been developed, mainly in the upper and middle parts of Indus-basin utilizing waters of Indus and its tributaries for the conventional flood-irrigation (Figure-3). In Pakistan, the system presently includes three major reservoirs (i.e., Terbela, Mangla and Chashma dams) and several other smaller ones, 19 barrages/headworks, 12 link canals, 45 canal commands and some 99,000 watercourses. The total length of the canal-system is about 58,450 km with watercourses, farm channels and field ditches running another 160,000 km in length. The canal system has a huge hydropower-potential at numerous sites/locations on these irrigation canals, ranging from 1MW to more than 10MW, which can be utilized for developing small hydro-power stations, using low-head high-discharge water-turbines in Punjab and Sindh provinces. For example, the Punjab province has an extensive network of irrigation canals, and at many sites, small waterfalls are available, which can be exploited to employ low-head high-discharge hydropower plants (Table-1).

**Potential of Solar Energy**

Pakistan being in the sunny belt, is ideally located to take advantage of the solar energy technologies. This energy-source is widely distributed and abundantly available in the country. During the last twenty years Pakistan has shown quite encouraging developments in photovoltaic (PV) technology. Currently, solar technology is being used in Pakistan for stand-alone rural telephone exchanges, repeater stations, highway emergency telephones, cathodic protection, refrigeration for vaccines and medicines in the hospitals etc. The Public Health Department has installed many solar water-pumps for drinking purposes in different parts of the country. Both the private and public sectors are playing their roles in the popularization and up-grading of photovoltaic activities in the country. A number of companies are not only involved in trading photovoltaic products and appliances, but also manufacturing different components of PV systems. They are selling PV modules, batteries, regulators, invertors, as well as practical low-power gadgets for load-shedding, such as photovoltaic lamps, battery chargers, garden lights etc.

PCRET and other public and private organizations have developed the know-how and technology to fabricate solar cells, modules, and systems. In addition to generating electricity, thermal energy can also be used for desalination of saline water.

**Wind-Power Potential in Pakistan**

Harnessing wind-power to produce electricity on a commercial scale has become the fastest growing energy-technology. Economic, political and technological forces are now emerging to make wind-power a viable source of energy. Though, apparently Pakistan has tremendous wind-potential, but at present the facilities for generating electricity from wind are virtually nonexistent in the country. Pakistan has a 1000 km long coastline, which could be utilized for the installation of wind-farms, as found in UK, Netherlands and other countries (Figure-4).

Pakistan is a late starter in this field. As of today, we have no significant wind-energy generation project. Even the preliminary wind-power potential studies of Pakistan are not available. In the same geographical environment as we have in Pakistan, India has set up the first of its ten 55 KW plants at Gujrat in 1986. The Ministry of Non-Conventional Energy Sources has estimated that the gross wind-power potential of India is about 45,000 MW and has identified more than 200 sites suitable for wind-power facilities. Bordering states of Gujarat, Andhra Pradesh, Madhya Pradesh, Maharashtra, and Rajasthan have the highest potential. India ranks fifth in the world in the number of wind-power installations. Wind-power installed capacity is now more

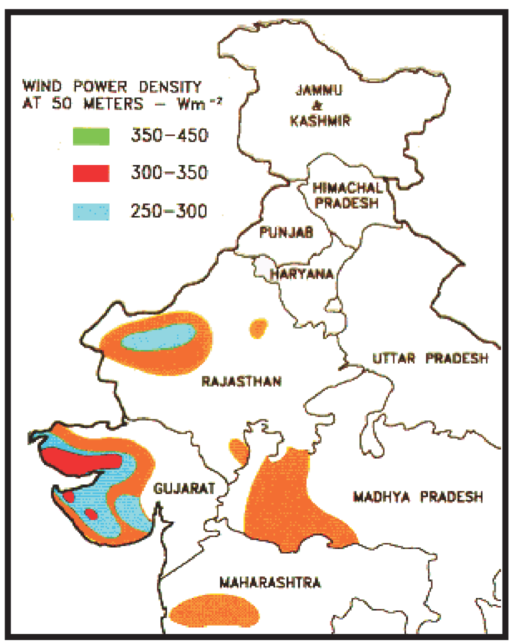
**Source:** *www.dti.gov.uk*

**Figure - 4: Blyth Harbour Wind-Farm in Northumberland, UK**

than 1,700 MW (www.windindia.com).

Considering the significance of the wind-resource model, the Ministry of Science & Technology recently provided funds to Pakistan Meteorological Department for establishing a network of wind masts along the coastal areas (in 2001-2002) to conduct an extensive wind-survey of the coastal areas to assess wind-power potential (Chaudri, 2002). The results are awaited.

However, PCRET has started a project to install small stand-alone-type of wind-turbines, to generate electricity in the southern coastal region of Sindh and Balochistan provinces, where grid-connection to villages is not available (PCRET website: www.gov.pk). The New Zealand Official Development Assistance (NZODA) has also provided funding to develop two wind-diesel hybrid systems in order to bring affordable electricity to poor villages in the desert of Balochistan province (Empower website: www.mft.govt.nz). Moreover, the United Nations Office for Project Services (UNOPS) are making efforts for developing the commercial electricity through wind-power in Pasni coastal areas. In addition, small-scale investment has also been made by the provincial irrigation departments of Agriculture Ministry to installed windmills to lift up the groundwater from wells where grid-electricity is not available (Fatehally, 2002).




**Source:** *www.windindia.com*

**Figure - 5: Map Shows Wind-Resources of North-Western India**

**Initiative of Private Sector**

Recognizing the vast potential that wind-energy offers, the Pakistan Venture Capital Limited (PVCL), a company in the private sector, took the initiative to establish the 5.0 MW capacity wind-farm along the Karachi coast in 2002 (Dawood, 2002). The PVCL approached the Karachi Port Trust (KPT), which agreed to the proposal. In deciding to undertake this project, the PVCL also approached PCRET and ADB, and has been greatly encouraged. Though this project was identified for the pre-feasibility studies under ADB (PREGA) Program, but so far no development is seen due to the non-availability of preliminary wind-potential data of the area.

**Energy from Wastes**

***i) City Wastes:*** Every day, we produce a lot of waste - in our homes, offices and factories, farms and hospitals, and so on. We need to reduce this amount. We also need to re-use as much of our waste as we can. Presently, the domestic solid-waste in Pakistan has not been managed in a satisfactory and adequate manner as far as its collection, transportation & disposal or dumping are concerned, regardless of the size of the city. Polluted dust blows and people suffer from living in such conditions. It is estimated that the urban areas of Pakistan generate over 55,000 tonnes of solid wastes daily. In Karachi alone, more than 7,000 tons of solid waste is generated every day. There are thousands of auxiliary mismanaged collection-dumps all over the city, causing noticeable environmental degradation, locally from street to street. The waste-pickers scatter the waste on the public spaces around the “kutchra kundis”, creating large-scale environmental pollution, directly of indirectly. Most of the sorting places are located near the storm drains, the nalas, under the bridges, in open spaces meant for parks and playgrounds and even at bus-stop sheds. This scattered waste creates chocking of the storm-drains, being used as sewage trunks, which causes other management problems and pollution to groundwater aquifers(Figure-6).

**Figure - 6: Waste-Pickers Scatter Solid-Waste after Collection of Saleable Waste**

As in other urban centers of developing countries, the solid-waste management services are inadequate and unsatisfactory. In Karachi, about 20% of the waste is picked up by the waste scavengers (Pickers) as the salable items (Khan & Athtar, 2000). There are scavengers' colonies in Karachi, where waste-transporters are attracted for delivering the waste to them, instead of taking it to the official waste-dump sites (Figure-7).

Almost 20% waste is left out in the dustbins on the mercy of Mother Nature to take care of (Figure-8) or, most often, burned openly to ashes. About 60% of the garbage produced in the Karachi metropolitan area, from official and/or unofficial dustbins of the city, is transported to the uphill areas located 30-35 km away from the city and disposed of in open air. In the background, huge piles of solid dumps can be seen (Figure-9).

At the dumping sites, more than 400 tonnes of organic waste is used, burnt to extract metals, where smoke and dust are generated to the crisis-level of the health environment (Figure-10).

Such huge amount of solid-wastes can be used as a fuel - and disposed of at the same time. For instance, wastes can be burnt in purpose-built incinerators. The heat can then be used to generate electricity, or to provide heating for buildings. Advanced technologies have been developed to ensure that the wastes' gases emitted from these facilities, would not be harmful to the environment. Heat and electric power can be generated either by incineration of the solid wastes or by anaerobic composting of solid-wastes, through proper landfill techniques. In Pakistan no "energy-from-

**Figure - 7: Solidwaste is Dumped for Picking up Salable Items in Front of Scavengers' Colony, Which can be Seen in the Background behind the Rail-Bridge at the Junction of Gulshan-e-Iqbal and Liquatabad Densely Populated Areas in Middle of the City**

**Figure - 8:** **After Picking of Salable Items, Almost 20% Waste is Left Out in the Open on the Mercy of the Mother Nature, which is one of the Major Cause of Multi-Dimensional Environmental Degradation**

**Figure - 9: 60% of Garbage Produced in the Karachi Metropolitan Area from Official and/or Unofficial Dustbins of the City is Transported to the Uphill Areas, Located 30-35 km Away from the City and Disposed in Open Air.**

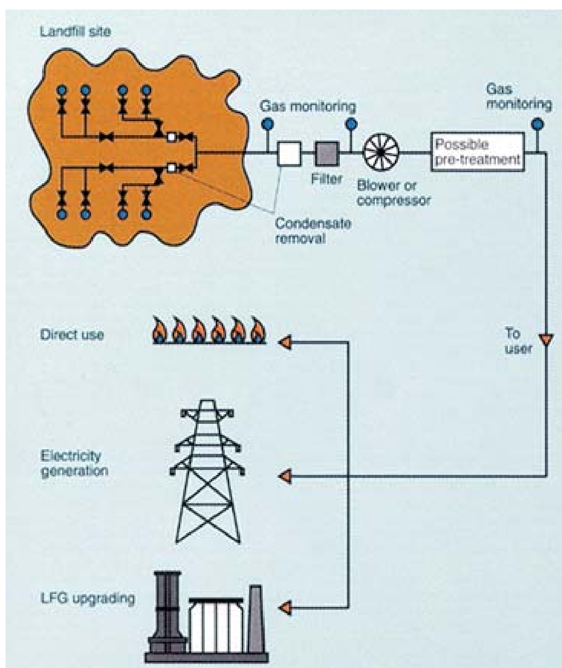
**Figure - 10:** **Citywaste Dumped in the Out Skirts is Burnt in the Open, as can be Seen in the Center. Huge Piles of Solid Dumps isAwaited to be Burnt in the Foreground**

citywaste" facilities has been built.

UK produces 28 million tonnes of household waste every year. This could be used to generate 1700MW of energy, which is enough to meet the needs of 2.7 million households. Currently, UK only recovers 11% of this, around 190MW, enough for 300,000 households. In Dundee, power station generates 10.5MW of electricity from incineration of 120,000 tonnes of municipal and commercial waste a year (Fig.11).

Most of the waste we produce is disposed of in "landfill sites", which is not the case in Karachi. The waste is dumped on surface without any soil cover. In case of proper landfill sites, as the waste decomposes in the oxygen-free environment below the surface, it gives off a gas that is rich in methane through a process known as "anaerobic digestion". This biogas, or "landfill gas" as it is called, can be collected through a system of wells, drilled into the waste, and pipelines. It is then used to fuel an electricity generator or to provide heat. Greengairs is Scotland's largest landfill site. It handles around 750,000 tonnes/year of waste. The power plant uses landfill gas to produce almost 8MW of power.

***ii) Energy from Miscellaneous Wastes:*** There is also scope to use the specialized wastes for energy generation. Waste from local chicken-farms (chicken litter), forestry waste,




**Source:** *www.dti.gov.uk*

**Figure - 11: Landfill Gas can be Collected and Burned to Produce Heat**

wood waste from furniture factories, agricultural waste, hospital waste and animal slurry from farms are just some of the kinds of waste that can be used as fuel.

Pakistan is not short of such wastes, but so far only the cattle waste is being utilized to generate biogas from dug-waste successfully at the local level. The country has significant potential to generate heat and electricity by utilizing other kinds of wastes.

***iii) Energy-Generation from City Poultry Litter:*** Poultry farms and animal processing operations create birds-wastes that constitute a complex source of organic materials, with environmental consequences. These wastes can be used to make many products, including the energy generation (Figure-12). The wastes can be burnt in purpose-built incinerators. The heat can then be used to generate electricity, or to provide heating for the buildings. Advanced technologies can be employed to ensure that the waste gases emitted from these facilities are not harmful to the environment. Chicken litter is one of those wastes produced from the farms and animal-processing operations. In Britain, the Thetford Power Station in Norfolk burns chicken litter waste from local chicken-farms. This usefully disposes of about 400,000 tonnes/year of poultry litter, to produce 38.5 MW of electricity (www.dti.gov.uk).

Pakistan has broad-based poultry farm industrial network, mainly in private sector in different cities and as such significant potential for power generation exists from chicken litter, but so far there is no such facility for its use to generate electricity around the country. Based on the Pakistan Poultry Association (PPA) statistics, in relation to the performance of commercial poultry-farming sector, it is found that there is a considerable increase in the growth of the farm-bird population from 1991 to 2001 in Pakistan (Table-2). Presently, more than a total of 15 million layer-chicken and 528 million broiler-chicken birds are expected to be produced in 2003 with a share of 22 %, 68 %, 3.5 %, and 6.5 % of Sindh, Punjab, Balochistan and NWFP provinces (inclusive of Azad Kashmir) respectively. These statistical figures seem to much more because, according to an unofficial estimate, hardly 5 to 10 % poultry farms have membership of PPA (Personal communications with a few stakeholders). Thus, the

**Figure - 12: The World's Third Poultry-Litter Fired Power-Station at Thetford in Norfolk**

**Table - 2: Growth of Farm Chicken-Bird Population in Pakistan, Based on PPA Statistics**

| Year | Number of Layer-Chicken on Farms (million birds) | Number of Broiler-Chicken on Farms (million birds) |
|---|---|---|
| 1991 | 09.550 | 072.800 |
| 1992 | 10.850 | 160.000 |
| 1993 | 09.220 | 144.000 |
| 1994 | 09.560 | 208.000 |
| 1995 | 09.600 | 249.000 |
| 1996 | 09.600 | 283.500 |
| 1997 | 10.060 | 162.000 |
| 1998 | 11.700 | 220.000 |
| 1999 | 14.000 | 280.000 |
| 2000 | 16.000 | 340.000 |
| 2001 | 15.000 | 528.000 |

total number of chicken-bird population seems to be much higher than this. A proper survey during pre-feasibility study would reveal the exact figures, if taken any in future.

Only in and around Karachi region, it is estimated that the growth of chicken-birds is about 100 million per year based on the personal communications with a number of stakeholders and the farm-owners of the poultry farms. Since, very small number of farms are registered with the PPA, the precise statistics are not available.

According to a preliminary estimate, 15tonnes/year chicken-litter is scraped out from a shed of 3000 chicken-birds in a poultry farm. Therefore, more than 500,000 tonnes/year chicken litter is expected to be produced in and around Karachi region, which has apparently no particular use. At present, this waste is being dumped here and there, causing enormous environmental damage. A section of poor people collect this litter free of cost (rather charging from a farm-owner for cleaning out the litter). At present, much of chicken-litter from the farms is dumped in open lands without proper environmental consideration. Thus, the ecosystem in the vicinity of outfall is breaking down.

Through installation of commercial units to generate electricity through purpose-built incinerator, like the Thetford Power Station in Norfolk, about 40 MW of electricity can be produced daily, which could be utilized to meet the domestic and commercial energy requirements of the project area, in addition to creating healthy environment. Later on, it can be replicated on other chicken-farm areas in the country. It would not be out of place to mention that the Pakistan Poultry Association and several individual stakeholders have indicated that a solution, which brings any financial benefit to their members and improvement in their environment will be welcomed.

***iv) Energy-Generation from Animal Slurry:*** Pakistan is an agriculture country. About 70% of the population resides in rural areas who meet 95% of their domestic fuel needs by burning bio-fuels, but in urban areas the bio-fuel consumption drops to 56%, because they use Kerosene oil, LPG and natural gases, etc., in addition to fuel-wood to meet their domestic fuel needs. As per livestock census of 2000, there are 46.69 million of animals (buffaloes, cows, bullocks) in Pakistan(FBS, 2002b). On the average, the daily dung dropping of a medium size animal is estimated at 15 kg per-day. This would yield a total of 700 million kg dung per day. Assuming 50% collectability, the availability of fresh dung comes to be 350 million kg per day. Thus, 17.5 million $M^3$ biogas per day can be produced through the bio-methanation (Hassan, 2002), besides, producing 50 million kg of bio-fertilizer per day or 18.2 million tons of bio-fertilizer per year, which is an essential requirement for sustaining the fertility of agricultural lands.

With the effective efforts of PCRET, COMSATS and other organizations, such cattle-waste is being utilized to generate biogas from dung-waste successfully at the local level in many parts of the country. But serious environmental problems are being faced in urban areas, where large cattle farms exist, for example, the Cattle Colony, which is situated in Landhi area in the southeastern part of Karachi city. Initially when the cattle colony was planned in 1965, there were only 379 farms, but as the time passed the farms were divided and re-divided and the number of farms became about 850 in 1991, which further continued increasing. This increase has consequently resulted in overcrowding. These farms supply about 80 % of the milk and the meat to the Karachi city (NEC, 2004, personal communication).

There are 860,000 animals available in the Landhi Cattle Colony, Karachi, which produce 6.5 million kg dung per day. At present, this waste is disposed off through open drainage, adjacent to the coastal area, causing enormous environmental damage. Through installation of commercial units of biogas plant, more than 2.0 million $M^3$ of biogas (methane) can be produced daily. The biogas so produced could be utilized to meet the domestic and commercial energy requirements of project area, which otherwise is escaping into the open atmosphere. In addition to biogas, more than 0.6 million kg of organic-fertilizer can also be produced daily from this project.

Gas from the project could be used either directly, or converted to electricity and used locally, or sold to the grid. Though at Landhi, both gas and electricity are available, the electricity supply is intermittent, and many farmers use standby diesel generators. The national grid and a local distribution line run alongside the colony, offering the possibility of sale of electricity from the project to the grid. Conversion of cattle waste of Karachi Cattle Colony into Biogas and Bio-fertilizer on commercial basis can be taken up, so as to replicate later on other cattle-farms in the country.

***Potential of Oceanic Energy (Wave & Tidal):*** Two distinct types of ocean resource are commonly mentioned as possible energy-sources: waves and tides. In both cases, the oscillating motion of an incoming and outgoing wave is used to drive turbines that generate electricity. It has been estimated that, if less than 0.1% of the renewable energy available within the oceans could be converted into electricity, it would satisfy present world-demand for energy more than five times over.

**i) Wave-Energy:** Power generation using wave-energy is at a much earlier stage of development, which offers more predictable outputs than wind. Wave-energy generation-devices fall into two general classifications, fixed and floating. Wave motion can be used to compress air to drive a turbine or hydraulic pumps. In November 2000, the world's first commercial wave-power station began to feed electricity into the UK's National Grid (www.dti.gov.uk). Situated on the Scottish island of Islay, the LIMPET (Land-Installed Marine-Powered Energy Transformer) has been installed to harness the action of waves to generate electricity. Rated at 500kW, the system can provide enough electricity for about 400 homes (Figure-13).

