Feasibility Evaluation of the Wind Energy as an Alternative Energy Source for the Irrigation of Greenhouse Crops

Adnan Rasheed *, Jong Won Lee **, Hyun Woo Lee ***‡

* Department of Agricultural Eng., Kyungpook National Univ., Daegu, 702-701, Republic of Korea

** Institute of Agricultural Science & Technology, Kyungpook National Univ., Daegu

702-701, Republic of Korea

*** Department of Agricultural Eng., Institute of Agricultural Science & Technology, Kyungpook National Univ., Daegu, 702-701, Republic of Korea

(adnan.upm.spain@gmail.com, leewon@knu.ac.kr, whlee@knu.ac.kr)

‡ Corresponding Author; Third Auther, Department of Agricultural Eng., Institute of Agricultural Science & Technology, Kyungpook National Univ., Daegu, 702-701, Republic of Korea, Tel: +82-53-950-5736,

Fax: +82-53-950-6752, whlee@knu.ac.kr

Received: 20.07.2016 Accepted:22.10.2016

Abstract- Wind energy is evaluated as an alternative energy source for the irrigation of greenhouse crops at four different locations in Asia; Shouguang (China), Sargodha (Pakistan), Buan and Gimhae (South Korea). We studied potential of the wind resources available at each location for the use of a wind pump, to meet tomato crop (same for all locations) annual water demand. Daily and monthly evapotranspiration of the crop under different greenhouse sizes and volume of water pumped by using wind pump are determined for the water budgeting and economic analysis of the system. The concept of Levelized cost of energy (LCOE) in US dollar (US$) is used for the economic assessment, and we compare LCOE of wind pump and other sources (solar photovoltaic pump, diesel pump, electricity from the grid) of water pumping being used for the irrigation purpose. The initial results indicate that the LCOE associated with diesel-powered pumps and electricity from the grid is low. However, in the case of Shouguang and Buan have not received conventional energy source yet and have adequate wind resources to fulfil the irrigation requirement of the large area. The average wind resources in Sargodha and Gimhae are found inadequate for the large area water pumping, but irrigation of medium size greenhouse could be doable. Wind pumping system's internal rate of return found at each location, Gimhae, Buan, Shouguang and Sargodha are 4.4 %, 10.0 %, 5.2 % and below 1.0 % respectively.

Keywords levelized cost of energy, Renewable energy, Tomato evapotranspiration, Wind pumping.

1. Introduction

Greenhouse technology could make a significant contribution in agriculture production, which is being affected by global issues such as energy shortage, water and environmental pollution [1]. Production of crops under the greenhouse is adventurous due to the controlled microenvironment of greenhouse. Water management is a major component of the greenhouse precise farming, to get the better crop yield, water management is a very important factor to be considered, on time, sufficient and economic supply of water plays a vital role in agriculture development [2]. Water management is an important factor to increase the crop production. Renewable energy and farming are the winning combination, which can provide farmers a long-term source of energy. Renewable energy sources, a topic that is currently receiving considerable attention worldwide.

The current research was conducted in three different regions of Asia, China (Shouguang), Pakistan (Sargodha), and South Korea's two locations (Buan and Gimhae) having different agricultural development in greenhouse sector and having different economic situation.

The world's biggest land covered area with greenhouses is in China, it is estimated that 3.3 million hectares of land are covered with greenhouse structures, Since 1970 greenhouses were introduced in China, greenhouse facilities have proliferated and rapid annual expansion is still taking place [3].

South Korea has the second largest land covered area with greenhouses, according to a report by LEI Wageningen UR, an independent agriculture economics research institute indicates that the production area under protective cover in South Korea is 52,000 ha, consisting of 50,000 ha single plastic tunnels, 1,700 ha multi-span greenhouses and 300 ha glass houses. Main production under greenhouses cultivations are tomato, cucumber, strawberries, and sweet pepper. Over the last decade, the Korea Ministry of Agriculture and Forestry has invested large amounts of money in the development of this sector [4].

