EXPLORING THE POTENTIAL OF SOLAR AND WIND ENERGY SOURCES FOR IRRIGATION: AN OVERVIEW FOR PAKISTAN

Abdul Wahab, Muhammad Yasin** & Muhammad Munir Ahmed****

ABSTRACT

Energy is one of the major concerns for pumping of water through tubewells, as it incurs high electricity tariffs and rising prices of diesel fuels. Cost-effectiveness (Capital and O&M) is essential for adopting solar and wind powered micro-irrigation for smallholdings.

Solar and wind-energy systems could provide economical ways to produce electricity for domestic and farm use, as well as pumping water for agriculture. This paper presents an overview of the potential of solar and wind energy-resources, and explores means to better understand and adopt pumping technologies with renewable energy sources, in an agrarian country like Pakistan. Some details of system design and comparison of solar and wind-powered systems are given.

Keywords: *Solar, Wind, Tubewell, Energy, Agriculture and Pakistan*

1. INTRODUCTION

The ever-increasing population of the world has increased the pressure on limited available fossil-fuels. The situation has forced the world to explore and develop the alternate sources of energy. The consumption of fossil-fuels (oil and natural gas) has reached the turning point, in view of confirmed energy reserves in Pakistan. The energy requirement of Pakistan is growing at a rate of 10-12% per year. It was 57.9 Million Tonnes of Oil Equivalent (MTOE) in 2006 and will rise to 177 MTOE in 2020.

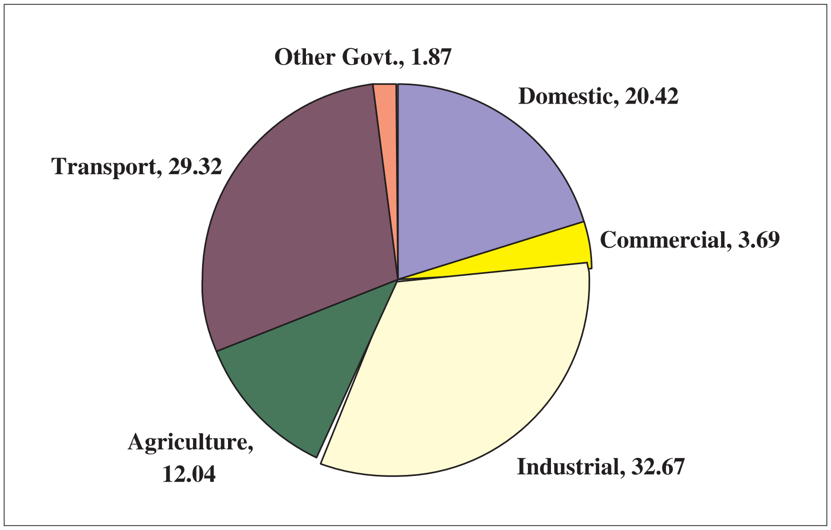
Energy availability and usage have been and will continue to be important factors in improving the productivity of agriculture system (Lewis, 1984). Increasing energy costs can be one of the biggest expenses for a small business or agricultural operation. Therefore, one must carry out its management in a systemic fashion. Due to low availability of electricity and high fuel prices, the farmers face difficulties in using the existing water pumping systems. Fortunately, by virtue of Pakistan's location and natural endowments, many technologically feasible alternate energy resources, like solar and wind, are available to meet the country's growing energy requirements. These systems can be applied without the worry of fuel-supply or electricity transmission lines. Energy from the wind and sun, coupled with appropriate pumps, could help to meet the irrigation requirements. This new arrangement would bring down the running costs and, subsequently, the costs of agricultural produce (Becenen and Eker, 2005). Provision of alternative energy and upgrading the existing practices relating to energy production to more energy-efficient machinery may be a good solution to the prevailing energy crisis. Keeping in view the scarcity of energy and importance of irrigation in the agriculture sector, exploitation of alternate energy resources for enhancing irrigation and pumping efficiency will not only conserve conventional valuable energy-supplies but also reduce pumping-costs leading to lower cost of crop production. This paper also describes the method to calculate the required energy and required amount of resources to harness the necessary energy for irrigation.