Pakistan has about 1000 km long coastline, with complex network of creeks in the Indus deltaic area (Figure-14). The erosional features along the Makran coastal areas show the relevance of strong wave-energy, which could be harnessed for the generation of electric power for rapidly developing coastal cities, Gawader, Pasni, Ormara, Gadani etc (Figure-15).

**ii) Tidal Energy:** Tidal stream-devices extract energy from the diurnal flow of tidal currents, caused by the gravitational pull of the moon. That is why the tide goes in and out at the seaside. Large structures called "barrages" can be built to use the tides to generate electricity. Tidal-energy schemes capture water at high tide and release it at low tide. Tide energy systems traps high tides in a reservoir. When the tide drops, the water behind the reservoir flows through a power turbine, generating electricity. Unlike wind and wave power, tidal streams offer entirely predictable output. Typically, tidal turbines, similar in appearance to wind turbines, are mounted on the seabed. They are designed to exploit the higher energy density. Tidal stream differs from established technology for exploiting tidal energy [eg estuarine tidal barrages, such as the 240 MW barrage operating in France (Figure-16) in that tidal flows are not captured and controlled by means of a large dam-like structure (www.dti.gov.ku). Rather, the tidal turbines operate in the free flow of the tides, meaning that large construction-costs and disruption of estuarine ecosystems associated with barrages may be avoided. However, as tidal streams are a diffuse form of energy and the purpose

**Figure - 13: The World's First Commercial Wave-Power Station, on the Scottish Island of Islay**

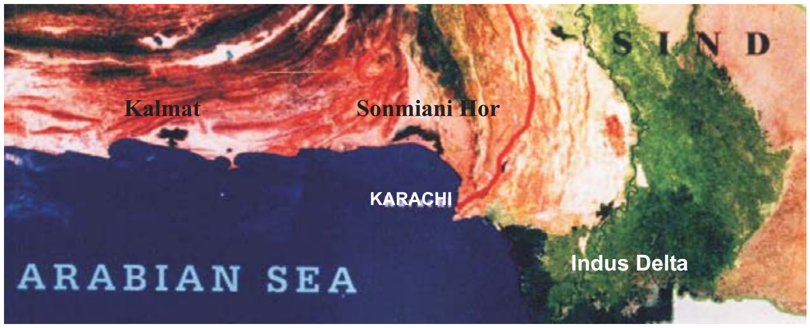



**Figure - 14: Coastline of Pakistan**

of the barrage is to concentrate tidal flow, this also means that large numbers of turbines, spread over relatively large areas of seabed, are required if significant amounts of energy are to be extracted.

The creek system of Indus delta extends over an area of 170 Km. Tidal water flows in these creeks with high velocity during flood and ebb tides, which is a very favorable requirement for the extraction of energy from tidal currents. The power resource potential of the Indus Deltaic Creek System is a great asset for future energy-supply in Sindh, Pakistan. On the basis of limited surveys carried out by the National Institute of Oceanography (NIO), the Indus deltaic region, where seawater inundates up to 80 km inland at some places due to the tidal fluctuation, show encouraging results. These creeks extend from Korangi Creek near Karachi to Kajhar Creek near the Pak India border. The current velocity in these creeks generally ranged from 4-5 knots but values as high as 8 knots were also recorded. The difference between tidal heights along the Pakistan coast varies between 2 to 5 meters. The tidal heights along the Sindh coast vary between 2-5 meters (Karachi) to over 5.0 meters (Sir Creek) in the Indus delta (Amjad, 2003, personal communication). It is estimated that about 1100 KW power

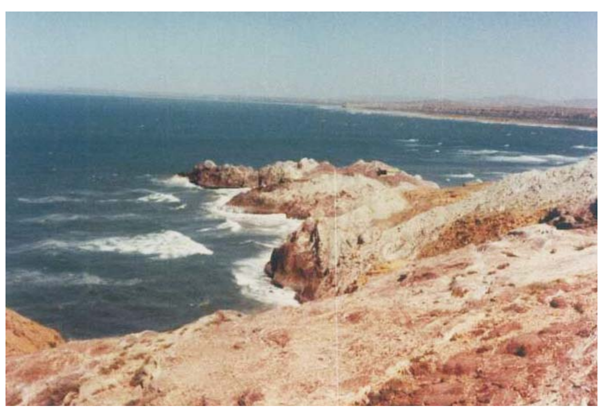


**Figure - 15: Gadani Coastal Area in Foreground and Gadani Beach Area in the Background**

can be produced from these creeks altogether. Development of indigenous capabilities for harnessing tidal energy, from Pakistan coast, could bring uplift of socio-economic conditions of coastal population of Pakistan and consequently would also minimize environmental pollution. However, detailed information is needed on the distribution function of waves at the selected site(s). In addition, the Sonmiani Hor and the Kalmat Khor are also good prospects for the development of Tidal Power in the Balochistan coastal belt (Figure-14).

**Potential of Geothermal Energy**

Geothermal energy is the energy derived from the heat of the earth's core. It is clean, abundant, and reliable. If properly developed, it can offer a renewable and sustainable energy source. People have used geothermal resources in many ways, including healing and physical therapy, cooking, space heating, and other applications. One of the first known human uses of geothermal resources was more than 10,000 years ago, with the settlement of Paleo-Indians at hot springs (GEP, 2002). Geothermal resources have since been developed for many applications, such as production of electricity, direct use of heat and geothermal heat-pumps. Most of the high-enthalpy geothermal resources of the world are within seismic belts associated with zones of crustal weakness, such as plate margins and centers or volcanic activity. A global seismic belt passes through Pakistan and the country has a long geological history of geotectonic events: Permo-carboniferous volcanism (Panjal traps in Kashmir) as a result of rifting of Iran-Afghanistan micropiates, Late Jurassic to Early Cretaceous rifting of the Indo-Pakistan Plate, widespread volcanism during Late Cretaceous (Deccan traps) attributed to the appearance of a "hot spot" in the region, emergence of a chain of volcanic islands along the margins of the Indo-Pakistan Plate, collision of India and Asia (Cretaceous-Paleocene) and the consequent Himalayan upheaval, and Neogene-Quaternary volcanism in the Chagai District (Kazmi & Jan, 1999; Raza & Bander, 1995).

**Figure - 16: On the River Rance in France, Rising and Falling Tides are Used to Produce Power**

**Source:** *IGA website*

**Figure - 17: Geothermal Manifestation, Ningzhong, Tibet (Zhao Ping, 2000)**

In Tibet, which occupies more or less the same geological position in Himalayan mountain ranges as Pakistan, more than 600 surface indications of geothermal energy resources have been discovered, with an estimated potential of 800,000 kilowatts (Figure-17). The Yangbajain Geothermal Power Station, the largest in China, started operation in 1988, sending annually about 50 million kwhs of electricity to Lhasa, i.e., about 40 per cent of the electricity turned out by the whole Lhasa grid, fully meeting the need of the local people. Exploitation of the geothermal energy resources in Tibet, though at its initial stage, has drawn the attention of world geologists and energy experts. Upon investigation, United Nations and Italian experts hold that the prospect is very promising and they have provided about $9 million as aid for the construction of geothermal fields in Yangbajain Nying Zhong, Naggu and Latoggang.

This geotectonic framework suggests that Pakistan should not be lacking in commercially exploitable sources of geothermal energy. This view is further strengthened by the fairly extensive development of alteration zones and fumeroles in many regions of Pakistan, the presence of a fairly large number of hot springs in different parts of the country, and indications of Quaternary volcanism. In Pakistan, these manifestations of geothermal energy are found within three geotectonic or geothermal environments, i.e. the geo-pressurised systems related to basin subsidence, the seismo-tectonic or suture-related systems, and the systems related to Neogene-Quaternary volcanism (Figure-18).

Geothermal exploration addresses at least nine phases of integrated study:

i. Identification of geothermal phenomena
ii. Classification of the geothermal field production
iii. Location of productive zones
iv. Ascertaining that a useful geothermal field exists
v. Estimation of the size of the resource
vi. Determination of heat-content of fluids that will be discharged by wells in the

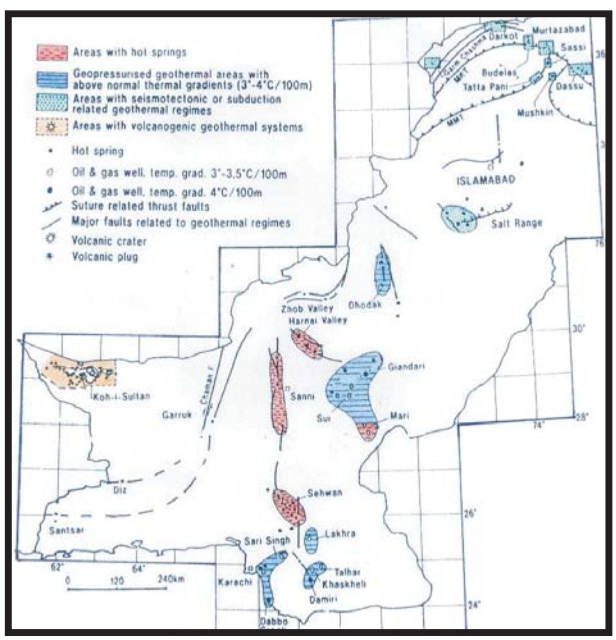
geothermal field

vii. Compilation of a body of data, against which the results of future monitoring can be viewed

viii. Assessment of pre-exploitation values of environmentally sensitive parameters

ix. Determination of any characteristics that might cause problems during field development

In Pakistan, the first three phases have so far been undertaken on limited scale to study the geological characteristics of the geothermal energy sources. Nearly half of the developing countries have rich geothermal resources, which could prove to be an important source of power and revenue. Geothermal projects can reduce the economic pressure of developing country fuel-imports and can offer local infrastructure-development and employment. For example, the Philippines have exploited local geothermal resources to reduce dependence on imported oil, with installed geothermal capacity and power generation second in the world after the United States. In the late 1970s, the Philippines Government instituted a comprehensive energy-plan, under which hydropower, geothermal energy, coal, and other indigenous resources were developed and substituted for fuel oil, reducing their petroleum-dependence from 95% in the early 1970s to 50% by mid-1980s (IAEE, 2003).




**Source:** *Geological Survey of Pakistan*

**Figure - 18: Map Shows the Occurrences of Geothermal Sources in Pakistan**

**Hot Dry-Rock Geothermal Energy Potential:** Renewable-energy technology is continuously evolving, with the goal of reducing risk and lowering cost. The goal of the geothermal industry is to achieve a geothermal energy life-cycle cost of electricity of $0.03 per KWh (U.S. Department of Energy, 2002). To achieve the goal of lowering cost and risk, other types of nontraditional resources and experimental systems are being explored. Among these are hot dry rock resources, improved heat exchangers, and improved condenser efficiency.

Hot dry rock geothermal technology offers enormous potential for electricity production. These resources are much deeper than hydrothermal resources. Hot dry rock-energy comes from relatively water-free hot rock, found at a depth of about 4,000 meters or more beneath the Earth's surface. One way to extract the energy is by circulating water through man-made fractures in the hot rock. Heat can then be extracted from the water at the surface, for power generation, and the cooled water can then be recycled through the fractures to pick up more heat, creating a closed-looped system. Hot Dry Rock resources have yet to be commercially developed. One reason for this is that well-costs increase exponentially with depth, and since Hot Dry Rock resources are much deeper than hydrothermal resources, they are much more expensive to develop. If the technology can be evolved to make hot dry rock resources commercially viable, hot dry rock resources are sufficiently large to supply a significant fraction of electric power needs for centuries. Aeromagnetic studies have revealed significant prospects for the "hot dry rock" geothermal energy in Kharan-Panjgur tectonic depression, in western part of Pakistan.

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# DEVELOPMENT OF ALTERNATIVE/RENEWABLE SOURCES OF ENERGY IN PAKISTAN

**Muhammad Sharif**
*Head, APC&I Centre*
*PCSIR Laboratories Complex, Lahore, Pakistan*

**Abstract**

*The depleting Conventional Energy Resources and highly raised prices of fuel oil, coal, firewood and such other fossil fuels, have forced the mankind to think about the utilization of Alternative / Renewable Sources of Energy. Alternative / Renewable Energy is very attractive, reliable and cost competitive energy. Sun is readily available to provide a clean, abundant and virtually infinite energy to meet the significant portion of mankind's energy-needs. The possible use of renewable-energy sources is discussed in this paper, in order to fill the estimated gap between the available energy-sources and energy-needs of our country in the near future.*

*Designing, Fabrication and Installation of different renewable-energy devices by PCSIR are also discussed in this paper. Different renewable-energy devices such as, solar water-heaters, solar cookers, solar dehydrators, solar water-desalination plants, solar heating and cooling of buildings, solar operated absorption-type chiller, solar furnace, solar architecture, developed by PCSIR are discussed in some detail so that the role of renewable-energy sources for their direct use (as heat and power) can be determined. Various technical aspects are discussed to reduce the unit cost with improved efficiency.*

## 1. Introduction

The use of alternative/renewable energy is greatly appreciated all over the world. The use of direct power from the Sun's radiation has many advantages. Solar Power is abundantly available even in regions remote from the sources of fossil-fuels. It is essentially a non-depletable source of energy in comparison with fossil fuels or nuclear fission-power and it is cost-free in its original radiation form. Of course there is a significant cost for the capital plant required for converting alternative / renewable energy to other forms of energy. If alternative / renewable energy is utilized locally, then the need for transporting the energy is avoided. Also, solar power can be used in small units as for an individual building or home. Alternative/renewable energy devices hold promise for the developing world, as well as for the economically developed world. Alternative / renewable energy resources burn no fuel and cause no air - or water-pollution. Our earth receives 700,000 TWH (Tera - 1012) every year. Since 1973, due to the crisis of petrol, every country in the world is trying to find the alternative solution to address the energy-crisis. The kilowatt hours saved by the use of Alternative / Renewable Energy, will be the best application in the industrial sector. In this way, we can fulfil the demand of energy of our nation. The current technologies for the usage of alternative/renewable energy are expensive, and it is necessary that cheaper technologies be introduced and developed.

## 2. Technological Activities of PCSIR in the field of Renewable Energy

PCSIR has already produced, demonstrated and sold an appreciable number of Alternative/renewable-energy appliances, such as solar water-heater, solar dehydrator, solar cooker, solar water-desalination plant, etc. Continuous Research and Developmental work on the following listed appliances is being done at PCSIR Labs., Complex, Lahore, and their Technology was publicitised through Seminars and Published Literatures:

i) Solar water-heaters for domestic and industrial purposes;
ii) Solar cookers (oven-type and concentrating type);
iii) Solar stills to suit the requirements of various regions of the country;
iv) Dehydrator for improved solar dehydration of vegetables, fruit, fish, meat and meat products;
v) Experimental model of solar architecture in conventional structure;
vi) Solar passive structures; and
vii) Fundamental studies on glazing materials.

Subsequently these appliances were also supplied to the following organizations:

i) Pakistan Rangers for their check-posts on the border areas in Cholistan, Punjab and District Tharparkar (Sindh);
ii) Pakistan Army;
iii) Land & Reclamation Department, Government of Punjab, Lahore;
iv) Home Economic College, Lahore;
v) Sindh Arid Zone Development Authority;
vi) Agriculture Department, Skardu;
vii) PCSIR Laboratory, Skardu;
viii) Pakistan Navy;
ix) M/s. Star Pharmaceutical Labs., Chung, Lahore; and
x) M/s. Petrochem Chung, Lahore etc.

## 3. Alternative/Renewable-Energy Appliances, Designed, Fabricated/installed by PCSIR

### i. *Solar Water-Desalination Plants*

PCSIR have designed and installed Solar Water-desalination plants in three different sizes in Thar, Cholistan, Baluchistan coastal area (Gwader) and desert border areas (For Pakistan Rangers and Pakistan Army). The units provide safe drinking-water by using solar heat for distillation of brackish or sea-water.

*Portable and Family Size:* This is a 10-12 litres per day capacity unit, especially

**Figure - 1: Solar Water-Desalination Plant**

useful for a single family or for remote/isolated Army/Rangers posts, where providing safe drinking-water is not possible. The unit was initially designed for border Police/Army posts, which can be transported and installed easily. A single unit would cost Rs.5000/.

*Medium Size:* Solar-water-desalination plants installed by PCSIR at Man-Bai-Jo-Tar (Chachro) and Vajuto in district Tharparkar each of capacity 250 gpd are being operated and maintained by PCSIR. These plants are producing potable water from brackish water available in these areas. The potable water received from these plants is being supplied to the local population.

*Large Size*-Water-Desalination Plant Gwader: PCSIR refurbished water-desalination plant at Gwader. This plant converts sea- water into potable water. The capacity of the plant was about 6000 gpd. Different Agencies have shown interest in this technology for installation of more such plants in the coastal area of

**Figure - 2: Solar Water-Desalination Plant, Vajuto-District Tharparkar**

**Figure-3: Solar Water-Desalination Plant, Gwader**

Baluchistan and arid zone areas of Pakistan.

Pakistan-Navy Water Desalination-Plant Gwader: PCSIR has also designed, fabricated and installed a Solar water-desalination plant (capacity 6000 gpd) for Pakistan-Navy's establishment at Gwader, Baluchistan. This plant converts sea-water into potable water.

**ii.** ***Solar Water-Heater***

Several types of solar water-heaters have been designed and fabricated on simple thermosyphon, forced-circulation and closed loop systems. Solar water-heaters of forced-circulation type, with anti-freeze heat carrying fluid, have been designed and fabricated for such areas where ambient temperature falls well below freezing point of water in winter season. Solar water-heaters fabricated are being commercialized. This heater can be used as a "community hot-water supply-system", especially applicable in Villages where fuel/fire-wood availability is scarce and costly. A single unit with 50 gallon storage capacity costs Rs. 20,000/-. Whereas, the specially designed unit for extremely cold climate costs Rs. 22,000/-.

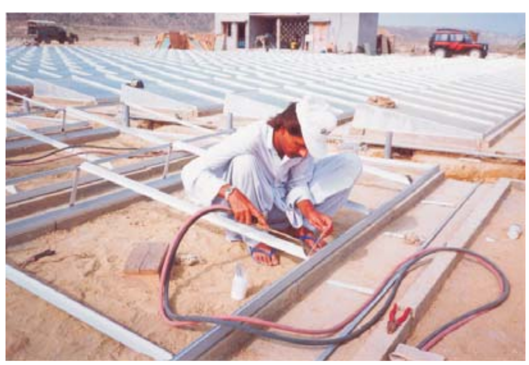

**Figure - 4: Pakistan Navy's Water-Desalination Plant-Gwader**

**Figure - 5: Solar Water-Heater**

These units were supplied to different parties on demand.

**iii.** ***Solar Dehydrator***
Different types of solar dehydrators designed and fabricated by the PCSIR, have been successfully tested and tried for dehydrating of vegetables, fruits, fish, meat and meat products. Investigations are being carried out for modification and improvement, keeping in view the cost-factor. The knock-down version, designed and fabricated for easy transportation and assembly, has also been tried and found successful. Efforts are being made for commercialization of Solar Dehydrators. A Single unit of 30 kg capacity with a drying area of 2 meter square costs Rs. 15,000/. These units were installed at Skardu.