Agriculture contributes largely in Pakistan's economy, approximately 70 percent of the population is directly or indirectly involve with the agriculture industry. Although currently in Pakistan greenhouse farming is under developing stage, but substantial growth in this sector is expected in future [5]. Withal, the electrical supply in the country is limited, especially in the rural areas of Pakistan. Moreover, the country has been experiencing a serious shortfall of energy over the last decade. A research was conducted in Pakistan on the feasibility of renewable energy resources, suggests a priority order for the selection of renewable energy as an alternative energy source. They placed wind energy second in order, among other renewable energies on the basis of, technical, social, environmental and economic aspects [6]. To save investment by avoiding installation of wind driven pumps on inefficient location it is necessary to evaluate wind energy resources available on the desired location, and economic feasibility of the system is another matter of concern [7].

One of the classical use of wind energy is water pumping. Wind energy has been using for pumping water since centuries for dewatering (drain) of large-scale areas, in America and Australia, wind pumps are widely used for pumping water for livestock and irrigation to crops [8]. The most common type of wind pump is so-called American farm wind pump [9]. For this study a mechanically working wind-driven piston pump was used which have the following specification: multi blade Iron man windmills, 2.4 m diameter of the blades, a tower height of 10 m, and one pumping rod. For conducting this research, wind data were collected at the altitude of 10 m, which is usually the same stature of the installation of wind tower for wind pumps. The manufacturing of wind pumps has become an established industry and the use of wind-driven pumps has led to increased productivity and an improved water supply to rural areas. Additionally, the manufacturing and use of wind pumps are also making a contribution to industrial development [10].

The feasibility of the wind pumps to use as an alternative source of energy to irrigate greenhouse crops was evaluated based upon these factors, available wind resources on site, crop water requirement, cost of technology, greenhouse size, storage tank capacity, price of tomato in the market, elevation of water, planting dates of tomato. While making a decision about adoption of wind-driven pumps an important consequent need to be considered was to check the economic feasibility of wind pumps compared with the other sources of energy that have been used for the water pumping such as electricity from the grid, solar photovoltaic (PV) pumps and diesel engine. For economic analysis, LCOE (described in section 2.7) of each technology for each location was determined. In addition, IRR of the wind pumping at each location were determined to check the financial suitability of the system.

The Purposes of this study were, determine the potential of wind resources available at each selected location for the suitability of wind pumps to irrigate greenhouse crops. Determination of daily and monthly tomato crop evapotranspiration under different greenhouse sizes. Moreover, estimation of water pumped at different heights for the water budgeting of greenhouse crop and estimation of storage tank capacity. In addition, economic feasibility analyses of wind pumping based on input (installation cost + running and maintenance cost) and output (volume of water pumped), comparison with other sources of energy being utilized for water pumping.

2. Material and Methods

Fig.1 represents flowchart of the whole experimental procedure. The detail of the each step is mentioned in the corresponding section of the material and methods. And all types of analysis and mathematical calculations are performed by using Microsoft Excel- 2013.

2.1. Wind data analysis

Four locations were selected from three different regions of Asia and relevant wind data for these locations were obtained from local meteorological stations. The first site, Shouguang, is situated in the north of China and the wind data was obtained from the China Meteorological Association (CMA). Sargodha is located in centre of Punjab Province of Pakistan wind data was provided by the Punjab Meteorological Department (PMD). The other two locations Gimhae and Buan are in South Korea and for these locations wind data were obtained from the Korea Meteorological Association (KMA).