2. AGRICULTURAL POWER SCENARIO OF PAKISTAN

The agricultural production system in Pakistan is in transition from the traditional, i.e. low energy-input methods of farming, to the modern agricultural production system that requires higher energy-inputs. Agriculture sector is an important but not the most dominant user of energy in Pakistan, as indicated in Figure-1. Generally, insufficient mechanical and electrical energy is available for agriculture and, hence, the potential gains in agricultural productivity through the deployment of modern energy-services are not being fully realized. Maintaining adequate energy-services for rural people would ensure increased energy-inputs to agriculture, leading to increase productivity, food-security and rural economic development. Moreover, to feed the constantly increasing population, it is of utmost importance to examine the current level of energy-use in agriculture sector and project future trends.

Lately, the agriculture sector of Pakistan is consuming energy of above 200 thousands Tonnes of Oil Equivalent (TOE) in the form of petroleum-products and almost 500 thousands TOE in the shape of electricity (Pakistan Energy Yearbook, 2003-04). During 2007-08, there were 895,511 public and private tubewells in Pakistan. Around 86% of these tubewells were located in the province of Punjab and the rest (14%) were located in the three other provinces of Pakistan, namely Sindh, Khyber Pakhtoonkhwa and Balochistan. The distribution of tubewells (based on

* Scientific Officer, **&*** Principle Scientific Officers, Water Resources Research Institute, National Agricultural Research Centre, Park Road, Islamabad, Pakistan. Email: wahab_siyal@hotmail.com

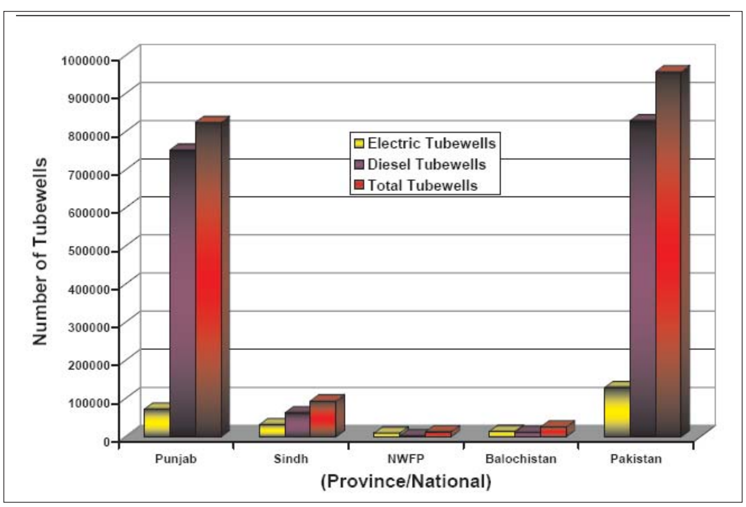


Source: *Pakistan Energy Yearbook 2007-08*

Figure - 1: Pakistan's Energy Consumption (% by Sector in 2007-08)