**iv.** ***Solar Cooker***
Three simple box-type Solar Cookers, with different heat-storage capacities, have been designed and fabricated. This solar cooker can store heat alongwith normal

**Figure - 6: Solar Dehydrator**

**Figure - 7: A Reflector-Type Solar Cooker**

cooking for off-hours and also can maintain cooking temperature in case of sudden decrease in ambient temperature. Different materials of fabrication were also applied in pursuance of cheap and efficient model. These cookers are being evaluated for various kinds of cooking performances. A parabolic reflector-type solar cooker has been designed, fabricated and evaluated for various kinds of cooking performances.  Efforts are being made for commercialization of this parabolic reflector-type solar cooker.

**v.** ***Solar (PV) Refrigerator (2 ft$^3$)***

A small two ft$^3$ refrigerator operated on solar-panel power for storage of vaccines, antibiotics and other life-saving drugs, in remote areas has been assembled by PCSIR.  This system is much cheaper as compared to the imported ones with same capacity and performance of the unit.

**vi.** ***Space Heating and Cooling of Buildings***

A private party M/s. Petrochem based in Lahore has approached PCSIR for provision of facility of space-heating/cooling in buildings. The unit was fabricated at PCSIR Laboratories Complex, Lahore, and installed at the premises of the party, 1-E Model Town, Lahore. The system is now working successfully and the private party is satisfied with the performance of the unit.

**Figure-8: Solar Cells Energizing 2 ft$^3$ Refrigerator**

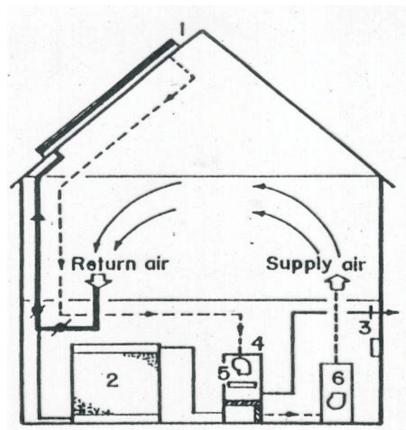


**Figure-9: Space-Heating from Solar Collectors**

**vii.** ***Installation of Solar Operated Absorption-Type Chiller (of 3 Tons Capacity)***
A Solar operated absorption type chiller of 3 tons capacity has been designed, fabricated and installed at PCSIR Laboratories Complex, Lahore. Research and development work on this project is being carried out for its commercialization. The running expenditure of this unit is negligible.

**viii.** ***Designing and Fabrication of Solar Furnace***
A Solar Furnace of 10 ft. diameter has been designed, fabricated and installed at PCSIR Laboratories Complex. Lahore. Different reflecting materials such as, aluminum-foil, glass mirrors are being tested for better results. This furnace will be used to run a steam-engine for production of power.

**Figure - 10: Absorption-Type chiller of 3 tons capacity**

**Figure - 11: Solar Furnace**

## 4. Major Research Projects Completed

The major research projects completed during 1980 - 2001 related to renewable energy, are as follows in Table - 1:

**Table - 1: Major Research Projects**

| S# | Name of Project | Duration | Cost (Rs.) | Sponsored By |
|---|---|---|---|---|
| 1. | Product Development & Dissemination of Solar Technology | 1985 to 1987 | 1.5 millions | Ministry of Science & Technology, Islamabad |
| 2. | Special Project of Installation of a Solar Water Desalination Complex at Man Bai-Jo-Tar | Dec, 1987 to June 1988 | 1 million | Prime Minister 's Scheme |
| 3. | Gawadar Water Desalination Plant (Renovation) | 1986 to 1988 | 2.0 millions | Prime Minister 's Scheme |
| 4. | Installation of Solar Desalination Plants in Thar | 1988 to 1990 | 2.5 millions | Sindh Arid Zone Development Authority |
| 5. | Pakistan Navy Solar Water Desalination Plant, Gawadar | 1989 to 1991 | 7.5627 millions | Pakistan Navy |
| 6. | Solar Dehydrator Plant of 100 Kg capacity | April,1998 to June 1998 | 0.1 million | Agriculture Deptt. Skardu |
| 7. | Solar Dehydrator Plant of 1000 Kg. Capacity | 1999 to 2001 | 0.7 million | PCSIR Laboratory Skardu |

*continue...*

...continued

| | | | | |
|---|---|---|---|---|
| 8. | Solar Water Heater of 50 gallons capacity | May 1985 to June 1985 | Rs. 12,000/- | PCSIR Camp Office Quetta |
| 9. | Solar Water Heater of 50 gallons capacity | April to May 2001 | Rs. 25,000/- | M/s Star Labs Chung, Lahore |
| 10. | Solar Water Desalination Plants portable | April 1985 to June 1985<br><br>April to May 2001 | Rs. 35,000/- | 1. Pakistan Rangers<br>2. Land & Reclamation Deptt. Govt. Of Punjab, Lahore<br>3 PCSIR Camp Office, Quetta<br>4. M/s Star Labs. Chung, Lahore |
| 11. | Solar Cookers | Sep, 1994 To Oct. 1994<br>April to May 2001 | Rs. 8,000/- | 1. Pakistan Army<br><br>2. M/s Star Labs. Chung, Lahore |
| 12. | Solar Water Heater of 50 gallons capacity with Collector Area 50 square feet | Jan., To March 2001 | Rs. 25,000/- | M/s Petrochem Chung, Lahore. |

## 5. Academic Assistance and Trainings Imparted

PCSIR Laboratories Complex, Lahore, has supervised the research-work of 128 (one hundred and twenty eight) students, from different universities of Pakistan in the field of Renewable Energy for the award of B.E. / M.Sc. degrees.

## 6. Present Status

Presently, the infrastructure for the development of Renewable Energy Technologies is adequately available at PCSIR Labs., Complex, Lahore. The facilities available for the development of Alternative / Renewable Energy Technologies, are supervised by the trained staff to undertake the projects relevant to Renewable Energy and its Sub Sector.

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# POTENTIAL MARKET-SIZE FOR RENEWABLES IN THE RESIDENTIAL SECTOR OF PAKISTAN

**G.R. Athar and M. Imtiaz**
*Applied Systems Analysis Group,*
*Pakistan Atomic Energy Commission,*
*P. O. Box 1114, Islamabad. Pakistan*

**Abstract**

*Renewable energy-sources can be used for meeting the energy-demand of various end-uses, like water-pumping for irrigation, process-heat for industries and desalination for potable water-supplies. However, the residential sector has the largest potential for renewable energy usage among all sectors of the economy. At present, the residential sector of Pakistan consumes some 26 million Tonne of Oil Equivalent (MTOE) energy: with more than 6 MTOE in the form of commercial energy (electricity, natural gas, kerosene, LPG and coal) and about 20 MTOE in the form of non-commercial energy (wood, dung and crop-residues).*

*Applied Systems Analysis Group (ASAG) has carried out a study to project the energy-demand of Pakistan up to the year 2024-25, using an energy-demand model MAED. This model uses simulation technique to evaluate the energy-demand implications of a scenario, describing the assumed evolution of demographic parameters, economic activities, lifestyle of the population and technological improvements. The demographic targets of the Population-Policy of Pakistan and economic targets of Government of Pakistan have been adopted as the basis of our reference scenario. The study shows that the energy-demand of the residential sector will increase by a factor of 1.7, compared to the base-year 2001-2002. The residential sector will need 41.9 MTOE energy, of which : (i) 5.9 MTOE (72.5 TWh) in the form of electricity to fulfill the energy-needs for lighting, cooling and other electric appliances, (ii) 24.4 MTOE for cooking, (iii) 5.7 MTOE for water heating, and (iv) 5.8 MTOE for space heating. In all these end-uses, renewable energy can make a contribution depending on the cost of energy, convenience of use and reliability of supply.*

*Although, the government is vigorously pursuing a rural electrification program, a portion of residential sector, particularly in remote areas, will not be electrified even by 2024-25. The non-electrified houses will require 3 to 5 TWh of electricity, by the year 2024-25, which can be supplied through renewables, depending upon resource-endowment of the area. Theoretically, all the thermal energy-needs of residential sector for cooking, water heating and space heating can be met by renewables. However, natural gas, followed by LPG and kerosene, according to availability of fuels and affordability by consumers, are preferred fuels for thermal uses. These commercial fuels can meet only 11 MTOE of thermal energy-requirements for cooking, water heating and space heating. The resultant shortfall of about 25 MTOE, by year 2024-25, will be a potential market for*

*renewable-energy sources in addition to the renewable-electricity market of 3 to 5 Twh.*

## 1. Introduction

Residential sector in Pakistan, consisting of 21 million households, has a large potential for renewable energy. One fourth of the households have no access to electricity and 80% are without piped natural gas. They meet their energy-needs (for cooking, space heating and water heating) through using of wood, dung and crop-residues. Although, Government of Pakistan (GOP) is expanding its electricity and natural gas networks, a significant portion of residential sector, particularly in remote areas, will remain without modern energy-services in the next 2-3 decades and will continue to rely on traditional fuels (hereinafter called as non-commercial fuels).

Applied Systems Analysis Group (ASAG) of Pakistan Atomic Energy Commission (PAEC) has assessed the potential market for renewables in residential sector of Pakistan with the help of MAED model, acquired from International Atomic Energy Agency (IAEA). Section-2 of this paper describes MAED methodology. Section-3 shows energy consumption-pattern of the residential sector. Section-4 estimates final energy demand of residential sector by the year 2025, whereas Sections-5 assesses potential market-size for renewable energy. Section-6 concludes the paper.

## 2. Methodology of the Study

The MAED model (Model for Analysis of the Energy Demand) has been used for the projection of energy-demand for this study. MAED is a simulation model designed for evaluation of energy-demand of a whole country or a sector of the economy, by developing a scenario, describing a hypothesized evolution of the economic activities and life-style of the population. In MAED model, the energy-demand is disaggregated into end-use categories, each one corresponding to a given service. The nature and level of the demand for a service is a function of several types of choices, like dwelling area per inhabitant, type and amount of electrical appliances to be used in households, evolution of the efficiencies of certain types of equipments, market penetration of new technologies or energy forms, etc. Model details are available in its User Manual [IAEA: 2002].

## 3. Pattern of Energy-Consumption in Residential Sector of Pakistan

The consumption of energy in residential sector of Pakistan is about 26 Million Tonnes of Oil Equivalent (MTOE), comprising 23% in commercial form and 77% in non-commercial form. Final commercial energy-consumption amounts to 6.1 MTOE (electricity: 31.6%, natural gas: 59.0%, kerosene: 4.8%, LPG: 4.6% and a small quantity of coal). As no survey has been conducted after the HESS survey [HESS: 1993], consumption of non-commercial fuels has been estimated with the help of HESS data, keeping in view the increase in use of commercial fuels after the HESS survey. It has been estimated that non-commercial fuel use during 2003 was 19.9

MTOE: Table-1 shows the energy-consumption of the residential sector for some selected years. Data series for the consumption of commercial fuels, in residential and other sectors, are available in Pakistan Energy Yearbook [GOP: 2003a]. The data for non-commercial fuels is only available for some years, i.e. 1975, 1982 and 1991 [GOP: 1978, GOP: 2003a, HESS: 1993]. The consumption of LPG, natural gas and electricity has increased at a rate of more that 12% per annum during the last 28 years, while consumption of coal and kerosene has decreased. The consumption of coal in residential sector has decreased to about one thousand tonne only [GOP: 2003a]. The overall increase in consumption of total commercial fuels was 7.6% per annum during the period 1975-2003. Consumption of non-commercial fuels has increased from 5.78 MTOE to 19.93 MTOE during the last 28 years, with an average annul growth-rate of 4.5%, which is 3.1 percentage point lower compared to commercial fuels, mainly due to expansion of electricity and natural gas networks and enhanced availability of LPG. Total energy-requirements of the residential sector are about 26.02 MTOE, which are highest among all the sectors of economy.

**Table-1: Final Energy-Consumption of Residential Sector (MTOE)**

| | **1975** | **1981** | **1991** | **2003** |
|---|---|---|---|---|
| Electricity | 0.08 | 0.22 | 0.85 | 1.92 |
| Natural Gas | 0.12 | 0.42 | 1.56 | 3.59 |
| Kerosene | 0.56 | 0.53 | 0.97 | 0.29 |
| LPG | -- | 0.03 | 0.09 | 0.28 |
| Coal | 0.03 | -- | -- | – |
| Total commercial | 0.78 | 1.20 | 3.48 | 6.09 |
| Non-commercial | 5.78 | 10.0 | 17.19 | 19.93 |
| Total Energy | 6.57 | 11.20 | 20.67 | 26.02 |

**Note:** .. less than 0.001 MTOE
**Sources:** *Ref. [GOP:1978, HESS:1993, GOP:2003a]*

## 4. Future Energy-Requirements of Residential Sector of Pakistan

In MAED methodology, the calculations of energy-demand for the household sector are performed, taking into account the living conditions of the population, i.e. the place of residence (a large city or a rural area), type of residence (a detached house or an apartment) and life style of the people (level of use of air-conditioners, appliances, etc.). This permits a better representation of the proper needs of the individuals, as well as a more appropriate definition of the potential markets for the alternative forms of final energy. For residential sector the determining factors are of demographic nature, like size of population, number of households. The categories of end-use considered in the residential sector are: space heating, air conditioning, water heating, cooking, and electricity for appliances (refrigerators, lighting, washing machines, etc.). The assumptions made for development of a scenario for MAED model are described in the following sections.

## 4.1 Assumptions

*4.1.1 Demography:* Pakistan is a very populous country, with 145 million inhabitants, as of January 2003. The population census has been carried out in Pakistan in 1951, 1961, 1972, 1981 and 1998. Table-2 reports the historic trend of population-growth since 1973, which shows that the population growth-rate of Pakistan has decreased from 3.06% per annum in 1973 to the present growth-rate of 2.10% per annum i.e., a reduction of 0.96 percentage points during the last three decades. The reduction in population-growth in this period has been possible due to the family planning programmes introduced by the GOP. The official targets set by the GOP in Ten-Year Perspective Development Plan 2001-2011 [GOP: 2001a] envisage reduction in population growth to 1.8% by the year 2011.

For the present study, the demographic targets of the Population Policy of Pakistan [GOP: 2002a] have been adopted as the basis of the demographic scenario. According to the Population Policy, Pakistan will achieve annual average growth-rate of 1.30% by the year 2020, through launching advocacy campaigns and promoting of small family norm.

The projected rural-urban split has been estimated with the help of past trends. The projected household size has been worked out, in line with targets of Ten Year Perspective Development Plan 2001-2011.

*4.1.2 Level of National Gross Domestic Product (GDP) per household*
During the last thirty years (1973-2003), Pakistan's economy has grown at an average growth-rate of 5.0% p.a. However, due to high population growth-rate, the

**Table-2: Demographic Parameters**

| Year | Total Population | | Share (%) of Rural Population | Persons per Household |
|---|---|---|---|---|
| | (Million) | Growth Rate | | |
| 1973 | 65.9 | 3.06 | 73.50 | 5.88 |
| 1978 | 76.6 | 3.05 | 72.40 | 6.36 |
| 1983 | 88.4 | 2.99 | 71.30 | 6.66 |
| 1988 | 101.0 | 2.77 | 70.30 | 6.67 |
| 1993 | 115.0 | 2.56 | 69.80 | 6.69 |
| 1998 | 130.0 | 2.34 | 67.50 | 6.80 |
| 2002 | 142.1 | 2.16 | 66.50 | 6.96 |
| 2003 | 145.1 | 2.10 | 66.50 | 6.85 |
| 2005 | 151.0 | 1.98 | 64.10 | 6.78 |
| 2010 | 165.2 | 1.70 | 60.20 | 6.49 |
| 2015 | 178.5 | 1.48 | 56.60 | 6.34 |
| 2020 | 191.0 | 1.30 | 53.20 | 6.22 |
| 2025 | 203.8 | 1.30 | 50.00 | 6.11 |

**Source:** *[GOP: 2001a, GOP: 2001b, GOP: 2003b, and GOP: 2003c]* per capita GDP has increased at only 2.3% p.a. during the same period. The present per capita income in Pakistan is Rs. 25,663 (US$ 435), which places the country among the group of low-income developing countries. Table-3 reports/projects the economic growth of the economy for the period 1973 to 2025. Since early 1990s the growth performance has been exceptionally low and the GDP growth-rate has slowed down to barely 2.2% p.a. in the year 2001. Due to the GOP's reforms in economy, the GDP growth has begun increasing again. During the year 2002, Pakistan's economy grew at the rate of 3.4% p.a. and the growth-rate further increased to 5.1% p.a. in the financial year 2003 [GOP: 2003b]. Table-3 also gives the assumed growth rates of total economy upto year 2025. These growth-rates are of medium scenario of a study [NTDC: 2003] carried out by National Transmission and Dispatch Company (NTDC). NTDC has developed the economic-growth scenario, in consultation with Pakistan Institute of Development Economics (PIDE).

With the above-mentioned targets (and assumptions) for demographic and economic growth, GDP per capita of Pakistan will rise upto Rs. 64,006 (US$ 1,042) in the year 2025. The per capita GDP value for the year 2025 is almost equal to half of the present level of GDP per capita of Turkey (US$ 2,230), and one-fourth of Malaysia (US$ 3,699) [*UNDP: 2003, pages 278-281*].

*4.1.3 Electrification and use of electricity*

To project electricity-demand of the residential sector, the extent of electrification has to be estimated in the first place. At present, about 77% of the total households have access to electricity [*GOP: 1999, GOP: 2001b, WAPDA: 2003a*]. Although the government is vigorously pursuing a rural electrification programme, the planning department of NTDC envisages that about 10% population of the country

**Table-3: Growth-Rates of Gross Domestic Product (GDP)**

| Period | Growth-Rates (% p.a) |
|---|---|
| 1973-78 | 4.90 % |
| 1978-83 | 6.55 % |
| 1983-88 | 6.16 % |
| 1988-93 | 4.92 % |
| 1993-98 | 4.23 % |
| 1998-99 | 4.18 % |
| 1999-00 | 3.91 % |
| 2000-01 | 2.22 % |
| 2001-02 | 3.36 % |
| 2002-03 | 5.08 % |
| 2002-05 | 5.20 % |
| 2005-10 | 5.80 % |
| 2010-15 | 6.30 % |
| 2015-20 | 6.30 % |
| 2020-25 | 6.30 % |

**Source:** [*GOP: 2003b*]

**Table-4: Total and Per-Capita Gross Domestic Product (GDP)**

| Year | Total GDP (Billion Rs.) | | GDP/Capita (Rs.) | | GDP/Household (Rs.) | |
|---|---|---|---|---|---|---|
| | 2002 Prices | Current Prices | 2002 Prices | Current Prices | 2002 Prices | Current Prices |
| 1973 | 813 | 61 | 12,337 | 923 | 72,544 | 5,425 |
| 1978 | 1,032 | 157 | 13,477 | 2,052 | 85,716 | 13,050 |
| 1983 | 1,416 | 292 | 16,017 | 3,304 | 106,672 | 22,003 |
| 1988 | 1,906 | 601 | 18,870 | 5,950 | 125,866 | 39,684 |
| 1993 | 2,400 | 1,192 | 20,862 | 10,358 | 139,566 | 69,293 |
| 1998 | 2,953 | 2,481 | 22,718 | 19,088 | 154,485 | 129,799 |
| 2002 | 3,377 | 3,377 | 23,771 | 23,771 | 165,444 | 165,444 |
| 2003 | 3,549 | 3,710 | 24,453 | 25,563 | 167,505 | 175,105 |
| 2005 | 3,935 | | 26,058 | | 176,674 | |
| 2010 | 5,216 | | 31,584 | | 204,979 | |
| 2015 | 7,080 | | 39,673 | | 251,526 | |
| 2020 | 9,609 | | 50,303 | | 312,887 | |
| 2025 | 13,042 | | 64,006 | | 391,080 | |

**Source:** *[GOP: 2003b for data of 1973-2003]*

will not be connected to the national grid by year 2025 (NTDC: 2003). In MAED model, electricity requirements of household are subdivided in two end-uses: air-conditioning and other appliances. After the HESS study [HESS: 1993] data about use of air-conditioners have not been assembled. Use of air-conditioners is growing in the household sector. It has been estimated that, in 2002, which was base-year of this study, approximately 4% of electrified household (3.1% total households) were using air-conditioners. It has been assumed that 11.5 % of total households would have air-conditioners in 2025, with average annual growth-rate of 6.1% p.a. As for other electric appliances, the base-year specific electricity consumption has been estimated. For future projection, this consumption has been linked to income-level of household (i.e. the electricity-consumption per household for appliances will increase in future in line with level of national GDP per household).