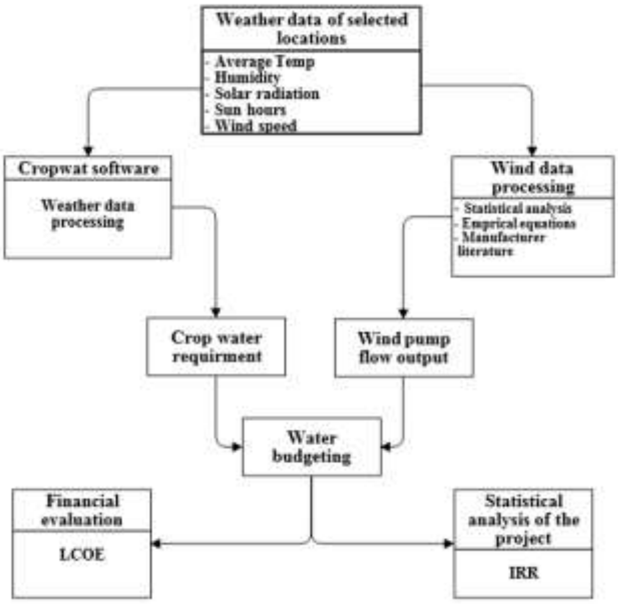

Fig. 1. Flowchart of experimental procedure.

Table 1 shows the particulars of the meteorological stations, type of sensors, measuring height at which the wind velocity was measured and the time series of the recorded data. Fig. 2 (a, b, c, d) shows the mean monthly wind velocity in m/s for all the locations.

The wind data were used to generate wind velocity histograms for each site by employing a particular methodology [12], and Weibull II distribution was applied to best estimate the wind situation and wind speed distribution function. Values of Weibull II distribution parameters k (shape factor) and c (scale factor) were used to simulate an average wind year, and low wind year using standard deviation of the data. Frequency histograms of the 2 hourly simulated wind velocities for an average year and Weibull distribution with scale and shape factor values are presented in Fig. 3 (a, b, c, d).

A methodology used by [11] was employed to downscale the average daily wind velocities to generate two-hourly wind velocities, the mathematical demonstration is as follows

$$W_h = W_{avg} + \tfrac{1}{2} W_{avg} \,\mathrm{COS}\,(h \cdot \pi) \qquad (1)$$

Where W_h is the wind speed at hour h, W_{avg} is the average wind velocity, and h is the number of hours. Several simulations were performed to get the mean two-hourly wind-velocity (W_{2h}) distribution, which was subsequently classified into eight frequency ranges of wind speed.

The purpose was to estimate the volume of water that could be pumped by utilizing the particular wind speed. The outcomes were used to ascertain the feasibility of wind-driven pumps for irrigation purposes, taking into account the water demand at the four test locations.

Table 1. Characteristics of meteorological stations

Location	Latitude/Longitude	Time series	Wind sensor	Measuring height (m)
Shouhuang (CMA)	44°60´N/125°40´E	2013-2014	OM-CP wind101A, Omega	10
Sargodha (PMD)	32°03´N/72°40´E	2011-2013	P2546A-L, Cambell	10
Gimhae (KMA)	35°13´N/128°50´E	2012-2014	JY-WS161B, Jingang	10
Buan (KMA)	35°43´N/126°71´E	2012-2014	JY-WS161B, Jingang	10