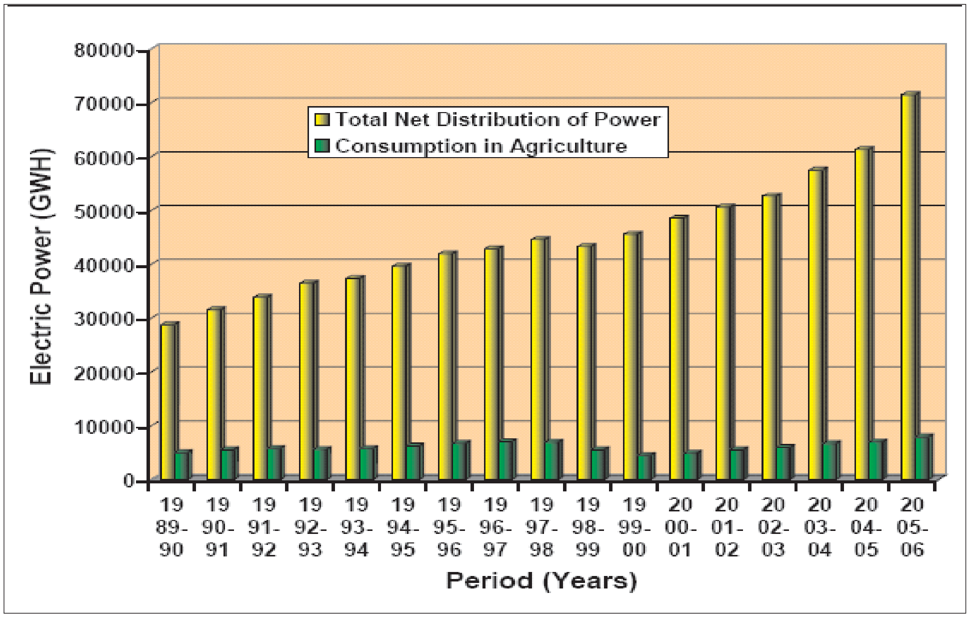
size of power) indicated that majority of electrically operated tubewells are in the range of 10-20 hp. The diesel-operated tubewells were in the range of 16-20 hp, because the diesel engines are normally available in this range. Population of diesel-operated tubewells in Pakistan was around 87% of the total number of tubewells available during 2005-06, whereas this percentage is around 88 in the province of Punjab. Thus, around 13% tubewells in the country were operated using electricity (Figure-2). Qureshi et. al, (2003) reported that more than 70% tubewells were operated using diesel in the province of Punjab. The total energy cost was PkR 16 billion for diesel tubwells and PkR 2.6 billion per year for electric tubwells. As a whole, farmers are spending about PkR 4 billion per year on repair and maintenance of private tubewells. Many efforts have been made to exploit the existing conventional energy-resources to build a strong indigenous exploration and production base. Inspite of all these efforts, the results achieved so far are neither cost-effective nor helpful in reduction of import dependence and promotion of self-reliance.

During 1990-2006, the net distribution of electricity to all the sectors had increased from 28,769 Giga Watt Hours (GWh) to 71,466 GWh.The growth-rate was



Sources: *Agricultural Mechanization Census 2004 of Pakistan*

Figure-2: Distribution of Electricity & Diesel Operated Tubewells at Provincial & National Levels



Source: *Ministry of Petroleum and Natural Resources, (2006)*

Figure - 3: Consumption of Electric Power in Agriculture at the National Level

5.85% per annum and the total increase during this period was 148%, which is a huge increase in availability of electricity in the country. The use of electric power in agriculture sector also increased from 5,027 GWh to 7,949 GWh during this period with annual growth rate of 2.9%, which is almost half of the overall growth in the power sector (Ahmad S., 2007) (Figure-3). Thus agriculture sector is a slow consumer of power in Pakistan. The per cent share of agriculture sector in usage of power was around 17% during 1989-90, which came down to 11% during 2005-06. This was primarily due to the increased availability of power, as a whole. There is a clear indication that availability of power to the agriculture sector is an issue, as the rural power infrastructure is limited and farmers have to pay considerable amounts of money for getting an electricity-connection. Thus, only resourceful rich farmers can have access to electric power.