*4.1.4 Thermal uses of energy*

For thermal energy-consumption in households, the end-use categories considered are cooking, water heating and space heating. On the basis of data given in HESS survey, energy-consumptions of these end-uses have been estimated for the base-year of the study.

In general, the energy-requirements per household for cooking increase with increase in income. However, this increase slows down by changing social behavior involving use of pre-cooked/semi-cooked food. Therefore, only 0.34% per annum growth has been assumed for cooking-requirement per household (overall 8.2% over the 23 years period).

As for heating water, it has been assumed that about 38% households will use this facility by 2025. The specific energy-consumption for water heating will increase in proportion to increase in the GDP per capita. It has been assumed that during the next 28 years of study period, the energy-intensity for this end-use will increase by a factor of 1.2. Table-5 gives the base-year and projected energy-intensities of various end-uses in household sector.

The end-use efficiencies of fossil-fuels for cooking, water heating and space-heating for the base-year 2002 have been worked out from HESS estimates for individual fossil-fuels. The end-use efficiency of non-commercial fuels has been assumed to increase from the base-year value of 13% to 14.6% by the 2025, in view of the efforts being made for introduction of improved cook-stoves. As for the penetration of electricity for different thermal uses in households, the fact is that, natural gas, if available, is the most preferred fuel. Furthermore, the Government is planning to provide natural gas to even small towns. As such, the use of electricity for thermal uses has been projected to be minimal and has been kept zero.

## 4.2 Final Energy-Demand of Residential Sector

Under the assumptions described above, energy-demand of residential sector increases to 41.9 MTOE by the year 2025 from 25.3 MTOE in 2002, with average annual growth-rate of 2.23%. The results of the MAED model are summarized in Table-6. Energy-demand for total thermal uses increases at 1.90% per annum, while electricity requirements increase at annual average growth-rate of 5.08%.

The increase in energy-demand for cooking is slow, due to expected changing social behavior involving use of pre-cooked/semi-cooked food, and envisaged efficiency

**Table - 5: Indicators of Household-Sector**

| | **Unit** | **2002** | **2010** | **2020** | **2025** |
|---|---|---|---|---|---|
| Dwelling size | square meter | 65.0 | 71.3 | 80.1 | 85.0 |
| Households with space-heating | % | 10.2 | 14.5 | 22.6 | 28.1 |
| Households with water-heating | % | 17.9 | 23.3 | 32.4 | 38.2 |
| Households with air-conditioners | % | 3.1 | 4.9 | 8.7 | 11.5 |
| **Energy Intensities (Useful) for the Household Sector.** | | | | | |
| Cooking | KGOE/ household/yr | 200 | 205 | 212 | 216 |
| Electrical appliances (final) (excluding AC) | kWh/ household/yr | 1,403 | 1,580 | 1,834 | 1,928 |
| Water-heating per person (of households having hot water facility) | KGOE/cap/yr | 19.0 | 20.4 | 22.3 | 23.3 |

**Note:** *KGOE = Kilogram of Oil Equivalent* improvements for fuel use. Therefore, energy-demand for cooking increases only 0.88% p.a. Demand for space- heating and water heating increases by 6.27% p.a., and 4.77% p.a., respectively. The electricity requirements for air-conditioning grow at 9.3% per annum, i.e. at much higher growth compared to economic growth.

**Table - 6: Final Energy-Demand of Residential Sector by End-Users (MTOE)**

| | 2002 | 2005 | 2010 | 2015 | 2020 | 2025 | Annual Average Growth-rate 2002-25 |
|---|---|---|---|---|---|---|---|
| Cooking | 19.96 | 20.88 | 22.31 | 23.16 | 23.78 | 24.44 | 0.88% |
| Space Heating | 1.43 | 1.76 | 2.46 | 3.30 | 4.39 | 5.81 | 6.27% |
| Water Heating | 1.96 | 2.29 | 2.91 | 3.67 | 4.60 | 5.74 | 4.77% |
| ***Total thermal use*** | ***23.36*** | ***24.93*** | ***27.68*** | ***30.13*** | ***32.76*** | ***35.99*** | ***1.90%*** |
| ***Of which fossil fuel*** | ***3.90*** | ***4.64*** | ***6.04*** | ***7.57*** | ***9.30*** | ***11.37*** | **4.76%** |
| Air conditioning | 0.086 | 0.117 | 0.191 | 0.296 | 0.451 | 0.668 | 9.31% |
| Electric Appliances | 1.80 | 2.18 | 2.97 | 3.90 | 4.58 | 5.23 | 4.74% |
| ***Total electricity*** | ***1.89*** | ***2.30*** | ***3.16*** | ***4.20*** | ***5.04*** | ***5.90*** | ***5.08%*** |

## 5. Potential Market For Renewables in the Residential Sector

### *5.1 Potential of Renewables for Thermal Uses*

In the year 2025, energy-requirements for the thermal uses of residential sector will be 36.0 MTOE, of which only about 11.4 MTOE can be met by fossil-fuels. The resultant gap of 24.6 MTOE is a potential market for biomass (wood, crop-residues and dung) and other renewables. In addition to capturing a part of this market of 24.6 MTOE, renewables can also substitute for the fossil-fuels. The study-team has made some assumptions to assess the potential market for renewables in year 2025, which are listed in Table-7. These assumptions have been made keeping in view the present status and efforts for renewables at national and global levels. Table-8 gives guesstimate of potential market of renewables in Pakistan in year 2025.

It has been estimated that the renewables can meet about 8.32-8.58 million TOE of thermal energy-demand of residential sector, through solar water-heaters, solar-cookers and other renewable applications like biogas. Solar water-heaters have a great potential in residential sector of Pakistan. Solar water-heaters are being manufactured at very limited scale in the country (GOP: 2003a). Awareness campaigns and tax incentives can increase the use of solar water-heaters. If solar water-heaters can capture 15-20% of fossil-fuel market for water-heating they can avoid 0.27 to 0.36 MTOE of use of fossil-fuels. ALGAS study has estimated saving of 0.2 MTOE of natural gas through use of solar water heaters in year 2020 [*GOP: 2003a, page 74*]. Solar water-heaters are penetrating into the market in some developing, as well as, industrialised countries. Nepal is a good example to follow. Table-9 shows the present status of renewable-energy use in Pakistan. During

1970s biogas-technology was introduced in Pakistan. Many biogas-plants were constructed at various locations. Unfortunately, most of them are not in operation now. However, there is substantial potential of biogas and it can meet about 30% of cooking requirements of the country [GOP: 2003a]. China and Bangladesh are good examples to follow.

**Table-7: Assumptions for Assessment of Potential Market for Renewables in 2025**

| | Substitution of fossil fusels | Probable supply from renewables To fill gap between demand and supply |
|---|---|---|
| **Thermal Uses** | | |
| Cooking | 3 5% of 8.1 MTOE, replacing Fossil fuel by solar cooker, biogas | One third of gap of 16.3 MTOE |
| Water heating | 15 -20% of 1.8 MTOE, replacing fossil-fuels by solar water-heater | Half of gap of 3.9 MTOE |
| Space heating | … | 10% of gap of 4.3 MTOE |
| **Electricity** | | |
| | 1 -2 % of 72.5 TWh with some policy initiatives (i.e. Tax incentives, subsidies) | 80% of gap of 3 5 Twh |

**Note:** .. negligible

**Table-8: Potential Market for Renewables in 2025**

| | Substitution of fossil-fuels | Probable supply from renewables to fill gap between demand and supply | Total Potential of renewables other than biomass |
|---|---|---|---|
| **Thermal Uses** | | | |
| Cooking | 0.24 – 0.41 MTOE | 5.43 MTOE | 5.67 - 5.84 MTOE |
| Water-heating | 0.27 – 0.36 MTOE | 1.95 MTOE | 2.22 – 2.31 MTOE |
| Space-heating | …negligible | 0.43 MTOE | 0.43 MTOE |
| Total Thermal use | 0.51 – 0.77 MTOE | 7.81 MTOE | 8.32 – 8.58 MTOE |
| **Electricity** | | | |
| | 0.73 – 1.46 TWh | 2.4 – 4.0 TWh | 3.13 – 5.46 TWh |

**Note:** .. means negligible

Biomass (wood, dung and crop-residues) is the only renewable source being widely used in residential sector for cooking, space heating and water-heating. Presently, biomass fulfils about 19.9 MTOE of energy-needs of the residential sector of Pakistan. It is expected that, in future, biomass will also be used for balancing between demand and supply of energy for thermal uses of residential sector. However, use of biomass has some social and environmental aspects, i.e.:

i. Biomass is used in traditional cook-stoves at very low efficiency that results in overuse.
ii. In some areas, children spend their time for collection of biomass and lose their opportunity for education.
iii. Indoor pollution damages the health of women. World Bank has collected data from 122 countries and concluded that female-male life expectancy gap is small in those countries where biomass share is high in energy-use. Some of the World Bank data is reproduced in Table-10.

Therefore, for sustainable development, use of biomass may be replaced with other renewables or commercial fuels.

### *5.2 Potential of Renewables for Generation of Electricity*

It is projected that electricity demand of Pakistan will increase to 72.5 TWh by the year 2025. NTDC envisage that about 10% of the population (i.e. 3.3 million households) would not be connected to the national grid. These non-electrified households will require 3-5 TWh of electricity, assuming electricity-demand of 100-150 kWh per household per month. This demand is a potential market for renewables like mini/micro hydro, wind-power, solar photovoltaic or electricity from solar thermal or from wastes. In addition to this potential, renewables can capture the market in the area of national grid on the basis of cost economy. As electricity-costs of renewables are decreasing [UNDP: 2000], it is expected that the renewables can meet about 3.13-5.46 billion kWh of electricity demand of residential sector of Pakistan by the year 2025.

**Table-9: Present Status of Renewable Energy in Pakistan**

| | |
|---|---|
| Photovoltaic | 18 solar station of 437 KWp were constructed during 1980s. However none of them is currently operational. |
| Solar thermal | • No solar-thermal power-plant exist/planned.<br>• Solar water-heaters are available in the country but are not popular. Awareness campaigns and tax incentives are needed for their promotion. |
| Wind | • Locally manufactured windmill (i.e. Tawana, Mujahid, Zorawar are working) to lift water.<br>• Feasibility study of 15 MW wind-power plant at Pasni.<br>• Data is being collected to asses the potential for wind-power. |
| Mini/Micro hydel | Large potential exists in north of the country and it is being Explored |
| Geothermal | Research work by GSP, PAEC |
| Biogas | Many units constructed with support of GOP, but, probably, most of them are not operational. |
| Biomass | 19.9 MTOE being used in household. Sugar industry also uses the biomass in the form of baggasse. |

**Table-10: Usage of Biomass and Demographic Indicators**

| Indicator | Share of biomass in total fuel-use | | | | |
|---|---|---|---|---|---|
| | 0-20% | 20-40% | 40-60% | 60-80% | Above 80% |
| Number of countries | 70 | 12 | 14 | 10 | 16 |
| Female life expectancy (years) | 74.7 | 68.8 | 62.0 | 56.1 | 48.3 |
| Male life expectancy (years) | 68.5 | 64.0 | 57.8 | 53.3 | 45.8 |
| Female-male life expectancy gap (years) | 6.2 | 4.5 | 4.2 | 3.1 | 2.6 |

**Source:** *Ref. [UNDP:2000]*

## 6. Conclusion

Renewables have a market of about 8-9 MTOE in thermal uses of residential sector of Pakistan. Furthermore, renewables have a market of 3-5 TWh of electricity-demand of households. Although some mini/micro hydro-power plants are providing electricity to some households, at present, biomass is the only renewable being used in residential sector in a big way. Biomass is being used at very low efficiencies and has various social and environmental impacts, including negative impacts on health of women.

Most of the photovoltaic and biogas-plants constructed with the support of Federal Government of Pakistan are not operational. Serious R&D and administrative efforts are required to exploit these renewable energy resources alongwith exploitation of other renewable resources, particularly, solar thermal and wind for residential and other sectors of the economy to reduce import-bill of energy and damage to human-health.


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# IDENTIFYING FACTORS THAT CAN MAKE GENERATION OF ELECTRIC POWER FROM SOLAR-PHOTOVOLTAIC TECHNOLOGY MARKETABLE IN PAKISTAN

**Waqasullah Khan Shinwari, Fahd Ali and A. H. Nayyar**
*Sustainable Development Policy Institute*
*#3 UN Boulevard, Diplomatic Enclave*
*Islamabad, Pakistan*

**Abstract**

*Solar photovoltaic systems are prohibitively expensive, in terms of installation-costs. Power from them is also available intermittently - only when energy from the sun is available. On the other hand, PV systems are free of the ever-rising costs of input fuel. They also incur much less operational and maintenance costs and are supposed to have a longer lifetime than, for example, a fossil-fuel based power- plant. Thus, using solar-PV power looks uneconomical in the short term, but may turn out profitable in the long term. It is therefore interesting to identify the factors that can make investment in solar PV power-generation acceptable.*

*This paper carries out a financial analysis of installing a 10 MW solar photovoltaic power-generation plant for sale of electricity to a grid. It compares the levelized cost of this mode of energy-generation as compared to a fossil-fuel plant. It also calculates the cost of electricity-generation and tariff for power from this plant. It then identifies the factors that can make the investment in a grid-scale solar PV plant more favourable than in other conventional and non-renewable sources.*

## 1. Introduction

The energy-demand in Pakistan is likely to increase steadily. Consequently, the current level of dependence on fossil-fuel for electricity-production will come under severe strain because of the high depletion-rate of the fuel. Currently, over 70 per cent of the total electricity-generation in the country is from fossil fuels, as shown in Table-1 below, for the year 2000-2001. In the year 2000-2001 alone, the total fossil- fuel consumption in electricity-generation amounted to 11.94 million tons of oil equivalent (TOE).

The fossil-fuel resources, however, are not expected to last for many years. In fact, at the current rate of use of oil and gas for electricity-generation, the existing oil reserves, if put to produce electricity only, can last for a little over six years only, and the gas reserves for about 75 years. According to some estimates, a large hydroelectric potential – to the tune of around 30 gigawatts – exists, which is likely to form the

**Table-1: Gross Generation of Electricity by Source in Pakistan For the year 2000-2001 (Gwh)[1,2]**

| Resource Type | Energy produced Gigawatt-Hours | Per cent of the in the year total energy produced |
|---|---|---|
| Hydel | 17,194 | 25.24% |
| Nuclear | 1,997 | 2.93% |
| Coal | 241 | 0.35% |
| Oil | 26,904 | 39.50% |
| Natural Gas | 21,780 | 31.97% |

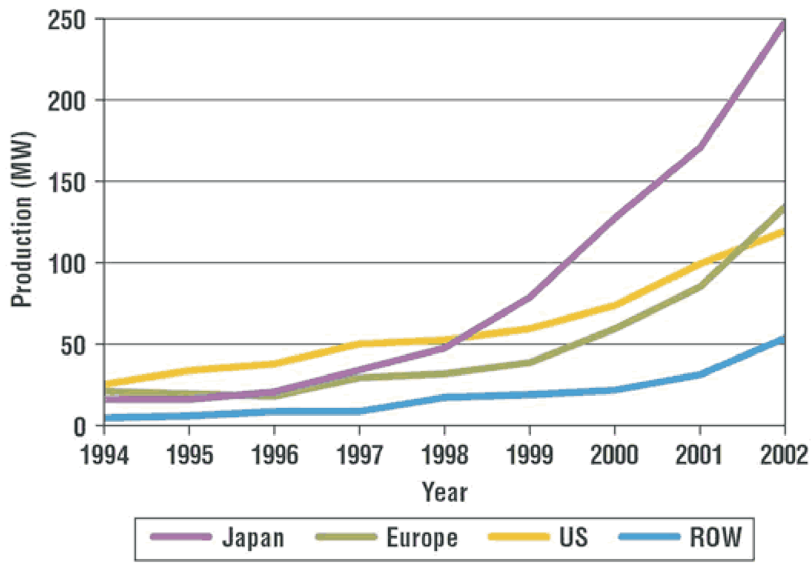
backbone of future electricity-generation. But there are issues – environmental as well as political - that make large-scale dams controversial. The mini- and micro-hydel plants, besides being too far removed from the national grid, add up to a small net generation, serving only some local communities. Even with a greater focus on microhydel plants, the benefit will remain confined mainly to the northern mountainous areas.

Among the various renewable-energy options, wind and solar energy stand out for a larger and possibly grid-scale potential. Wind-energy potential is currently being charted out by a state agency and in view of the sharp drop in installation-costs, may help attract private investment in power-generation. The potential is, however, likely to remain significant only in the coastal areas, mostly far away from the national electricity-grid, and perhaps only to the tune of a couple of gegawatts.

Solar energy, being in abundance almost all over the country, is justifiably seen as the ultimate resource to tap. Although mainly supplemental in nature, it is also a resource that addresses the problems of atmospheric pollution and climatic change. A number of projects aiming at different modes of utilization of solar energy have been initiated over the years by a number of state-run organizations in Pakistan, but have failed to make any significant contribution.

Photovoltaic (PV) is one of the many ways of using solar energy, and PV cells are the means to convert incident sun-energy directly into electricity. Attempts have been made in Pakistan both at installing small-scale photovoltaic power-generators and at creating an indigenous PV fabrication-capability. The indigenous fabrication-facility exists only at the state-run National Institute of Silicon Technology whose capabilities remain at pilot-scale. Water and Power Development Authority (WAPDA) ventured into installing imported PV panels for small-scale power-generation, but failed to sustain it. Imported solar modules are available in the open market in Pakistan, but at exorbitant prices.

Clearly then, the PV solar-energy technology in Pakistan could neither be sustained at the user level, nor has it been attractive to prospective investors. It would therefore be interesting to find ways that could make solar-energy technology marketable in the




**Source:** *PV News, Vol. 22, No. 3, 2003*

**Figure-1: World solar-photovoltaic cell/module production (in megawatts of production capacity), both consumer and commercial, from 1994 to 2002**

country. Among the host of factors that form an answer to this question, one is the economic viability.

In this study we look into the economic viability of a PV cell based power-plant as compared to a fossil-fuel plant. One basic objective of this study is to compare investment in a solar PV plant as against that in a thermal-power plant.