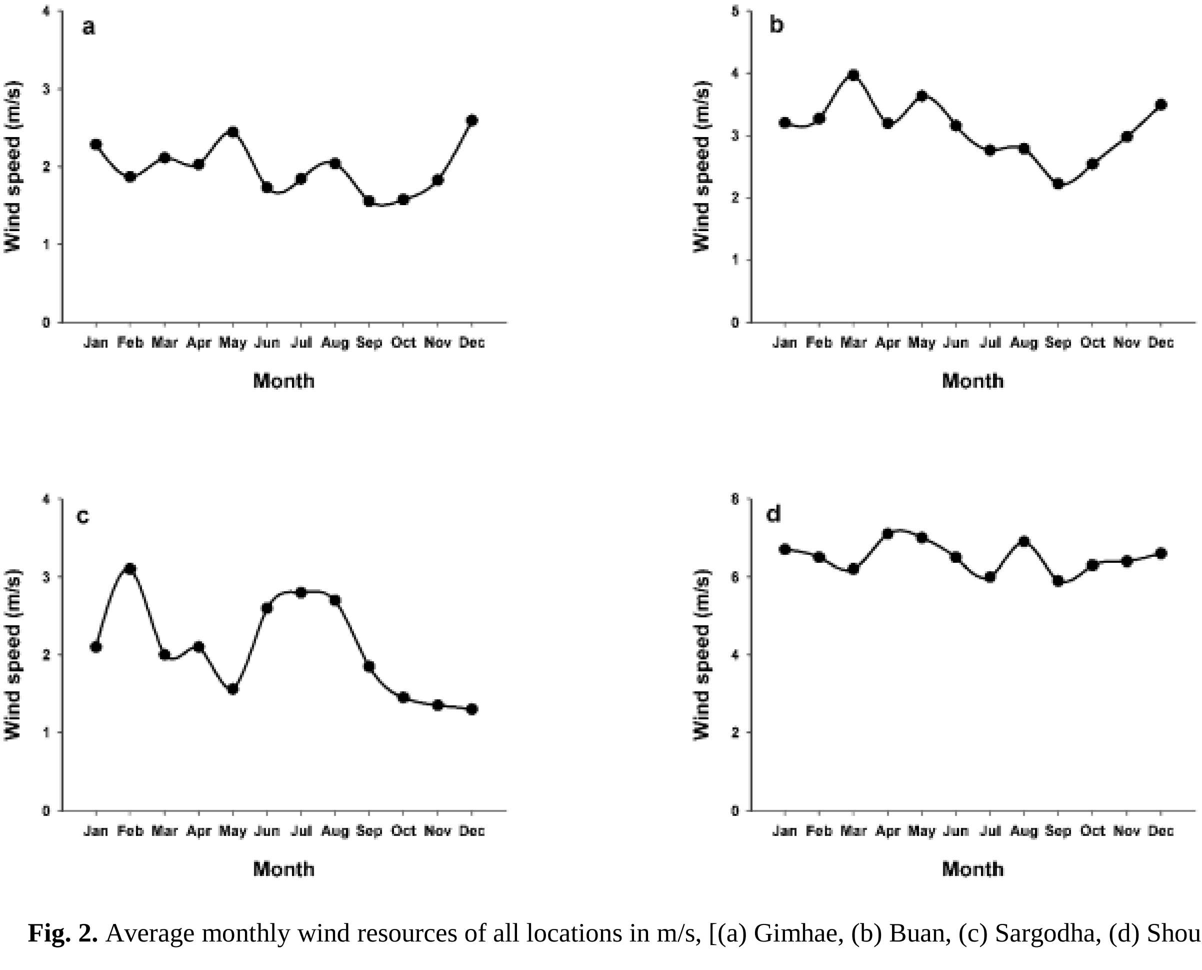

Fig. 2. Average monthly wind resources of all locations in m/s, [(a) Gimhae, (b) Buan, (c) Sargodha, (d) Shouguang]