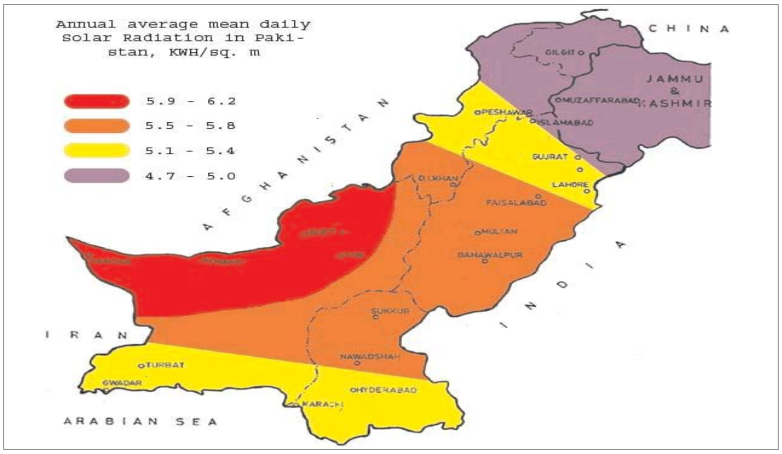
3. POTENTIAL OF SOLAR AND WIND ENERGY RESOURCES IN PAKISTAN

The energy-production and consumption of a country have a significant impact on its economic development. To be economically feasible for agricultural applications, the cost of water delivered must be less than the value of the benefits obtained through the use of irrigation water, either through improved yields or by enabling more crops to be grown per year. So we present here some relevant figures for solar and wind energy pumping.

3.1 Solar Energy

Solar energy is pollution free and can replace a part of conventional energy. It is available in abundant quantities and is free of charge. The annual average mean daily solar radiation in Pakistan is 4.7 to 6.2 KWh on each square meter area, and most parts of the country enjoy clear sky for 300 or more days per annum (Figure-4). The monthly daily mean solar-energy profile of major cities of the country is shown in Table-1, which indicates that it is the most promising potential source of energy for Pakistan. The average Rabi irradiation is 20 M.J/m^2/day in Quetta; 25 in Peshawar; 24 in Multan; and 22 in Lahore (Zakir et. al, 2000).

Solar energy is used mainly for pumping water for livestock or for domestic use. It is seldom used for irrigation, because of the large amounts of water needed for growing crops. However, solar pumps are feasible for irrigation that use very low heads or has very low lifting requirements, such as drip irrigation, which uses less water than other types of irrigation-systems. Solar pumps work by converting solar radiation into electricity, through the use of photocells made of silicon, usually called photovoltaic (PV) cells. The PV cells are enclosed in a glass frame making the



Source: *National Renewable Energy Laboratories (NREL) of USA*

Figure - 4: Annual Average Mean Daily Solar Radiation in Pakistan

solar module. Usually, an array of solar modules is needed to produce enough energy for the pump. The modules are mounted on a frame in an assembly called a PV array. The PV array is connected to a controller and then through an electrical power cable to the motor/pump subsystem in a well. Solar pumps usually use a direct current (DC) motor (The motors that use alternate current (AC) must have an AC to DC inverter). DC motors are recommended because using an inverter costs more, and some power is lost in the AC to DC conversion.

A problem with DC motors in the past has been that they needed carbon brushes, which wore out and needed regular replacement. Maintenance-free DC motors have recently been developed that use an electronic circuitry to perform the same function as the brushes. Today, most submersible pumps use brushless DC motors or AC motors with an inverter. The cost of photovoltaic modules has come down by a factor of 400 per cent in the last 30 years (Helikson et. al, 1991). This trend continues and will help in reducing the cost of photovoltaic-powered water pumping systems. A solar pump requires low maintenance and can operate without any attendant. With the rapid decline in the price of cells and associated equipment, the system has a potential to spread widely in the coming years of probable energy shortage. Photovoltaic technology will also continue to improve the power-conversion efficiency of the photovoltaic cell. Increase in photovoltaic cell efficiency will decrease the cost of photovoltaic power, because fewer modules will be required to produce the same amount of power.

Table - 1: Monthly Mean Solar Radiation in kWh/m^2/day in Major Cities of Pakistan

Month	Karachi	Lahore	Multan	Peshawar	Quetta
January	4.38	2.97	3.52	0.35	3.91
February	4.97	3.86	4.27	4.06	4.59
March	5.82	5.04	5.20	5.07	5.64
April	6.23	5.79	6.30	6.02	6.63
May	6.44	6.32	6.70	6.96	7.61
June	6.30	6.18	6.52	7.19	8.22
July	5.31	5.70	6.42	6.50	7.45
August	4.94	5.20	6.02	5.91	7.32
September	5.50	5.06	5.65	5.37	6.70
October	5.38	4.19	4.64	4.40	5.64
November	4.66	3.44	3.84	3.53	4.48
December	4.12	2.83	3.20	2.90	3.77