Photovoltaic cell production and installation have both increased worldwide in a significant manner in the past decade. The most recent available data clearly shows a many-fold increase in these areas in the Far East and in Europe, although only a modest increase in North America and the rest of the world. Figure-1 shows the PV-panel production magnitudes (in megawatts of installed capacity) from 1994 to 2002[3]. The rate of increase has been the largest in Japan. The total PV cell and module production all over the world stood at over 560 MW in the year 2002, which was an increase of 43.8% over the production in 2001.

Clearly the increase reflects a rising trend towards installing solar panels, not only for domestic electricity generation but also for grid-scale production. Often PV-plants are considered at the level ranging from kilowatts to at most a few megawatts. But since the per Watt installation-cost of a utility scale PV-plant is hardly any different from that of a domestic scale one, grid-scale production, particularly in countries that have larger insolation, seems to be a viable option. The world has in fact seen a rapid rise in the grid-scale domestic and commercial PV installations. While grid-scale solar PV power-generation was at the most 1 MW in 1990, it grew to 270 MW in 2002, experiencing a rise of 70 MW in the last year alone.

Fossil-fuel based thermal power-plants are a good investment if they are 10 megawatts or higher in power rating. Solar PV plants of 10 megawatts have so far not been common but, given the above facts, are being increasingly considered. This study will therefore, consider a 10 megawatt solar PV power-plant and will calculate the economic factors that may be of concern to potential investors. It will then compare the investment in it with that in a thermal-power plant.

## 2. Methodology

Given the possibility of investing in one of two energy-production ventures, a means to measure the choice that would give better returns is the levelized cost CL defined by

$$C_L = \frac{I + O + R + F}{E_1 \sum_{t=1}^{n} \frac{1}{(1+k)^t}} \quad [\$/\mathrm{Kwh}] \qquad (2.1)$$

Here I, O, R, F are discounted values of investment; operations and maintenance; replacement and input-fuel respectively, $E_1$ is the energy produced by the plant in the first year (taken as the average annual energy produced), k is the discount rate and $n$ is the number of years envisaged as the lifetime of the plant. Levelized cost is thus, the total cash flows of a project divided by the discounted energy produced over the lifetime of a project[4].

The various quantities that go into defining the levelized cost are defined below. In all of these, the year the plant starts producing energy is taken as the zeroth year.

The value of an asset changes with time because of (i) the opportunity cost of the capital, (ii) inflation and (iii) the increase in prices without any change in the quality or quantity of the goods.

The discounted installation-cost for a plant that takes $P$ years for its construction is:

$$I = \sum_{t=1-P}^{0} I_t \beta^{t} \qquad (2.2)$$

Where the discount factor

$$\beta = \frac{(1+e)(1+h)}{1+k}$$

Takes into account, inflation through the rate $h$ and real increase in prices of capital goods through the rate $e$. The discount rate $k$ – the opportunity cost of capital – is

defined as the best rate of profit that can be earned on an alternative investment.
The production of energy incurs operational and management costs that are also to be discounted over the period of operation. The discounted value of the operational and maintenance cost after $n$ years of operation is:

$$O \quad {}_{t\;1}^{\;n} \; O_{annual} \;\; ( \quad {}_{o})^{t} \qquad (2.3)$$

where $O_{\text{annual}}$ is the annual operational and maintenance cost, and

$$_{o} \quad \frac{1 \quad e_o \quad 1 \quad h}{1 \quad k}$$

now contains $e_{\text{o}}$ as the annual real increase in the operations and maintenance costs.

With time, many components of the plant would need replacement. For a replacement-cost $R_{\text{t}}$ in year $t$ ($t<n$) in zero year dollars, the discounted replacement- cost over the lifetime of the project is:

$$R \qquad {}_{t} \; R_t \; \frac{1 \quad h}{1 \quad k_n}^{\;t} \qquad (2.4)$$

Fossil-fuel plants also accrue cost of input-energy that changes with time too. In principle, the discounted input-fuel costs $F$ are to be evaluated in a way similar to the above:

$$F \quad F_{annual} \quad {}_{t\;1}^{\;n} \; P_t \quad {}_{f}^{\;t} \qquad (2.5)$$

where $F_{\text{annual}}$ is the annual amount of required fuel (input-energy), $P_{\text{t}}$ is the average price per unit of input-energy purchased in the $t^{\text{th}}$ year and:

$$_{f} \quad \frac{1 \quad e_f \quad 1 \quad h}{1 \quad k}$$

If $e_{\text{f}}$ is the average real rate of increase in the fuel prices, then the price $P_{\text{t}}$ in year $t$ can be taken as the value per unit of the input energy in the first year.

***Parameters values***

Discount rate "$k$": For most public and private-sector analysis, one uses a 10% discount-rate, but some private investors sometimes have a more pessimistic approach and they use 15-20% discount rates to evaluate the return on their investment. In this analysis we shall use a 10% discount rate, which is probably the best rate of interest one can obtain from a bank. At present the official rate by Government of Pakistan is 7.5%.

***Rate of inflation, "h":*** For most public-sector investments in Pakistan, the rate of inflation considered is 3-4%. In general, however, the average rate of inflation over the last ten years, as documented in the Government of Pakistan's economic surveys[5] , has been 6.8%. To keep our estimations more favourable to an investor, we shall take this value of the inflation-rate.

***Real rate of increase in prices of capital goods, "e":*** The average real rate of increase in the prices of manufactured goods over the last ten years, as listed in the Economic Survey[6], has been 3.7%.

***Real rate of increase in the operations and management costs, "$e_o$":*** We shall take this to be the same as the average rate of inflation, that is, 6.8%.

***Real Rate in the prices of input-energy (fuel), "$e_f$":*** The average rate of increase in wholesale prices of fuel, as documented in the Economic Survey [7], is 11.4%.

An observation is in order here. Equation (2.5) requires using both inflation and the real increase in prices of fuel in calculating the discounted value of input-fuel. This however, enormously inflates the discounted input-fuel prices, which has an adverse impact on the levelized cost of energy from thermal-power plants. It can be argued that the real increase in fuel-prices plays a major part in inflation. Hence, taking both the increase in fuel-prices and inflation separately would amount to counting the impact twice. Only one of the two should suffice. The rate of increase in the real price of fuel being larger than the discount rate, one should consider the former and ignore the latter in Equation (2.5).

## 3. A 10-Megawatt Solar PV Electricity-Generating Plant

Photovoltaic-solar power-plants are known to be prohibitive in capital costs, but the advantage of not incurring any fuel costs, and a longer lifetime may, in the end, make it competitive over the plant life-time when all the costs in generating electrical energy are together taken into account.

PV-power plants are usually considered for smaller areas of distribution, consuming kilowatts to megawatts, although it has been estimated that the economy of scales lowers the capital-cost of commercial scale plants by a small margin[8]. But as mentioned above, grid-scale installations are increasingly coming into consideration. Installing commercial scale [megawatt] solar-PV power-plants would require placing solar-cell panels over a very large area, and can be viable only in a region that receives a high level of insolation for most part of the year. The area must also be close to the national grid, to avoid large transmission-losses. Pakistan's vast desert regions in the southern Punjab or the northern and eastern Sindh, appear quite suitable in this respect.

**Table - 2: The Monthly Average-Radiation Data for Jacobabad, Pakistan[11]**

| Month | Average daily radiation on a horizontal surface (W/ $m^2$) | Average day length (hours) |
|---|---|---|
| January | 380 | 10.4 |
| February | 423 | 11 |
| March | 497 | 11.8 |
| April | 550 | 12.7 |
| May | 564 | 13.4 |
| June | 590 | 13.8 |
| July | 559 | 13.6 |
| August | 537 | 13 |
| September | 524 | 12.2 |
| October | 514 | 11.3 |
| November | 384 | 10.6 |
| December | 342 | 10.2 |
| Average | 489 | 12 |

We will consider installing a 10 MW photovoltaic-power plant in a desert region of Pakistan. The insolation data is available for Jacobabad[9], as in Table-2. Jacobabad is among the hottest and the most arid areas of Pakistan, having weather conditions quite similar to those of a desert. We shall, therefore, assume that the Jacobabad data is suitable for studying installation of such a plant. This is a conservative assumption, in that the insolation is likely to be higher in deserts[10].

Maximum efficiency of a common silicon solar PV-cell is around 15%, so the power-density that can be extracted from the incident solar flux is

$$489 \times 15\% = 73.3 \text{ W/ m}^2$$

Roughly two-thirds of the total area of a panel consists of photovoltaic cells. So a one meter square PV-panel can generate about 48 watts from the incident flux. Thus, in order to produce 100 W of electricity from solar cells in an area like Jacobabad, the required area of a PV panel should be about 2.1 square meters.

The installation of a PV-cell power-plant of 10 MW capacity would require a total of 100,000 PV-panels of 100 watts each, for which the required total area of PV-panels would be about a quarter of a square kilometer. This gives an idea of the size of the 10 MW power plant.

PV-cells are usually sold in Pakistan at the rate of $7 per watt along with storage batteries, converters, and installation charges[12]. A 10 MW plant would therefore, cost around 70 million US dollars[13]. One must also consider economy of scales, as is indicated by the following quote from a US Department of Energy document[14].

"Small, single PV-panel systems with built-in inverters that produce about

75 watts may cost around $900 installed, or $12 per watt. A 2-kilowatt system may cost $16,000 to $20,000 installed, or $8 to $10 per watt. At the high end, a 5-kilowatt system that will completely offset the energy-needs of many conventional homes may cost $30,000 to $40,000 installed, or $6 to $8 per watt. These prices, of course, are just rough estimates".

Moreover, recent trends in grid-scale power-production from PV-cells indicate a substantial decrease in costs. With the increase in the production of PV-modules from a total of 17.4 MW in 1995 to 251MW in 2002, the pre-subsidy price has reportedly dropped from US$11/W in 1996 to $6/W in 2002[15]. The factory prices for single and polycrystalline silicon modules have decreased to between US$2.90 and $3.25, while amorphous silicon modules were also reportedly being sold at prices of $2.00-3.00 per watt[16].

We shall, however, consider in this analysis the installation-cost of PV-modules to be $7 per watt, and shall at the end consider the impact of these reduced costs.

We thus assume that 70 million dollars is the total capital investment[17]. To avoid further complications in the economic calculations, we are considering only the cost of PV-cell panels and their installation, and assuming that the connection to the national grid costs and the civil construction costs will be quite low, as compared to the cost of PV-cells.

Pakistan has a very limited capacity of producing PV-cell panels. National Institute of Silicon Technology (NIST) is the only establishment involved in PV-cell production, and that too on a pilot scale. An investor in a PV-power plant will have to import the modules from major manufacturers abroad. Most manufacturers have a production capacity of around 5 –10 MW annually[18], but the capacity of some (e.g. Sharp Co. Japan) has now increased to over 120 MW a year. The total PV-module production capacity, world-wide, has increased to over 550 MW a year. On the use side, the grid-connected residential and commercial installation in the year 2002 alone has been to the tune of 270 MW. A 10 MW solar-PV plant will, therefore, not be an unusual venture.

Given the huge cost of investment, it is reasonable to assume that an investor will stagger the total investment over a period of five years ($P=5$ in Eq. (2.2)), investing $14 million a year.

The various discounted costs that go into calculating the levelized costs are described and tabulated below for a PV-plant and a fossil-fuel based thermal power plant.

### *3.1 Discounted Cost of Investment*

The total discounted construction cost[19], calculated from Eq.(2.2), when the investment is taken to be equally divided over each year of the installation period, is

$$I = \text{US\$ } 69.06 \text{ million}$$

Therefore, as far as an investor is concerned, the cost of installing a 10 MW PV-cell power plant will be 69.06 million US$. In contrast, the Kalabagh Dam power-plant, which has been abandoned for the present, was planned to have a generation-capacity of 2400 MW. It was going to cost around 6 billion dollars. The construction cost per watt of electricity-generation capacity would therefore, have been around $2.5/ W. The cost of the 300 MW Chashma Nuclear-Power Plant was 1.033 billion US dollars. For it, therefore, the capital cost was about $3.44 per watt of the installed capacity. A comparison of these generation-costs is given, together with other indicators, in Figure-2.

In the following paragraphs we intend to add to this elementary estimate of the capital cost for the plant an analysis that brings out costs over the life-time of the plant, the need for including fuel-costs and operational and maintenance costs to have a good picture. As the fossil-fuels deplete, the costs would continue to rise, and the operational and maintenance costs of, for example, a nuclear-power plant are prohibitively high. In contrast, the operational skills for a PV-power plant will be much less demanding. In addition, there are long-term adverse effects of other large projects like hydroelectric dams. It would be interesting to see also, in a future analysis, if such adverse effects could be quantified and brought up in a comprehensive analysis.

### *3.2 Total Value of Electricity Produced by the PV-Cell Plant*

The total energy in a year from this 10 MW PV-cell plant can be calculated by using the data in Table-2 for average monthly insolation in Jacobabad. This average

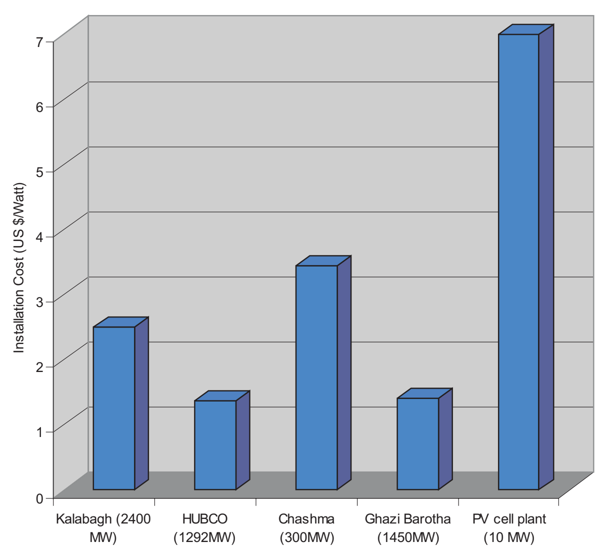



**Figure - 2: Construction/Installation Costs in US$ per Watt of Electricity Production-Capacity**

value of the incident solar power and its availability for utilization is assumed to have taken into account the cloudy days and the variation in the incident solar flux due to seasonal variation round the year. Although the daylight is recorded to be available on the average for 12 hours a day, we assume that for power-generation purposes it is available for only ten hours.

The energy generated by each 100W panel in a year for an average of 10 hours a day is $0.1 \times 10 \times 365 = 365$ kWh

This is possibly an over-estimation because this assumes that there are no maintenance outages. We assume that solar PV-plants are robust enough to require such outages of no more than 10%. Discounting for this, a 100W panel is, thus, expected to generate a total of about 330 kWh of electrical energy in a year.

Total annual electricity generated by a 10 megawatt plant would thus be

$$330 \text{ kWh} \times 10^7 = 33 \text{ GWh/ annum}$$

In comparison, a 10 MW furnace-oil thermal-power plant working at 60% capacity- factor is expected to produce 52.56 GWh of energy a year.

### *3.3 Total Discounted Operational and Maintenance Costs*

The operational and maintenance cost of PV-solar modules has been estimated as \$0.005/ kWh[20]. This is however in the United States. The labour cost in Pakistan is usually much smaller, particularly for low-skilled maintenance jobs. The 1994 Power-Policy takes the O&M cost of thermal-power plants as equivalent of 0.1 cent per unit of energy produced[21]. The skills required in operating and maintaining a solar-PV plant are expected to be much lower. Yet we take the O&M cost for PV-plant to be also \$.001/kWh. So the annual operational and maintenance costs are

$$O_{annual} = 33 \times 10^6 \text{ kWh} \times \$0.001/\text{ kWh} = \$\ 33{,}000.$$

The discounted operational and maintenance cost over the 30-year lifetime , from Eq.(2.3) is therefore:

$$O = \$\ 1.82 \text{ million},$$

### *3.4 Discounted Replacement-Cost*

There is no certain way to determine the replacement-costs over the project's lifetime. Assumptions will have to be made. Although the solar cells usually have a long lifetime of their own, but because the modules are subject to the elements of nature, which are expected to be rather harsh in a desert environment, we assume that 30% of the equipment would need replacement over the 30-year life of the plant. We also assume that this is equally spaced in time so that the yearly

**Table - 3: Summary of the Calculated Quantities for a 10 MW Photovoltaic Electricity Generation Plant**

| Quantity | Calculated value |
|---|---|
| Discount value of the investment | 69.06 million US dollars |
| Discounted operation and maintenance cost | 1.82 million US dollars |
| Discounted replacement cost | 13.73 million US dollars |
| Levelized cost | 27.2 cents/kWh |

replacement cost is I*0.3/30 = I/100. Discounted over the plant's lifetime, Eq.(2.4) gives the replacement cost as

$$R = 13.7 \text{ million dollars}$$

Putting all these numbers in Eq.(2.1), the levelized cost of producing electricity from a 10 MW solar-PV plant comes to 27.2 cents/kWh as shown in Table-3.

We shall next consider similar costs for a fossil-fuel power-plant of the same size, to be able to compare the two costs, hoping to find reasons why PV-plants are not attractive in the market.

It may, however, be noted that the environmental advantages of the solar-power plant have not been considered in the above. There also are other factors to which the costs involved in the solar-power plants are sensitive. These will be considered in Section- 5.

## 4. A Fossil-Fuel Based Power-Plant of 10-MW Capacity

Whenever a power-plant based on renewable-energy sources is proposed, it is compared with a fossil-fuel based power-plant, to compare the financial and environmental advantages and disadvantages. We, therefore, consider a fossil-fuel power-plant, so that the economic indicators can be compared with PV-cell power-plant. All the economic values are pre-tax, both in the case of the PV-cell plant and the fossil-fuel power-plant.

### *4.1 Cost of Investment*

The construction cost of a fossil-fuel power-plant is normally taken to be around 1$ per watt of capacity of electricity-production. The cost varies, depending on the type of plant. Gas-fired combined-cycle plants cost the least, while diesel and oil-fired combined-cycle plants cost a little higher. The variation is, however, less than 10 per cent. Hubco, a large fossil-fuel power-plant of 1292 MW installed generation capacity, quotes that installing a 1 megawatt fossil fuel power-production facility would cost around $ 1.37 million dollars[22]. The construction delay may have pushed up the cost and offset any reduction due to the economy of scales. It therefore seems reasonable to take $1.37 per watt as the cost of installation of a thermal power plant. Thus, the total cost of installation of a 10 MW plant will be $13.7 million.

The construction-period is taken to be around 3 years. We divide the total estimated cost of the power-plant equally in three years. Discounted cost, determined by Eq.(2.2), thence comes to:

$$I = \$13.61 \text{ million}$$

***4.2 Discounted sum of Input-Energy Expenses:***

Equation (2.5) requires the annual amount of energy required, the unit price of input- energy, and the real-rate-of-increase in prices of the input energy. Assuming a 60% capacity-factor, the 10 MW plant is expected to produce 52.56 GWh of energy a year.