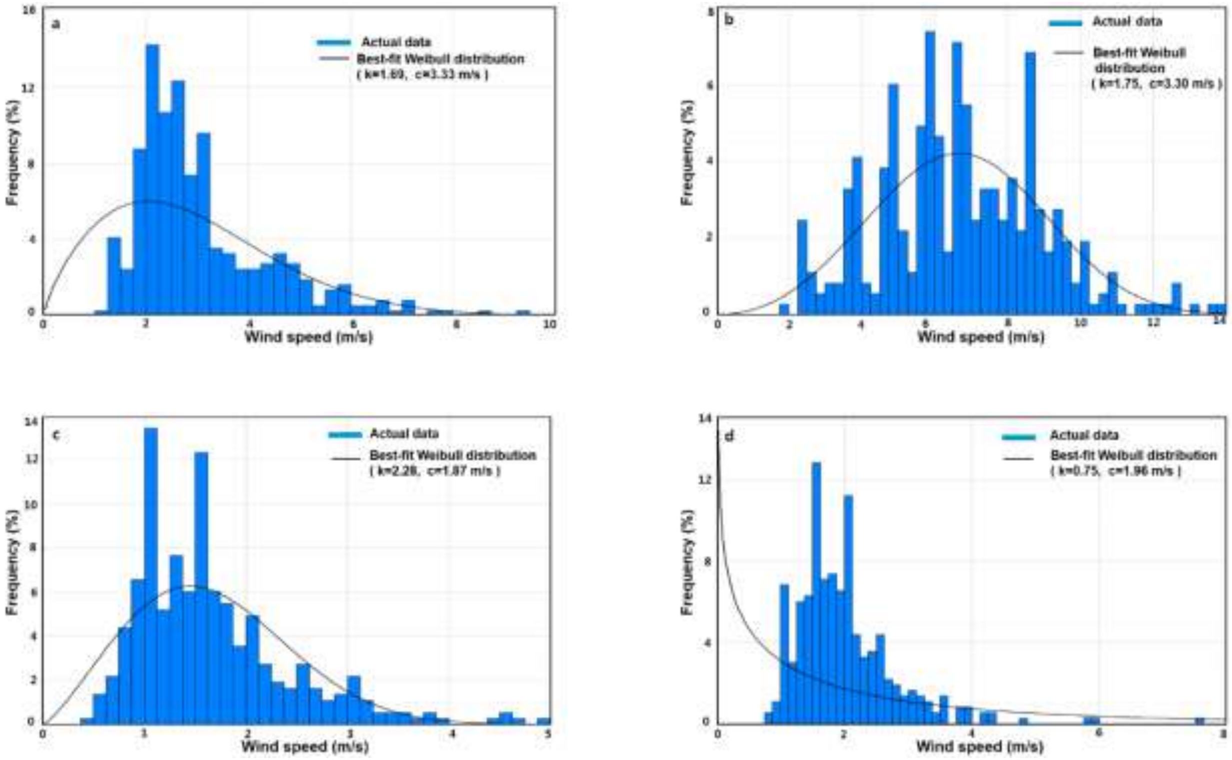

Fig. 3. Average two-hourly wind velocity (W_{2h}) frequency distribution with Weibull distribution at all selected locations. [(a) Buan, (b) Shouguang, (c) Sargodha, (d) Gimhae]

2.2. Size of greenhouses

Two different sized (the ordinary sizes of the greenhouses currently being constructed in South Korea) greenhouses, 1,000 m^2 and 6,500 m^2 were selected to conduct this research. Greenhouse sizes were specified to estimate their energy and power need (section 2.6) and crop evapotranspiration (section 2.4). We applied all analysis on selected greenhouses, to determine the effect of varying greenhouse size on the economic feasibility of wind pumping. Moreover, we have found out the potential of available wind resources to satisfy the water demand of selected greenhouses. We select one small and one average size of greenhouse currently being constructed in our selected locations. Fig. 4 shows the present situation of greenhouse sizes in South Korea on the basis of area covered and farm size [13].

2.3. Planting dates for tomato crop

To determine the accurate crop water requirement typical planting dates and duration (planting to harvesting) of the crop were considered. Table 2 shows the typical planting dates and duration of tomato crop for both growing seasons (Autumn and spring) at each selected location, duration is expressed in number of days and Planting dates are months of the year.

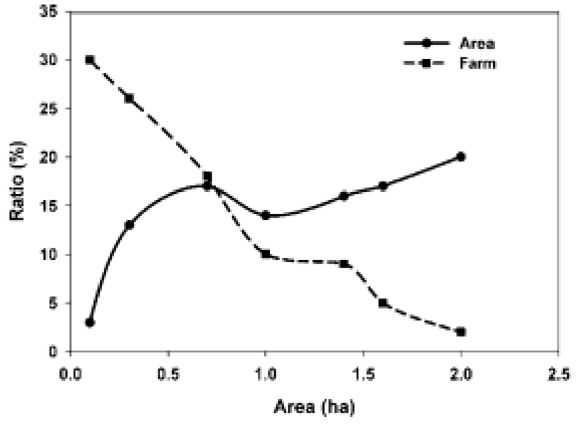

Fig. 4. The percentage of the greenhouse sizes, with respect to the farm and out area greenhouses

Table 2. Characteristics of meteorological stations

Location	Autumn crop		Spring crop	
	Planting date	Duration	Planting date	Duration
Shouguang	Oct	97	Jan	140
Gimhae, Buan	Aug	135	Jan	160
Sargodha	July/Aug/Sep	135	Dec/Jan	165