Source: *Pakistan Meteorological Department (PMD)*

Table - 2: Monthly Benchmark Wind Speeds for Jhimpir site

Month	Monthly Benchmark Wind Speed				
	30 m	50 m	60 m	67 m	80 m
January	4.25	4.70	4.90	5.02	5.24
February	4.50	4.98	5.18	5.32	5.55
March	4.77	5.28	5.50	5.64	5.89
April	6.39	7.03	7.29	7.46	7.75
May	8.29	9.05	9.36	9.56	9.90
June	8.79	9.50	9.78	9.96	10.25
July	8.83	9.59	9.89	10.08	10.40
August	8.20	8.89	9.16	9.34	9.63
September	6.63	7.28	7.54	7.72	8.01
October	4.22	4.68	4.87	50.00	5.22
November	3.59	3.98	4.14	4.24	4.43
December	3.96	4.38	4.56	4.67	4.88
Annual Average	**6.0**	**6.6**	**6.8**	**10.8**	**7.3**

Source: *Pakistan Meteorological Department (PMD) & Alternative Energy Development Board (AEDB)*

3.2 Wind Energy

Pakistan has a considerable potential of wind energy in the coastal areas of Sindh, Balochistan, as well as the desert areas of Punjab and Sindh. Sites having good wind-speed will be useful for modern windmills, which require minimum wind speed of more than 7 MPH for achieving wind power for pumping drinking water and small scale irrigation. This renewable source of energy, however, has so far not been utilized significantly. The coastal belt of Pakistan is blessed with a natural wind-corridor that is 60 km wide (Gharo ~ Keti Bandar) and 180 km long (up to Hyderabad). This corridor has the exploitable potential of 50,000 MW of electricity generation through wind energy. The wind-data of selected areas have been collected by Pakistan Meteorological Department (PMD) and analyzed by the Alternative Energy Development Board (AEDB) to make a wind-resource study to setup the benchmark for wind-speed values at different levels from Gharo and Jhimpir regions (Table-2).

Wind is often used as an energy source to operate pumps and supply water to livestock. Because of the large quantity of water needed for crops, wind power is rarely used for irrigation. As larger and more efficient wind-mills are developed, single or groups of these wind-mills are expected to be used for irrigation projects.

A windmill consists of the following parts:

- A very large fan with 15 to 40 steel or galvanized blades;
- A gear-box mechanism driven by the blades. This mechanism converts the rotary motion of the blades to an up-and-down motion;
- A piston pump, which is driven by the up-and-down motion produced by the gear box mechanism;
- A pump-rod that descends from the windmill to the well;
- A pump cylinder, which is placed in the water near the bottom of the well and is driven by the pump rod.

The propeller should have many blades to develop a high starting torque, which is needed to start the piston pump. Generally, windmills begin working when the wind speeds exceed 7 MPH.

3.3 A Comparison: Advantages and Disadvantages of Solar and Wind Energy

The main advantage of using renewable energy for pumping water to meet irrigation needs is that there is no energy cost. The power source – either wind for a wind pump or sunshine for a solar pump – depends on the weather conditions of the given place. However, these conditions generally are constant at a given location from year to year, but vary with the season.

The water pumped from wind and solar systems is generally stored in tanks. In case of breakdowns or poor pumping conditions (unfavourable weather), the storage tank needs to be big enough to store a supply of water for several days. When the water tank is full, the extra generated energy can be stored in batteries. However, there are several drawbacks of storing energy in batteries:

- It is expensive.
- Only a small amount of energy can be stored (less than 1,000 or 2,000 watts per hour, depending on the number of batteries and their capacity).
- The batteries need to be replaced at least every 5 years.
- Storage batteries raise the initial cost of the total system.

Some advantages and disadvantages of using solar or wind energy are presented in Table-3.

4. SYSTEM DESIGN AND INSTALLATION

To make a wise decision on renewable energy sources, some basic aspects should be kept in mind, including:

- How solar and wind energy pumps work?
- The main components of these pumps;
- The advantages and disadvantages of solar and wind energy pumps;
- How to calculate pumping requirements?

It is also important to consider the costs of buying and using a pumping system, which include the initial cost, energy cost and maintenance cost.