To evaluate the cost of input-energy we assume that the plant is run on refined furnace-oil[23]. The amount of oil needed to generate a kWh can be estimated from its calorific value, which is quoted as 43 gega-joules per tonne[24], equivalent to saying that 1 kWh is produced by 0.084 kg of furnace-oil. With a standard efficiency of 30%, a thermal power plant would produce a kWh from 0.28 kg of furnace-oil. The current (year 2001) price of furnace oil is Rs. 11,195 per tonne[25]. Thus, fuel-charges for producing a kWh from a thermal power plant, running on furnace-oil, will be Rs. 3.134, or 5.2 cents at the exchange rate of Rs 60 to a US dollar. Hubco claims 37% efficiency for its combined-cycle power-plant. With that efficiency, the fuel-charges come down to 4.2 cents per kWh. The average fuel cost claimed by various private power producers running their plants on the refined furnace-oil are given in Table-4. These average to 4.11 cents/kWh. Our choice of 4.2 cents/kWh is close to it.

The rate of increase in the price of input-fuel has been taken by averaging the increase in fuel-prices, in general, over the past 10 years, as given out by the Government of Pakistan[26]. It comes to 11.4%.

**Table - 4: Input-Fuel Charges for RFO based Thermal-Power Plants**

| **Power Station** | **Installed Capacity (MW)** | **Average Fuel Cost (Ps/kWh)** | **Average Fuel Cost (cents/kWh)*** |
|---|---|---|---|
| AES, Lalpir | 362 | 305.60 | 5.09 |
| AES, PakGen | 365 | 288.44 | 4.81 |
| Gul Ahmed | 136 | 123.56 | 2.06 |
| HUBCO | 1292 | 237.26 | 3.95 |
| Japan Power | 135.6 | 280.46 | 4.67 |
| Southern Electric | 117 | 280.12 | 4.67 |
| Tapal Energy | 126 | 211.44 | 3.52 |

**Source:** *Energy Year Book 2001, Table 5.11, p 62*

** Excahnge rate taken as Rs 60 to a US$.*

The discounted input-fuel cost is calculated using Eq.(2.5), which in itself is re-formulated now to:

$$F \quad E_{annual} \quad c_{fuel} \quad \overset{n}{\underset{t\ \ 1}{}} \quad {}_{f}^{\,t}$$

With $E_{annual}$ = 52.56 GWh, the per unit fuel-charge $c_{fuel}$ = \$ 0.042, $e_f$ = 0.114, and h and as given above in section-2, the value of input-energy discounted over 30 years comes out to be:

$$F_{annual} = \$\ 81.05 \text{ million.}$$

This value excludes the transportation and inventory costs of the fuel.

***4.3 Operational and Maintenance costs.***

The operational and maintenance cost of a fossil-fuel based plant in the United States of America is estimated at \$0.007/ kWh[27]. In Pakistan, however, the labour being cheaper, the Energy-Policy of 1995 estimated it as \$0.001/kWh[28]. We have discussed this above. So the annual operational and maintenance costs of a 10 MW thermal power station are likely to be:

$$O_{annual} = 52.56 \times 10^{6} \text{ kWh} \times \$0.001/\text{ kWh} = \$\ 52{,}560.$$

Eq.(2.3) for the total discounted value of the operational and maintenance costs gives

$$O = \$\ 2.9 \text{ million}$$

Which is about 20% of the capital-cost.

***4.4 Discounted Replacement-Costs***

Assuming again that 50% of the capital-equipment would need replacement over the 30-year lifetime of the plant, and that the replacement is spread evenly over the plant's life. The discounted replacement-cost would be

$$R = \$\ 4.48 \text{ million}$$

**Table - 5: A Comparison of the Values of Various Quantities Calculated for 10-MW Solar PV and Thermal-Power Plants**

| | 10 MW Solar PV | 10 MW Thermal |
|---|---|---|
| Discounted value of the investment | 69.06 m$ | 13.61 m$ |
| Discounted operation and maintenance cost | 1.8 m$ | 2.9 m$ |
| Discounted replacement cost | 22.88 m$ | 4.48 m$ |
| Input energy cost | ------ | 81.05 m$ |
| Levelized cost | 27.2 cents/kWh | 20.59 cents/kWh |

It must be mentioned here that, had the rate-of-inflation been included in addition to the real increase in fuel-prices, in the calculations, the levelized cost of energy from the thermal power plant would have climbed up to over 60 cents a unit.

Thus, taken over the life-time of the plants, the difference between the levelized costs is not that big. Nevertheless, for an investor, it is still more profitable to invest in a thermal power plant – unless the levelized cost of energy from a solar plant could be brought down in some manner. In order to see how this could be done, we look at the sensitivity of the levelized costs on the quantities, like investment-cost and discount- rate, etc.

## 5. Sensitivity Analysis

Clearly the largest contribution to the levelized cost of electricity from a solar-PV plant comes from the exorbitant installation-cost. If this somehow comes down to about $5.3 per watt, the levelized cost of solar-PV electricity would come at par with the electricity from a fossil-fuel thermal plant. Any lower installation-cost would make investment in a solar-PV plant more profitable.

The dot in Figure-3 represents the values in Table-5, and the horizontal dotted line shows the levelized cost of a thermal-power plant, as calculated above. The figure, thus, shows that if the installation-cost of a solar-PV plant is brought down to about 5.3 $/W, the investment would be as good as that in a thermal power plant.

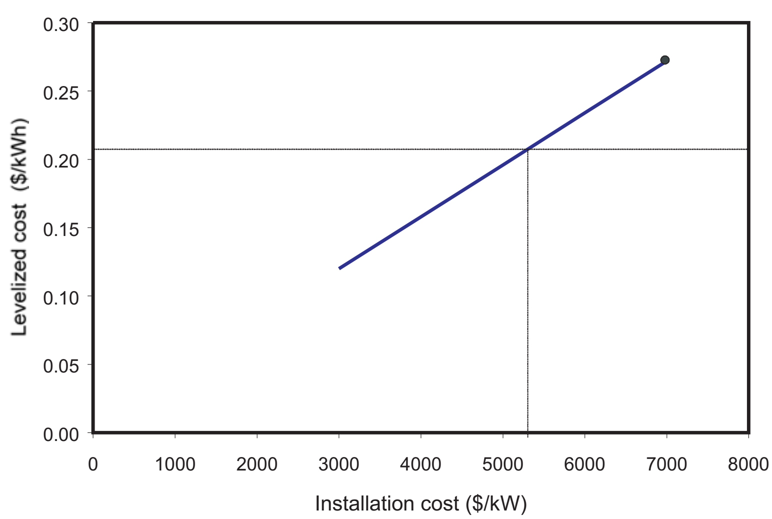



**Figure - 3: Dependence of the levelized cost of electricity from a Solar-PV plant on the installation cost**

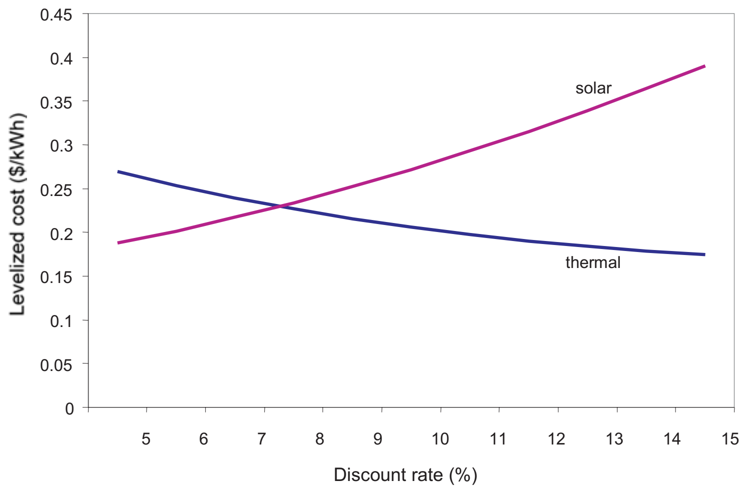



**Figure - 4: The dependence of the levelized cost on discount rate for solar PV and fossil-fuel thermal-power plants**

Japanese PV-industry has been aggressively seeking export-markets and in the process has brought down its prices from $11/W to $6.5/W in 2002[29] . We do not know the trends since then. It is possible that the prices may have come down even further.

Discount-rate is another variable that can act as a handle in the analysis. Quite recently, the Government of Pakistan reduced the discount rate from 10% to 7.5%. Discount-rate is a variable that has an interesting effect on the levelized cost of the two technologies. In the case of solar-PV systems, a reduction in discount-rate decreases the levelized cost, while for a fossil-fuel thermal power plant, the reduction increases the levelized cost of energy, as shown in Figure-4, this is understandable, because in the former case the levelized cost is predominantly determined by the installation-cost, while for the latter, the input-fuel charges dominate the calculations. While a smaller discount-rate reduces the discounted installation-cost, it increases the discounted cost of input-fuel, hence the opposite effect. This implies that there can be discount-rates below, which the levelized cost of energy from a solar-PV plant would become less than that from a thermal power plant. This crossover, as shown in Figure-4, is roughly at a discount-rate of 8%, which means that at the discount-rate of 7.5% that the Government of Pakistan has now fixed, investment in solar-PV system is already slightly more profitable than in a thermal-power plant.

***Alternatives***

*5.1.1 Amorphous Si-technology*

Amorphous silicon systems (a-Si and a-SiH) are indeed available at an installation cost nearly $3.5 per watt, but then they have a much shorter lifetime, would incur a high replacement-cost and almost zero salvage-value[30. In fact, in spite of the installation-cost being reduced by half, these factors raise the cost of electricity-generation from amorphous silicon PV plants to a higher value of 8.84 cents per kWh.

*5.1.2 Indigenous Production*

Indigenization of PV-cell production can reduce the cost. Importing a set of 1kW PV cell-panels and other components costs around Rs. 500,000[31], while at the National Institute of Silicon Technology (NIST), which has a pilot facility of producing crystalline silicon PV-cell panels, it costs around Rs. 375,000[32]. There is thus a possibility of atleast 25% reduction in the capital-cost, if the panels are manufactured locally. In the above calculations, a 25% reduction in the capital investment already brings the levelized cost at par with thermal power electricity.

*5.1.3 The Concentrator Technology*

Using large mirrors to concentrate solar energy on PV-cells can reduce the number of PV-cells required in a panel, in turn reducing the cost proportionately. Many experimental projects have recently proven the practicality of using solar concentrators in combination with PV-cells, to produce electricity. Solar concentrators work by collecting sunlight from a large area and concentrating it onto a small area, with the help of mirrors and lenses. The PV cell panels are integrated into a very cheap and efficient system, by adding a concentrator (a parabolic or spherical mirror, or a lens), a cooling system (using heat sinks, and fins), and a sun-tracking system (one or two dimensional). In projects where concentrators have been used, efficiencies as high as 25-30% have been achieved[33]. Capital-costs have been reduced and in some cases system costs have been reduced by more than 50%[34]. Solar concentrators for PV-cells have been used in quite hot and dry climatic areas, like Saudi Arabia, Madrid (Spain), Texas, and California, so the available data from the experimental projects in these areas can be applied to Pakistan as well.

A study based upon the EUCLIDES (European Concentration Light Intensity Development of Energy Sources) Prototype predicts that for a grid-connected PV-cell concentrator-system of size 10 MW, the initial capital-cost would be at 3.3 $/W of peak capacity. This is at least 50% less than the cost on flat PV-cell systems. But this is a predicted figure assuming that the process of manufacturing and installing the parts involved in a concentrator type PV-cell power-plant would be on a mass-scale and streamlined. Nevertheless, a cost of installation reduced to $3.5 to a watt makes the solar PV technology very competitive.

## 6. Calculating Tariff for a 10-MW PV-Cell Electricity-Generating Plant

Sections 4 and 5 clearly establish a case for investing in PV-cell plant. Although, the difference in levelized cost of the two investments is large, however, the sensitivity analysis done in Section-5 shows how this difference can be reduced. A reduction in installation cost, using a low discount-rate, investing in cheap solar PV technology and indigenization of technology can give an edge to investments in solar-power plants comparable to fossil-fuel plants.

The question that arises here is that if one is to invest in solar-cell PV plants at all, then at what price the investor shall sell the electricity to the distribution utility/company. The price should be attractive enough for the investor, but should not be too high to be marketed. It would, therefore, be interesting to find out the cost of electricity-generation and thence a suitable tariff rate for electric power from such a plant. This will also help determine the cash flow to the PV power utility.

## 7. Methodology

The methodology given in Section-2 only calculates factors required for a levelized cost analysis[35]. To do a detailed investment analysis, one must also know various other factors like discounted-value of energy-produced in the life-time of the plant, plant's salvage-value, depreciation-cost, Net Present-Value, and payback time of the investment. The methodology for calculating these factors is given below:

The discounted value E of the total energy produced in n years is given by

$$E = \sum_{t=1}^{n} E_{annual} \left( {}_{e} \right)^{t} \qquad (7.1)$$

where $E_{annual}$ is the value of the electricity produced every year:

$${}_{e} = \frac{(1+e_e)(1+h)}{1+k_n}$$

where and $e_e$ is the annual-real increase in the price of energy.

***Salvage-Value:*** A plant after a certain period of operation has a salvage-value of its capital investment. This is usually estimated at the start of the project, and then gets discounted similar to other economic parameters. The discounted salvage value after *n* years of operation is evaluated by the formula

$$S = S_n \left( \frac{1+h}{1+k_n} \right)^{n} \qquad (7.2)$$

where $S_n$ is the salvage or resale-value of the plant in the year "*n*" as estimated in the zeroth year.

***Depreciation-cost:*** A plant gets depreciated in value with use. Often an accelerated depreciation is allowed as an incentive for investment. For a depreciation expense $D_t$ in year t and a depreciation period of d years, the discounted depreciation is

$$D \qquad {}_{t\;\;1}^{\;\;d} D_t \frac{1}{(1 \quad k_n)^t} \tag{7.3}$$

Net Present-Value (NPV): After-tax NPV, which represents the discounted cash-flow over the lifetime of a plant can in general be stated as:

$$NPV \quad (1 \quad T) \quad (E \quad S) \quad (F \quad O \quad R) \quad T \; D \quad I \tag{7.4}$$

The expenses on the project are subtracted and the revenues from the projects and the salvage-value are added, weighted suitably by the marginal tax-rate *T*. All the quantities are discounted as defined above.

One important economic parameter is the pay-back time *TPB* of the initial investment in an energy project. This is usually defined as the ratio of the initial capital- investment *I* to the net-income (difference between the value of the energy produced in the first year of operation, $E_1$, and the sum of the expenditure on operation and maintenance in the first year, $O_1$, as well as on the input-fuel, $F_1$);

$$T_{PB} \quad \frac{I}{E_1 \quad O_1 \quad F_1} \text{ years} \tag{7.5}$$

*7.1 Objective of the Analysis*

For an individual investment, the basic principle for determining suitability is that the Net Present-Value be positive. In principle, any positive NPV assures a profitable business. NPV can be calculated easily if the unit price of energy from an investment is known. On the other hand, if the unit price of energy from an investment is not already fixed or known, because of which one cannot evaluate the discounted value E of the energy produced, or NPV, the principle of positive NPV provides a convenient way to determine price of energy. We take as cost of energy-production the value that makes the Net-Present Value zero (a break-even situation where the capital is returned with a gain that is only equal to the discount-rate), and the unit price of energy as that which includes a reasonable markup on the cost. Thus, if x cents per kWh of energy renders NPV zero, then *x* is the cost of energy production. And if 20% is regarded as a reasonable markup rate then 1.2 times *x* will be the price, which the producer will charge the buyer for each kWh sold. This is the principle that will be used below to find the reasonable unit price of energy. But first we shall look at the NPV and the Pay-back Time, using the tariff-rate that is usually paid to the independent power- utilities

*7.2 Fixed Sale-Price Results*

Total annual revenues from this generation would depend upon the agreed tariff for the purchase of power by the distributor. The state electric-power distribution utility WAPDA (Water and Power Development Authority) currently purchases electricity from independent power-producers at an average rate[36] of 5 cents (Rs.3.00) per unit (kWh)[37], so total value of electricity produced by the PV-cell plant in a year would be:

$$E_{annual} = 33 \times 10^6 \text{ kWh} \times .05 \text{ \$/ kWh} = \text{US\$ } 1.65 \text{ million/ annum.}$$

The lifetime of a solar-PV cell is very large compared to that of other electricity-production sources. While a hydroelectric or a nuclear-power plant has a designed lifetime of about 30 years – and likewise for a fossil-fuel thermal-power plant – that of a solar plant can be easily 50 years. We shall however take the lifetime of the latter to be also 30 years, and reflect the larger lifetime in its large salvage-value.

***Discounted Value of the Energy Produced***

The discounted value of the energy produced from a PV-cell plant over the lifetime can be calculated using Eq. (7.1). With the value $E_{annual}$ of the annual energy- production estimated at US$ 1.65 million, and the real rate of increase in the price of electricity taken as that of the capital goods, the discounted value E of the energy produced over 30 years comes to:

$$E = 55.1 \text{ million dollars}$$

This is the discounted value of the revenue that the PV cell plant would generate during its lifetime of 30 years.

***Discounted-Salvage Value***

Next, we estimate the discounted salvage-value of the PV-cell plant after 30 years of operation. If properly maintained, 50% of the solar cells can be sold at the rate of its initial cost, as crystalline-silicon PV-cells are very resilient and can sustain their usefulness through very tough weather conditions. So, using Eq.(7.2) the salvage value is estimated to be:

$$S = 14.4 \text{ million dollars}$$

***Discounted-Depreciation Cost***

Even though crystalline PV panels are taken to be very resilient, allowing accelerated depreciation forms a standard incentive for investment. We assume that a 30 year depreciation can be allowed, implying that the entire initial investment will be depreciated to a zero value after 30 years. We also assume a uniform depreciation. That is, the depreciation each year is I/30, and we then discount depreciation over 30 years using Eq.(7.3). It comes to

$$D = 21.9 \text{ million dollars}$$

Net Present-Value (NPV), cost of electricity-generation and the electricity-tariff. We are now in a position to evaluate after tax NPV for the plant using Eq.(7.4). The tax rate to be used for this purpose is assumed to be 30%, almost the highest tax-rate in Pakistan, although investment incentives could include lower tax rates. With the values above, the net present value of the plant comes to

NPV = - 31.1 million dollars,

a rather high negative value. We keep in mind the basic principle that an investment is attractive only if it gives rise to a positive net present value. The price of 5 cents a unit clearly does not make investment in a solar PV plant viable. Another indication is the payback time as calculated from Eq. (7.5). It comes to 43 years, much higher than the lifetime of 30 years considered here.

Thus we need to find out a just cost and sale price. For a viable investment in any venture, the after-tax NPV must be positive. We take the zero of NPV to define the energy production cost and add 20% on it, as markup, to get the energy sale price. The cost of producing a unit of energy that makes NPV zero is given from Eq.(7.4) by

$$c = \frac{I + (1-T)(O+R+S) - T\,D}{(1-T)\,u \sum_{t=1}^{n} e^{-t}} \qquad [7.6]$$

Where u denotes the number of energy units produced in a year. Substituting the values from above, we get the cost of electricity-generation from a PV plant equal to 9.03 cents per kWh. With a markup of 20% allowed on this cost, the tariff comes to 10.83 cents a unit. The total revenue generated over 30 years would be 119 million dollars, and the Net Present Value would become close to 14 million dollars. The plant will pay-back the investment in 20 years or so. The results os this analysis are summarized in Table-3.

These numbers are, expectedly, sensitive to the values of various parameters that go into the enumeration. The sensitivity-analysis below identifies the factors that can provide a handle to encourage investment in PV-power technology in the country.