2.4. Determination of crop water needs

CROPWAT model was used to estimate the reference crop evapotranspiration (ET_o) outside of the greenhouse. Many researchers used CROPWAT model for the estimation of crop evapotranspiration and also validate the modelled results [14-18]. This model is considered very useful decision-making tool for the irrigation planning and management, irrigation scheduling, cropping pattern, crop yield, crop evapotranspiration, under various management and local weather conditions. The Model was designed by FAO (Food and Agriculture Organization) which uses Penman-Monteith (PM) equation for the calculation of ET_o [19]. The model requires following climatic parameters, air temperature (maximum and minimum), relative humidity, wind speed, and sunshine hours, as input. ET_o was multiplied by the crop factor (K_c) to get the crop evapotranspiration (ET_c) outside the greenhouse by using following relation:

$$ET_c = ET_o \cdot K_c \tag{2}$$

K_c is crop factor, its values lies between “0.45 to 1.05” depending upon the crop growth stage (initial, development or mid-season and mature stage).

The environment inside the greenhouse considered under completely controlled situation to support the optimum growth of the plants. Apart from other factors, irrigation management is also very important part of the controlled greenhouse environment. It was estimated that the irrigation required for the tomato crops inside the greenhouses was less than that outside of the greenhouse. On the basis of observed climate data inside the greenhouse the ET_c is 75-80% less than the outside ET_c. [20] by assuming the 80% reduction in ET_c, crop evapotranspiration inside the greenhouse $ET_c[g]$ for all the locations were calculated by the following equation:

$$ET_c[g] = 0.80 ET_c \tag{3}$$

Table 3 shows estimated daily and monthly evapotranspiration at each location, for the respective duration of the tomato crop season, in mm/day and mm/month respectively.

Table 4 shows the annual (for both spring and autumn seasons) irrigation requirement of tomato crop expressed in m^3/year. ET_c was estimated for 1000 m^2 and 6500 m^2 greenhouse sizes at all locations. Irrigation requirement was calculated for efficiency evaluation of our energy technologies.

2.5. Wind pump flow output

The volume of water pumped by the wind pump was estimated for different pumping heights and wind resources at each location. Discharge was calculated with the below mentioned empirical equations by the manufacturer-supplied literature. These equations have been used by [12, 21].

$$Q(10) = 16.00 \cdot \ln W - 13.47 \tag{4}$$

$$Q(12) = 09.13 \cdot \ln W - 07.34 \tag{5}$$

$$Q(15) = 07.31 \cdot \ln W - 06.08 \tag{6}$$

Where Q is discharge of water, litter/min and W is wind velocity, m/s.

These equations were used to calculate the hourly discharge in order to obtain the daily and monthly volume of water pumped by high low and medium wind velocity [22].

Table 5 shows the discharge of selected wind pump in m^3/year under available low, medium, and high wind speed at different elevation.

Table 4. Evapotranspiration of all locations, m^3/year

Location	$ET_c[g]$	$ET_c[g]$
	1,000 m^2	6,500 m^2
Shouguang	579	3,763
Gimhae	536	3,484
Buan	395	2,567
Sargodha	685	4,453

Table 5. Volume of water produced by wind pump, m^3/year

Location	10m	12m	15m
Shouguang	18,113	14,945	11,812
Gimhae	4,873	3,940	2,476
Buan	6,601	5,448	3,404
Sargodha	2,521	2,081	1,644