4.1 Energy for Pumping Water

For pumping water, first the hydraulic energy (E_h) is calculated by using the following equation:

$$E_h = \mu g v h$$

where

E_h = required hydraulic energy in joules
v = required volume of water (m^3)
h = total head (m)
μ = density of water (1000kg/m^3); and
g = gravitational acceleration (9.81 m/s^2).

Example: The energy requirement for pumping 60m^3 of water through a head of 10 meter will be:

$$\begin{aligned} E &= \mu g v h \\ &= 9.81 \times 60 \times 10/1000 \\ &= 5.89 \text{ MJ Approx.} = 1.64 \text{ kWH} \end{aligned}$$

The power required to lift a given quantity of water depends on the length of time for which the pump is

Table - 3: Comparison of the Advantages and Disadvantages of Solar and Wind Energy Systems

	Factor	Wind System	Solar System
Advantages	Favorable Weather Portability	Steady winds are most productive	Pumping of water is consistent round the year. Can be portably mounted to use in different locations.
	Lifetime	Can exceed 50 years, except for the piston pump, which requires maintenance every 1 to 2 years.	More than 20 years. The pump lasts less time.
	Stormy weather	Wears more rapidly in high winds. Destructive winds can ruin system.	Panels can be damaged by hail. Cloudy weather and short days reduce energy production.
Disadvantages	Time of year power requirements	Power production stopped when wind speeds are low, which occurs in July and August when water is needed most.	
	Initial cost	Lower initial cost.	Higher initial cost.
	Maintenance cost	Requires more maintenance.	Less maintenance.

Source: *Encisco and Medic, 2004*

used. Power is the rate of energy supply, so the formula of hydraulic power is obtained from the formula for energy by replacing volume with flow-rate Q in cubic meters per second.

$$P = \mu g Q h \text{ Watts}$$

If flow rate Q is in litres per second, then hydraulic power is:

$$P = 9.81\ Qh \text{ Watts}$$

For example, the average hydraulic power required to lift 60 m^3 of water through a 5 m head in a period of 8 hours, i.e. an average flow rate of 2.08 lit/sec, would be 9.81x2.08x5 = 102 watts (approx). With a typical pump efficiency of 60%, the mechanical power required would be 102/0.6 = 170 watts.

The head has a proportional effect on the energy and power requirements, with the result that it is cheaper to pump water through lower heads. A pump consists of two parts: static-head or height, through which the water must be lifted, and the dynamic-head, which provides pressure equivalent of the velocity of the fluid. The static-head can easily be determined by measurement and there are formulae for calculating the dynamic head. The latter depends on flow-rate, pipe-size, and pipe materials. The smaller the pipes and greater the flow-rate, the greater pressure required to force the water through the pipes (Chaurey et. al, 1992).

For a solar system, the number of solar panels should produce the number of watts needed by the pump. Solar panels or modules have different capacities; there are modules of 25, 50, 70 or 75 watts.

4.2 Estimating the Size of the Windmill

Before installing a wind-mill, it is necessary to know the requirements of a particular area, such as: wind speed, type of head and daily water-consumption. A wind-mill's pumping output is affected by three factors: wind speed, wheel or blade diameter, and the diameter of the cylinder (Table-4). Wind speed has an important effect on the pumping output. In fact, the power available from the wind is proportional to the cube of the wind speed. This means that *when the wind speed doubles, the power increases upto eight times.* Most windmills do not operate at wind speeds of less than 7 MPH or more than 30 MPH, as the mill can be damaged by high-speed winds.