## 8. Sensitivity-Analysis

The costs calculated in sections 7 are dependent on

1. Investment cost
2. Tax rate
3. Discount rate
4. Depreciation rate.

We shall look at the sensitivity of the generation-cost or the electricity sale-price to these factors one by one.

### *8.1 Investment-Cost*

The dependence on investment-cost should be the most sensitive factor in determining the generation-cost, and hence the sale price of energy, the tariff. This is seen for the solar-PV plant in Figure-5 below . The variation is linear and has a large slope. The current installation cost of US$7 to a watt translates in the analysis of this study to an electricity-generation cost of 9.03 cents a kWh, as displayed by the dotted lines. Independent power producers in Pakistan are currently allowed, on the average, to charge a tariff of 5 cents a unit on the electricity they sell to WAPDA. In our formulation, the tariff of 5 cents amounts to a generation-cost of 4.17 cents a unit. It can be seen from Figure-5 that in order for the tariff for electricity from a PV-plant to be 5 cents a unit, the installation-cost must come down from $7 a watt to about $3.35 a watt. In the sensitivity analysis done for the levelized cost calculations, we have discussed in detail the alternatives available to reduce initial installation-cost and how adoption of these alternative can lead to a lower cost of production.

### *8.2 Tax rate*

Tax rate is an important parameter, the dependence on which can provide clues to the policy interventions that would encourage investment in the technology. Fig. 6 shows that the cost of generation is fairly mildly dependent on the tax-rate, up to about 50%, and rises rapidly after about 70%. We have chosen a tax rate of 30%. Giving a tax benefit by reducing it to 20 or even 10% would change the cost of generation from 9.03 cents a unit to only 8.26 and 7.67 cents respectively, which are hardly near the desired 4.17 cents. Fig. 6, in fact, shows that increasing the tax rate to 40% or 50% would not increase the generation cost dramatically.

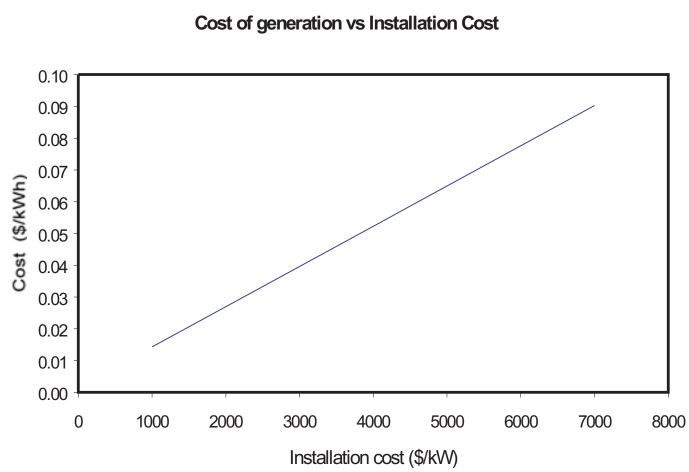



**Figure - 5: Dependence of the energy-generation cost on initial investment**

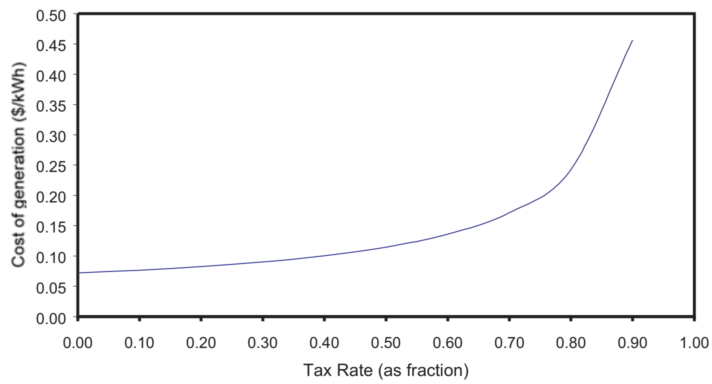



**Figure 6: Dependence of the electricity-generation cost on the tax rate**

### *8.3 Discount rate*

Discount rate is a taken as a useful handle, with the state, to encourage investment. A dependence of the generation-cost on discount-rate would show where and how the incentives for investment in solar PV technology could work. Figure-7 below shows the pattern of dependence. We have taken the rate of 10%. For the generation cost to be reduced from 9.03 to the desired 4.17 cents a unit, the discount rate will have to come down to about 5.7%. The government has recently announced a reduction in discount arte to 7.5%. Given everything else the same, this step alone will help reduce the generation-cost to about 5.42 cents a unit.

### *8.4 Accelerated Depreciation*

We now consider the sensitivity to the time over which an accelerated depreciation of the plant is allowed as an incentive. This is shown in Figure-8. An interesting aspect of this result is that the effect on the cost of generation is very little for depreciation time. Insofar as the incentive is meant to reduce the cost of

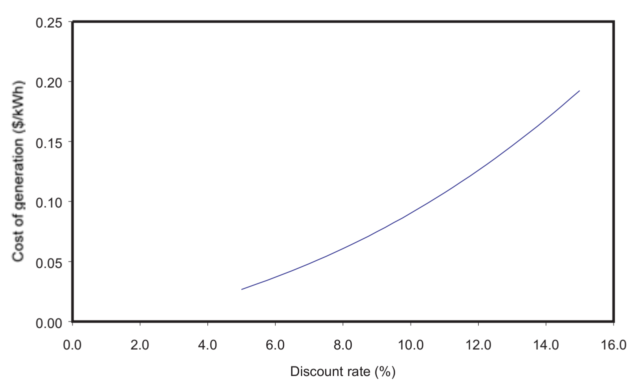



**Figure 7: Dependence of the generation cost on discount rate**

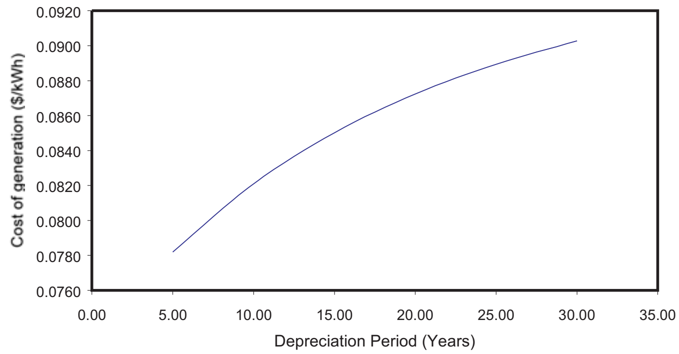



**Figure - 8: Generation-cost as a function of depreciation period**

generation, allowing an accelerated depreciation dramatically to, say, five-years would not produce the desired results. The cost of generation for a five year depreciation period is 7.82 cents/unit, which is nowhere near the desired value of 4.17 cents.

## 9 Conclusions and Policy Recommendations

The Ad Hoc Expert Group Meeting on Commercialization of Renewable-Energy Technologies and their Transfer of Technology, organized by ESCAP in Bangkok 22-24 September 1999, emphasized the need for private-sector participation in renewable-energy projects. The experts suggested that: 'To motivate the private- sector into renewable-energy development, it will be necessary to promote an enabling policy-framework, which will include an appropriate power-purchase agreement, access to technologies and fiscal and other benefits.' It is clear that the main initiative for promotion of commercialization of renewable-energy technologies has to come from governments. International and regional organizations can only play a catalytic role, particularly in terms of capacity-building and promoting regional and sub-regional cooperation.

Marketability of solar-PV technology for grid-level power-generation would be determined by the cost of electricity generated and a secure and reasonable return on investment. Among the variables that can significantly affect the cost of electricity there are some that can be used as a policy tool to create a suitable environment for investment into the solar-PV technology. These are (i) installation-costs, (ii) discount-rate, and (iii) accelerated depreciation.

It is very clear that, if it had not been for a larger capital, involved in installing a PV- cell power-plant, it would have been a very clear winner in the economic comparisons. The installation costs can come down by encouraging.

(i) Solar-collector technology, (ii) indigenization of the technology, and
(iii) giving duty-relief on import of technology.

Using solar collectors with photovoltaic cells in itself is sufficient to cut down the investment-costs by half and, consequently, bringing solar PV-power production at par with a fossil fuel plant.

Local generation of PV-cells on a commercial scale can bring about a substantial decrease in the capital prices involved in PV-cells production, further decreasing the levelized cost of energy. The only organization that indigenously produces Si-photocells is the National Institute of Silicon Technology, which only has a pilot scale production facility. Even then it is able to produce PV-cells at a cost that is two-thirds of the cost of an imported system. Enhancing the capability of NIST, in the long term, will prove very cost-effective. In addition, if NIST can extend its capabilities to that of producing radiation-collector based PV-panels, the grid-scale solar-power generation technology will look extremely attractive to an investor.

Further, a reduced discount-rate, as has recently been announced by the government, can be greatly helpful. It is already enough to make investment in solar-PV system more attractive than in a fossil-fuel thermal-power plant.

Though the culture of PV-electricity in the country has been mainly of small household or building units - a few hundred watts to a few kilowatts - it is time to break out of this thinking and plan for setting up grid-size solar-PV plants. This will be in direct accordance with the Kyoto Protocol and the UNFCCC's (United Nations Framework Convention on Climate Change) CDM (Clean Development Mechanisms). Though the price on the carbon abatement has been kept high in this discussion because the tremendous potential social and economic development opportunity provided by such a project. To gain REC points, any Annex-1 country can be convinced to invest in such a project under CDM. But connecting such a power-plant to the national grid will provide opportunity for others to follow suit and justifying the expenditure on connection to the national grid because of its size will set an example for other countries. By setting a precedent of large PV-cell based power plants, prices of PV-cells can be brought down by a large margin, as this would provide opportunity and resources to people working in this field to invest in R & D activities, bringing down the prices consequently. In the end, it needs to be emphasized that market-based economic systems tend to have short-term outlook. The high capital-cost of renewable-energy technologies and long gestation are not attractive for private-sector financing, which has many other competing uses for the money. This is especially problematic under the new regime of liberalization and privatization. The initiative in investments on renewable-energy technologies ought to come from the public-sector.

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# THE ROLE OF PARTICIPATORY APPROACHES IN THE DISSEMINATION OF RENEWABLE-ENERGY TECHNOLOGIES IN RURAL SUDAN

## The Experience of the Energy Research Institute

**Samia Ibrahim Abdelmagid**

*Head, Technology Development and Dissemination Department*
*Energy Research Institute, Ministry of Science and Technology, Sudan*

**Profile of Sudan**

Sudan is the largest country in Africa and the Middle East. It has an area of 2.7$m^2$. This represents more than 8% of the African Continent and almost 2% of the World total area. The country is regioned into 26 states, 112 Provinces and 614 Localities, constituting the Federal Republic.

The geography of Sudan is classified from North to South into desert (34%), semi-desert (20%), wood-forest- (35%), agricultural land (7%) and swamps and wetlands (1%). The population of the country is estimated to be 30.3 million, which is unevenly distributed over the 26 states.

The majority of the population is concentrated in 6 states of the central region. About 60% of the population live along the banks of the Nile. Natural disasters and civil conflicts have resulted in high rates of rural-urban migration reaching approximately 15%.

Egypt is in the North of Sudan, The Red Sea in the Northeast, Ethiopia and Eritrea in the East, Kenya in the South, Central Africa in the Southwest, Chad in the West border of Sudan and Libya in the Northwest. The climate of Sudan is wholly tropical and rainfall varies with an average less than 75mm/ annum in the desert and 75-300 mm/annum in semi-desert confined entirely to July and August, to an average of 300-1500mm/annum in woodland savanna.

**The Energy Research Institute**

Energy Research Institute of Sudan (E.R.I) is dedicated to carry out applied research in the field of renewable energy technologies under the Ministry of Science and Technology. Energy Research Institute has four major specialized departments:

- Solar energy department;

- Wind and Mini-hydro energy department;
- Biomass-energy department;
- Technology development and dissemination department.

The Energy Research Institute has a plan for applied research that is based on the utilization of local resources. Renewable-energy is considered to be the enduring foundation for rural development, environmental conservation in an attempt to bring about sustainable development in Sudan.

The institute, since its establishment in 1972, has had only three departments (solar, wind, biomass), each of which conducts research in the name specified field. Soon in 1983, arises the need for the forth department named technology development and dissemination to take the role of technology-transfer and adoption with the following mandate:

- Conducting socio-economic, marketing and environmental studies for the technically feasible technologies;
- Capacity-building through training of both users and producers beside the organization of conferences, seminars and forums;
- Participating in the implementation, monitoring and evaluation of pilot projects;
- Dissemination of information and awareness-raising to both public and policy officials;
- Organizing visits and field-days to university students and government officials at the premises of ERI (experimental area) at soba _20 km Southwards Khartoum;
- Enhancing commercialization of renewable-energy through local production and development in collaboration with the private and public sector enterprises.
- Availing technical expertise for the implementation of joint projects in the field of renewable energy with both national and international organizations.
- Rendering consultancy services whenever demanded.

The Technology development and dissemination department is working together with the other three mentioned departments in the dissemination of renewable-energy technologies since its establishment. The experience gained from feed-back studies and acceptability-surveys, reveals that technology-focused dissemination programmers have limited success and low acceptability. While strategies designed to tackle dissemination as a process starting from the stage of proper situation analysis; proved wider scope commitments from beneficiaries. Since renewable-energy technologies were introduced early in Sudan (seventies), their large scale dissemination is not yet attained; this is mainly due to their high initial cost and low acceptability associated with the lack of information in this field to users and producers (in addition to factors associated with each technology).

Therefore, the adoption of dissemination model contains different steps. In each step, there is a chance to deal with factors affecting renewable-energy technology dissemination and these could be illustrated as follows:

- Identification and Study of the 'target-group', which is considered as the step of situation-analysis of the target-group by using Participatory Rapid Appraisal (P.R.A.), structure and attitudes. Because, rural communities of Sudan are characterized by tribal leadership that affect decision-making process, guided by the following facts:
  - Women and men have a wealth of traditional knowledge that they use to deal with energy-problems and to select options for themselves. So their views should be respected and they have to participate in the decision-making process.
  - The role of the outsider is to learn, convene and catalyze sharing of information among communities.
  - The aim is to encourage communities to better understand their energy-problems and assess ways of addressing them.
- Awareness raising, which is the step of familiarizing users of new technology by using dissemination methods to draw their attention.
- Dissemination of information showing economic and environmental benefits, this is the step of interaction and to enlighten producer and consumer about the new technology in order to create market-potential and study the existing supply and demand.
- General demonstration, this is the step of technology-demonstration showing physical and technical nature of the technology and provides comparative information.
- Selection of interested customers, these are the potential-users of the technology.
- Training of trainees in usage and up-keeping, this is to provide technical assistance and conduct training/workshops to localize production and facilitate commercialization to sustain the process.
- Develop financial mechanism, this is mainly to push the 'purchasing power' of the users.
- Evaluation, which is considered as an important step for feed-back to maintain the quality of replication.

**Participatory Approaches**

Recent years have seen a rapid growth in interest of community participation covering wide range of sectors and contexts, including health environmental management urban regeneration agriculture conservation and local economic development.

There has been a revolution in the past two decades in participatory methodologies. Emerging from a range of different traditions and disciplines, the use of it has been expanded during 1980s-1990s in developing countries. Among these methodologies, participatory rapid appraisal is adopted in energy-issues at different project levels .
Participatory Rapid Appraisal

The most practiced participatory approach is participatory rapid appraisal (PRA) which is now called participatory learning action (PLA) .It refers to a set of approaches and methods that are used in policy-making to give local people a chance to participate, enhance and analyze their knowledge of life and condition to plan and act (Champers 1994). Rapid appraisal is a form of qualitative research derived from the participant observation methodology of socio-cultural anthropology. Rapid Appraisal (RA) is a fast and flexible method. It is grounded in recognition that all dimensions of local system cannot be identified in advance, and that attempts to do so, reflects primarily the outsider's culture. Instead, a team of individuals with contrasting expertise can develop an understanding of a system by synthesizing information from several sources like prior research and reports, direct observation, and semi-structured interviews (with group, individuals & key informants).

During conducting PRA, time is allocated to ensure interaction of the team members in an effective learning process. The goal is to grasp an insider's perspective on the system and to understand it as a whole, rather than to come up with a statistical description of its constituent units. Which lay the basis for empowering beneficiaries and producing sustainable results (Pretty&Hine, 1999).

PRA encompasses a growing group of approaches, methods and behaviors that enable people to share, enhance and analyze their knowledge of life and condition to plan, act, monitor and evaluate. It employs a range of methods to enable people to express and share information, and to stimulate discussion and analysis.

The participatory approaches emphasize on reorientation in the relationship between the "outsider" and the "subject" of development activities and research, i.e. reciprocal learning process in the relationship has replaced the one-way "transfer of know-how" idea. (Mwanje, 2001)

The popularity of techniques of participatory rapid appraisal in rural-research and project- planning largely due to their usage in generating information of the community level directly with the community members. Such information is regarded to be more reliable and more relevant to community-interests. Improving both the quality of information available to planners, and communication between outsiders and community members, is central to the rational for participatory approaches. Many developmental efforts take place in highly complex social and physical environment, which place a premium on the use of people's knowledge and judgment (e.g. assessing new technologies).(Champers,1991).

Techniques of PRA not only draw on the complexity and sophistication of people's technical and social knowledge, their practical expertise in managing livelihood and so on: it also draw on hitherto unrecognized abilities of diagrammatic and symploic representation among informants through a range of mapping and other techniques usable by non-literate people.

**Types of Participation**

Participation can be in many different ways. It can be finding something out and proceeding as originally planned; it can also mean developing processes of collective learning that change the way people think and act. The many ways that organizations interpret and use the term participation can be resolved into six distinct types. These range from passive participation: where people are told what is to happen and act out in a predetermined way; self-mobilization: where people take initiatives, largely independent of external institutions . The list is given under Table-1.

The problem with participation as depicted under types one to three (1-3) that the achievements are likely to have no positive lasting effect on people's lives. The term participation can be used, knowing it will not lead to action. Types four to six by contrast, involving building of social and human-capital. Great care must, therefore be taken while using as well as interpreting the term 'participation'. It should always be qualified by reference to the type of participation, as some types will threaten rather than support the goals of community regeneration. What is important for institutions and individuals to define better ways of shifting from the more passive, consultative-

**Table - 1: Types of Participation**

| Typology | Characteristics of each type |
|---|---|
| 1. Passive participation | People participate by being told what has been decided or has already happened. Information being shared belongs only to external professionals. |
| 2. Participation by consultation | People participate by being consulted or by answering questions. Process does not concede any share in decision-making, and professionals are under no obligation to on board people's view. |
| 3. Bought participation | People participate on return for food, cash or other material incentives. Local people have no stake in prolonging technologies or practices when the incentives end. |
| 4. Functional participation | Participation seen by external agencies as means to achieve their goals, especially reducing costs. People participate by forming groups to meet predetermined objectives. |
| 5. Functional participation | People participate in joint analysis, development of action plans and formation or strengthening local groups or institutions. Learning methodologies used to seek multiple perspectives, and groups determine how available resources are used. |
| 6. Self-mobilization and connectedness | People practice by taking initiatives independently to change systems. They develop contacts with external institutions for resources and technical advice they need, but retain control over the way of resources are usage. |

driven participation towards the interactive end of the spectrum.

**Research Techniques of Rapid Appraisal**

***Systems perspective***

Semi-structured interviews;

Use of "individual respondents" to represent variability and "key informants" who can describe the broader system beyond their own direct participation; and Drawing diagrams and pictures.