5. PROSPECTS OF SOLAR AND WIND POWERED PUMPING SYSTEMS IN PAKISTAN

Recognizing the importance of sustaining the fulfilment of agricultural energy-requirements, the Government of Pakistan should take initiatives to formulate solar and wind-powered water pumping programme and explore the viability of widespread use of these renewable energies, to satisfy the irrigation requirements of the agriculture sector. From a macro-perspective, solar and wind-powered pumping systems can prove to be the most

Table - 4: Pumping Capacities as Influenced by the Diameter of the Cylinder and Blade Diameter of the Windmill

Cylinder diameter (inches)	Pumping capacity (gallons per hour) Wheel diameter (feet)		Blade diameter (feet)					
	6	6 to 8	6	8	10	12	14	16
			Pumping elevation (feet)					
2	130	190	95	140	215	320	460	750
2 1/2	225	325	65	94	140	210	300	490
3	320	470	47	68	100	155	220	360
3 1/2	440	640	35	50	76	115	160	265
4	570	830	27	39	58	86	125	200
4 3/4	-	1,170	-	-	41	61	88	140
5	900	1,300	17	25	37	55	80	130
6	-	1,875	-	17	25	38	55	85
8	-	3,300	-	-	14	22	31	50

Source: *Encisco and Medic, 2004*

appropriate and economical solution if direct and indirect subsidies are given to renewable energy sector. Seventy per cent of agricultural production is in the hands of small farmers who are the backbone of agricultural production of Pakistan, but unfortunately are not in a position to absorb the up-front payment required to procure solar and wind-powered pumping systems. In addition, there is little effective infrastructure in place, even if investment solutions are found. On the other hand, the private sector has insufficient expertise to provide systematically designed solutions for farmers' energy-requirements. The private sector depend is only on some thumb rules and general information. That is why almost all systems installed throughout the country are either over or under-designed, resulting in great failure and a sense of disappointment to the farmer-community.

6. CONCLUSIONS

a. The introduction of solar and wind-energy systems could provide economical ways to produce electricity for farm-use and pumping water for livestock and irrigation.
b. The solar and wind-powered pumping systems can play a significant role to replace electricity and diesel operated tubewells, provided the government takes initiatives at mass level and formulates a policy at national level to provide subsidy on initial costs of solar and wind-powered pumping systems.
c. Furthermore, there is a need to develop a comprehensive strategy and approach to promote the private sector to take a technological lead in this field.

REFERENCES

- Ahmad, S., 2007. Growth of Agricultural Tubewells and State of Energy in Pakistan - Is Subsidy a Sustainable Option for Helping Farmers? Water for Balochistan. Policy Briefings. Vol. (3), No. (8). TA-4560, (PAK), Quetta, Pakistan

- Becenen, I., Eker, B., 2005. Powering of Water Pumps by Alternative Energy Sources in Thrace Region. Trakia Journal of Sciences, Vol. 3, No. 7, 2005 28

- Chaurey, A., Sadaphal, P.M., and Tangi, D., 1992. Performance Evaluation of PV Pumping Systems, RERJC International Journal Vol.14, No.2

- Enciso, J., and Mecke, M., 2004. Using Renewable Energy to Pump Water. Texas Agriculture Communications, the Texas A&M University System. Available at http://aces.nmsu.edu/ces/windmill/documents/using-renewable-energy-to-pump-water.pdf [Accessed June 2, 2010]

- Helikson, H.J., Haman, D.Z., and Baird, C.D., 1991. Pumping Water for Irrigation, Using Solar Energy

- Lewis, C., 1984. The Need for an Alternate Energy Strategy in the Agricultural Economics of the Third World. Energy in Agriculture, 9(8): 651-659

- Pakistan Energy Yearbook, 2003. Ministry of Petroleum and Natural Resources, Government of Pakistan. Islamabad: Hydrocarbon Development Institute of Pakistan.

- Qureshi, A.S., Shah, T., and Akhtar, M., 2003.The Groundwater Economy of Pakistan. Working paper 64. Lahore, Pakistan: IWMI

- Zakir, M.N., et al, 2000. Potential of Photovoltaic in Balochistan and Northern Areas of Pakistan: Proceeding of Seminar on Renewable Energy Technologies and Dissemination and Market Development, April 3-6, 2000. In COMSTECH, NIST, IBD, MOST, InterIslamic Network on renewable energy sources, Islamabad, PP: 201-205.

BIBLIOGRAPHY

- Faizullah, M., 2001. System Sizing for Solar Photovoltaic Water - Pumping, J.eng. & appl.sci. Vol. 20 No.2.