***Triangulation***

I. Multidisciplinary teams;

II. Information; collected in advance; and

III. Direct observation.

The second principle is 'triangulation'. The term comes from navigation. It means try to find a position or location by means of bearings from the known points. When applied to rapid appraisal, it is systematically combining the observations of team members with different backgrounds and using variety of research methods. The assumption is that for most situations, there is no single "best" way to obtain information, and even if there was, it could not be foreseen. Similarly, no single person's impressions of a situation can be perfect. Team members must employ triangulation in a highly conscious fashion, maintaining clarity about each person's tendencies toward bias, the sources of information, and the system being investigated. This improves the quality of information and ensures cross-checking. Rapid appraisal must triangulate among people by listening to the viewpoints of different groups. It is also necessary to triangulate among methods, to combine information from interviews and direct observation with information collected in advance.

**Iterative Data Collection and Analysis**

1. Structuring research-time to allow the appraisal team interaction

***The Iterative Process:***

The third basic principle of rapid appraisal is iterative data collection and analysis. As information is collected, it is used to modify the research process. Research-time is structured so team members have plenty of time to interact. Rapid appraisal is a process during which the researchers begin with information collected in advance, and they progressively expand their knowledge and deepen their understanding by sharing their interpretations of new information as it is collected. It can be considered as an open system that uses feedback to encourage participants to rapidly change questions, interviews, and directions as their understanding evolve. (PRA, 1999).

***Absolute Requirement:***

The three basic principles allow for tremendous amount of flexibility on which techniques are used and on how the pieces are put together. However, there are few absolute requirements. First, it is not possible to start with a questionnaire and have a system perspective. Second, at least two people must be in a team, ideally both insiders and outsiders, for the principle of triangulation to be observed. Third, a rapid appraisal cannot be a one-shot effort. The process must consist of collecting information, discussing, analyzing it, and then collecting additional information.

A rapid appraisal should be neither too short nor too long. There is a danger that too many resources will be invested in it. The purpose is to get enough information so that additional research can be carried out or an activity can be started up.

To maintain a certain amount of rigour in the process, a checklist should be prepared .It should specify the team members, time spent, types of people contacted, types of information collected and so on. Ideally, this checklist should note down the date when some of the issues raised and it should be revisited.

***Core Principle of Participatory Methodologies***

Four important common principles uniting most of them:

- *Systemic and group learning-process*
  The focus is on cumulative learning by all the participants through system learning and interactive methods. The complexity of the world is revealed through group-inquiry and interaction, implying investigators of three types: from different principles, different sectors, and from both professional and local context.
- *Multiple perspective of stakeholders*
  Central aim is to seek diversity, rather than characterize complexity in terms of simple averages. Different individuals and groups make different evaluations of their situations, which lead to different actions/procedures. All views of activity or purpose are heavy with interpretation, bias and prejudice, implying that there are multiple possible descriptions of any real world activity.
- *Facilitation leads to transformation*
  The methodology is concerned with transformation of existing activities to try to bring about changes, which people in the situation regard as improvements.

  The role of an external expert is best thought of as helping people of their situation carry out their own study and so achieve something.

- *Learning lead to sustained action*
  The learning process leads to debate about changes, and debate changes the perceptions of the stakeholders and their readiness to contemplate action. The debate and the analysis define changes, which could bring about improvement, and so seek to motivate people to take action to implement the defined changes. Agreed actions represent accommodations between different conflicting views. These actions include institution building or strengthening, so increasing the

capacity of the people to initiate further action on their own.

**Benefits of Participation**

- What has become clear in recent years and in range of sectors, is that interactive participation can lead to improvements in performance and outcomes. Limited number of comparative studies has been conducted on rural and urban development programmers in recent years.
- The typical impacts of these deliberative and participatory methodologies have included:
- Enhanced social capital: Increased cohesiveness between and amongst groups, greater motivation to act, emerges of new leadership and readiness to revitalize existing structures increasing of self-reliance.
- Enhanced human capital: greater confidence of individuals, personal empowerment through changes in skills, knowledge, attitudes and action.
- Enhanced natural capital: improvements in natural resources management, increased production of natural resources goods and services; greater added value for local communities.

**Energy Research Institute Experience**

The model of dissemination mentioned above was successfully applied to all renewable energy technologies in rural Sudan and studies showed that the methodology of P.R.A.applied in all project cycle have greater impact on the dissemination effort.

**Recommendations**

- Participatory methods should be brought into generation and execution of activities to improve the local quality of life by bringing local cohesion and self-confidence.
- Participatory methods of planning and management are also needed at the local government level to ensure accountability and create transparency as well with great variety of stakeholders.
- Efforts should move beyond self-help and be more conscious of the need to empower poor communities to participate in a more coherent and forceful way in decision –making process.
- The method of PRA should be adapted to different localities, for, rural areas varies according to the region.

# CHALLENGES FOR THE PROMOTION OF RENEWABLE-ENERGY TECHNOLOGIES IN PAKISTAN

**Parvez Akhter**
*Pakistan Council of Renewable Energy Technologies*
*Islamabad, Pakistan*

**Abstract**

*This paper emphasized on the importance and challenges for the promotion of SET in Pakistan. 75% of the energy is supplied by the fossil-fuelds and 13% of energy needs are meet by biomass. The fossil-fuel for the use of energy has harmful impacts or effect on the environment in many ways. The magnitude of Renewable-Energy Sources (RES) is enormous, and hte energy gap can be filled by promoting these RES. Pakistan is an energy-deficient country and these RES can be utilized to meet the challenges of energy deficit. But these energy technology are unable to compete with conventional energy sources in open-market and is facing number of challenges.*

## 1. Introduction

About 75% of the world's energy-supply come from, fossil-fuels, i.e. from coal, gas and oil, whereas 13% of our energy-needs are met by bio-mass which is the traditional fuel of the third-word countries. Oil is the most important among all conventional sources of energy and it meets 35% of our global energy-needs [1-2]. We have limited reserves of fossil-fuels and these are fastly depleted. The production of American oil has already crossed the peak in seventies, while world's oil, excluding that of Middle East, has reached the peak. The production of oil of Middle East may start declining after 2020 [3], resulting in the widening gap between demand and supply. This gap is to be filled by alternate or renewable-energy sources. It is believed that after 2050, 50% of the world's energy-supply will come from renewables. Furthermore, there are two billion people (one third of world's population) in the world that are living below the poverty level and have no access to any commercial energy. The existing energy-systems have failed to provide them the basic necessities of life.

The processing of fossil-fuels for use as energy has harmful impacts on the environment at every stages of processing, such as extraction, transportation, refining, etc,. However, most harm is done at the end-use, where, on combustion, these release toxic gases into the air. These are creating great risks to health in the form of respiratory disease, and also cause acid-rain, etc,. The health-cost due to transport activity in urban areas, has been estimated as equal to \$0.54 and \$5.15 per liter of gasoline and diesel, respectively [4].

Fossil-fuel prices do not include external costs (monetary and non-monetary) such as, risk to health; environment degradation; and military expenditure for having a control on the fields and to safeguard the flow of oil. In case these external costs are included in the price-factor of the fossil-fuels, they would have become unaffordable for many people of the world. Hence fossil-fuels are heavily subsidized.

The magnitude of Renewable-Energy Sources (RES) such as solar, wind, biomass, and geothermal is enormous. It is 140 times the worldwide annual energy-consumption. Presently only 0.1 % of these are being used [1]. These are enough to meet all our growing energy-needs for long-times to come in the future. There are number of

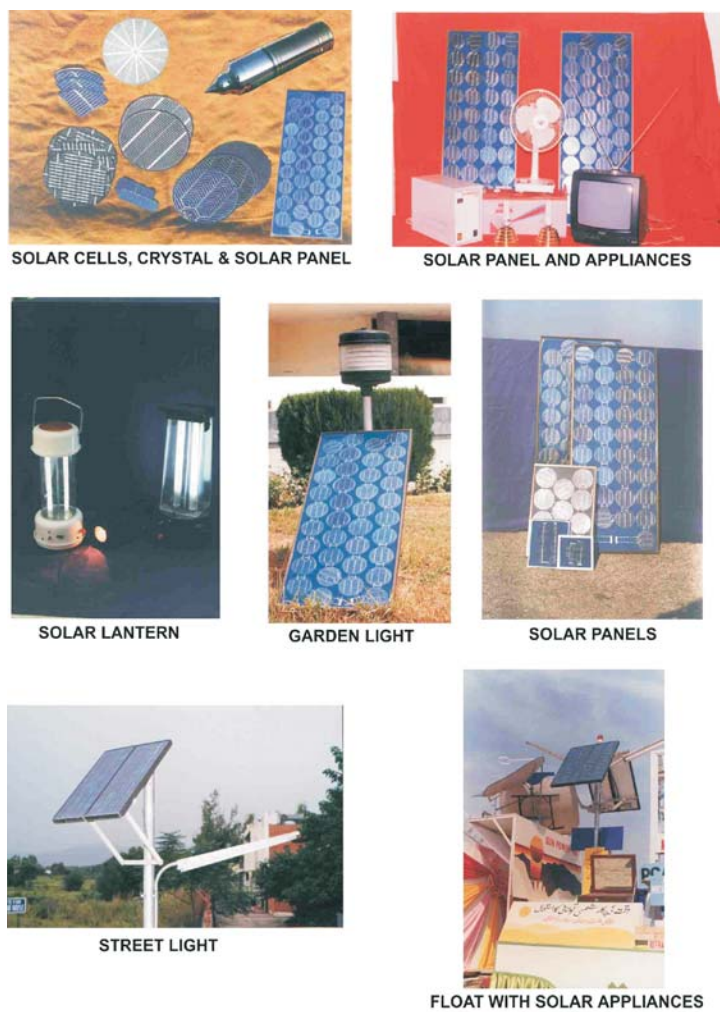


**Figure - 1: Photovoltaic Appliances from PCRET**

incentives for the Governments to promote RES. Some of these are the clean environment, new employment-opportunities, energy-independence, provision of social services and improving the living conditions in the remote areas, reduction of mass migration from the rural to urban, and saving of foreign-exchange on import of energy. These incentives could provide enough driving force for the governments to fund and support the development of renewable-energy market.


**Figure - 2: Solar Thermal, Wind, Biogas and Micro-hydel Appliances from PCRET**

## 2. Options For Pakistan

Pakistan is an energy-deficient country that spends 3 Billion US dollars every year to import oil with annual growth-rate of nearly 1% [5]. Majority of the people living in remote rural areas have no access to the commercial-energy sources. Energy-services are to be extended to the poorest of the poor living in the far-flung areas, to raise their standard of living to a respectable level. This goal can be achieved by utilizing renewable-energy sources. Fortunately Pakistan is blessed with plenty of these, of which solar energy is the most abundant and widely spread in the country. The mean global irradiance falling on horizontal surface amounts to 1.9 - 2.3 MWh per square meter in a year [2,6]. Wind, micro-hydro, biomass, and biogas are other important renewable-energy sources that can be effectively utilized to meet the challenges of energy-deficit in the country [2]. Our Northern Mountains are rich with micro-hydro sources. About 300 MW has been estimated in the mountainous region of Pakistan [7].

Pakistan started using renewables in sixties when 18 villages were electrified using photovoltaic, and solar stills were installed to desalinate the seawater. In early 1981, National Institute of Silicon Technology (NIST) was established to do research, development and promotion of photovoltaic technologies. Since then the infrastructure and know-how have been developed in the field of photovoltaics and solar-energy technologies. The laboratories are equipped to produce Silicon-wafers, solar cells, and PV modules. A number of appliances such as, solar lantern, solar home-light system, street and garden-lights were developed and are shown in Figure 1-2. Recently the Government realizing the importance of the renewables in the development of remote areas, has established an organization namely Pakistan Council of Renewable Energy Technologies (PCRET) to do research, development, promotion, dissemination, policy-making, advising and assisting government and related industries in this field. Alternate- Energy Board has been established in the country to facilitate the deployment of the RETs.

There are large areas in the country having extremely remote character. These are far-away from the grid-line and there is no hope that these areas will get electricity, even in coming 50 years. PV is quite viable and economical source of electric power for these areas [2]. A total of about 650KW of PV has been installed in the country. More recently three villages of Balochistan have been electrified using wind/PV/diesel hybrid and solar- home systems. Another four villages are in the pipeline for electrification through PV. A number of parks have been illuminated through solar garden and streetlights. Photovoltaics are also being used to power the telecommunication-systems.

Two plants each consisting of 250 stills with a capacity to clean water upto 6,000 gallon per day, were installed in Gawader in sixties [7]. This was followed by other smaller plants of capacity 250 gallons per day each in rural areas, to convert brackish water into potable water. A number of other solar thermal appliances such as, solar cooker, solar water-heater, and solar stills have been designed and introduced in the country.

Solar drying is another application that is effectively being employed for drying fruits in the northern mountainous region.

The biogas activity was initiated in the country in the early seventies, when more than 4,000 plants of capacity varying from 5 – 15 cubic meter per day were installed in the country. Recently, 1,200 bio-gas plants have been installed throughout Pakistan on cost sharing basis, where 50% cost is to be borne by the beneficiary.

Fuel-wood is still the cheapest of all energy-sources in the country and is the main source of energy in rural areas [8]. PCRET, in 1995, launched the Fuel-Saving Technology (FST) Project to conserve energy at a domestic level. It reduces family's fuel-needs upto 30 – 40% and safely disposes off the smoke through the chimney. The Council has so far installed/disseminated more than 60,000 energy conserving, improved cooking devices all over the country, and has provided training in construction and use of such devices to the workers of various NGOs and local population.

Uptill now over 300 micro-hydro power-plants with generation-capacity exceeding 3MW have been installed in the country [9]. These projects are based on community participation and cost sharing mechanism. Another project that will utilize the hydropower of the canals to produce the electricity on micro-scale is at its developmental stage.

For the purpose of harnessing wind-energy, a project, now in its final stage, is to produce wind-maps for the coastal areas of Balochistan and Sindh. At the same time under another project more than 130 small wind-turbines are being installed on experimental basis.

## 3. Challenges

Inspite of the fact that the growth-rate of some of the renewables is highest in the energy- market, yet these energy-technologies are unable to compete with conventional energy- sources in the open-market and are facing a number of challenges. The most important of these challenges are grouped into four categories and are described hereunder:

### *3.1 Capacity-Development*

*a) Human-Resource Development:* The technologies being knowledge-intensive, need highly qualified and trained manpower for research, development, and deployment of these energy-technologies that cover a wide spectrum of scientific and technical subjects. The universities have to play a very important role to accept this challenge, to introduce new subject to cater the need of emerging technologies. On the other hand, the deployment of technologies demand training of semi-skilled and skilled manpower that can provide the services such as, installation; operation & maintenance; and troubleshooting of the system. Such trained manpower is extremely important for the success and sustainability of the renewable-energy projects. This will also buildup new business in areas like support-structures and other system-components. It will help to develop niche/consumer-market. So effective training will eventually help to establish local industry and commercial activities for generation of income.

*b) Resource Assessment*: Reliable data and assessment of energy-sources, technologies, human-resources, research and development, etc., are extremely important and essential at all levels, such as planning, pre-feasibility, feasibility, project-formulation, assessment, and analysis, etc. So there is a strong need of developing necessary resource-assessment tools and information databanks.

***3.2 Infrastructural Development***

The basic infrastructure for the research, development, and deployment of renewable- energy technologies either does not exist or is very poor and inefficient in the countries / regions where renewables are most needed. The essential areas are as follows:

*a) Human-Infrastructure:* This includes capabilities of individuals, as well as institutes. The improvement of proficiency is a continuous process of learning. The individuals are to frequently update their knowledge and skills, to extend it to the new opportunities. So the qualified manpower needs to be exposed to renew their existing know-how and understanding of the fast developing technologies. Similarly, the institutes are to be upgraded through the incorporation of new facilities and manpower. The important element is to strengthen the existing institutes rather than to setup new organizations that will infact result in the thinning of both manpower and financial resources.

*b) Field Experience:* The experience gained in the field through installation, operation, and maintenance is an extremely important part of the learning-curve. This provides a wealth of feedback-information that helps to improve and perfect the technology in the existing environment. So it is important to go through the process of learning by installing a number of demonstration-projects, at the early stage of technological development.

*c) Infrastructure for Decentralized Delivery-System:* RET's are decentralized in character, whereas our current experience of handling is only those of centralized energy- systems, which have need entirely different requirements. So we have to develop the infrastructure that can handle the decentralized energy-delivery systems more effectively and efficiently.

*d) Market-Support Infrastructure:* This includes network of dealers, after sale services, up-and down-stream support-technologies. Such an infrastructure is important for sustainability, acceptability, growth of the market, and to lower the cost of technology.

### *3.3 Policy Instruments*

*a) Renewable-Energy Policy:* The non-existence of energy-policy and planning in many developing countries of the world is an obstacle in the development of renewable-energy technologies. The main initiative for the promotion of renewable-energy technology has to come from the governments who have to make a clear-cut long-term energy-policies that must include a progressive increase of renewable-energy technological component. Targets are to be fixed and implemented. Consistent policies with positive climate is a must, to encourage the private investors in the field.

*b) Level Playground:* There is a need to provide level playground for conventional and renewable-energy systems. This means that the conventional energy-sources have to be priced realistically, i.e. to include health and environmental cost; and to transfer all subsidies such as due to low tariff of gas and electricity, and subsidies on kerosene-oil, etc., to renewables such as solar lantern, solar home system etc. This will make RES compatible.

*c) Market-Development:* Renewable-Energy Technologies are facing a tough time in competing with the conventional energy-sources. Public-sector can play an important role in expanding the market by using renewable-energy technologies on public buildings, etc. Market expansion will increase production-yield and lower the prices to compete in the free-market. Some governments have taken bold steps to increase the market-volume of renewable-energy technology. For example, Germany has installed photovoltaic modules on government buildings [10], whereas Australia extensively used solar energy during Sydney Olympics when stadium was illuminated using PV, and each house of Olympic-village was provided with PV power and solar water-heater [11].

*d) Technology-Transfer:* It is extremely important to develop the technologies indigenously for the low price and sustainability of the technology. If some hardware is to be imported, then it must be linked with transfer of know-how for value added development or complete indigenisation. Care must be taken not to make the country a dumping ground for foreign technologies.

*e) Financial Incentives:* Currently, RETs are largely subsidy-driven. So there is a strong need for initiating bold steps to provide brave incentives to deploy renewable-energy technologies and to develop the mechanism to provide easy credit facility, to attract the investment and market-development. A study has shown that in the Sun-belt region, only a tax rebate of 15% can make the PV commercially viable [7] and compatible with the electric utility.

Governments can provide balanced budgetary resources; provide credits, subsidies, tax rebates, and soft loans; and develop micro financing mechanism for this purpose. Definite, positive developments are seen wherever such facilities have been provided.

## 4. Cultural Challenges

### *4.1 Benign Energy Technologies*

Energy technologies have a very long life. Internal combustion-technology took about one hundred years to take over external combustion. Now renewable-energy technologies are threatening the internal combustion-technology and it is expected that renewables will take over by the end of this century. So we need to understand and live within these established limitations.

### *4.2 Social barriers*

Social structures have strong inertia that provides opposition to the penetration of new technologies. The elements of this inertia vary widely from society to society. We need to identify such elements, and provide necessary training to motivate the masses to accept new changes and technologies for their own socio-economic benefit.

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