Table 3. Daily and monthly ET_o, mm

Month	Shouguang		Gimhae		Buan		Sargodha	
	Daily	Monthly	Daily	Monthly	Daily	Monthly	Daily	Monthly
Jan	1.48	45.83	1.68	52.02	0.66	20.61	1.29	40.05
Feb	1.75	48.94	1.59	44.57	0.94	26.39	2	56.12
Mar	2.17	67.24	2.32	71.97	1.74	53.93	3.13	97.18
Apr	3.59	107.80	3.46	103.72	2.71	81.43	4.42	132.7
May	5.08	157.52	4.85	150.42	3.99	123.84	5.81	179.96
Jun	4.67	140.17	3.82	114.5	3.52	105.56	7	209.96
Jul	5.95	184.31	4.44	137.71	3.44	106.71	6.33	196.26
Aug	4.60	142.55	3.28	101.62	2.86	88.61	4.75	147.21
Sep	2.95	88.61	3.32	99.72	2.76	82.82	3.83	114.94
Oct	2.06	63.93	2.66	82.47	1.9	58.79	4.14	128.27
Nov	1.56	46.77	1.99	59.77	1.18	35.32	2.2	65.98
Dec	0.84	26.19	1.66	51.39	0.72	22.39	1.28	39.77

2.6. Water Budgeting

Daily water demand and volume of water pumped by the wind pump was used for the water budgeting of greenhouse crop to estimate the storage tank volume. The maximum value of the annual cumulative deficit is considered capacity of the storage tank, to ensure the regular supply of the water [23, 24] . We estimate the storage tank volume for all the locations under different scenarios of the water pumping, results presented in section 3. Table 6 shows an example of the water budgeting in Sargodha for 6,500 m^2 greenhouse. The daily volume of water pumped in the month of July was computed with the daily 19.8 m^3 of water demand (calculated in m^3/day by using daily ET$_o$ value in mm) to estimate the cumulative deficit of water for this month.

2.7. Power and energy needs

Power and energy demand were estimated for, selection of the pump capacity to satisfy annual crop water requirement, financial and technical assessment of the systems. After determining the annual crop water requirement for the tomato crop (section 2.4) the energy demand for pumping (EC) in kWh/year and minimum power (EP) in kW were determined for selected greenhouse sizes for all locations by using the following equations [21].

$$\mathrm{EC} = \frac{\rho \cdot g \cdot \mathrm{WN} \cdot \mathrm{H}}{3.6 * 10^6 \cdot \eta} \tag{7}$$

$$\mathrm{EP} = \frac{\mathrm{EC}}{\mathrm{D} \cdot \mathrm{t}} \tag{8}$$

Where ρ is the water density, H is the pumping height or elevation of water needs to be pumped, WN is the crop water requirement, η is the average efficiency, t is the irrigation time/day, D is the number of days/year and g is the gravitational acceleration. Table 7 shows the EC (kWh/year) for different pumping technologies and different greenhouse sizes, considering fixed water elevation 10 m for all locations. The EP was calculated over energy demand 3 h (t) per day and 365 days (D) per year. The values of η for wind pumps, PV pumps and diesel pumps were as follows ηw =0.25, ηpv = 0.39, ηd =0.75. For the financial assessment 2 kW of pump for all technologies was considered, as we select maximum value according to our water requirement.

2.8. Financial assessment of wind pumps

For financial assessment of energy systems, the concept of levelized cost of energy [25] was used. The purpose of the assessment was to determine the ability of renewable energy source to meet the annual irrigation requirement of the crop in terms of cost per unit of energy. LCOE was used to compare the energy generation costs of the renewable resource with that of the standard fossil-fuel [26].

Table 7. Energy demand for pumping (EC), kWh/year

Location	Pump type	EC	
		6,500 m^2	1,000 m^2
Shouguang	Wind pump	470	72
	PV pump	301	46
	Diesel pump	294	45
Gimhae	Wind pump	378	58
	PV pump	242	37
	Diesel pump	236	36
Buan	wind pump	278	42
	PV pump	178	27
	Diesel pump	174	26
Sargodha	Wind pump	483	74
	PV pump	310	47
	Diesel pump	302	46

Table 6. Sample of water budgeting to compute 19.8 m^3 of daily demand, m^3

Day	Discharge by wind pump	Deficit	Surplus	Cumulative deficit	Day	Discharge by wind pump	Deficit	Surplus	Cumulative deficit
1	12.4	7.3		7.3	17	4.5	15.2		151.1
2	0	19.8		27.1	18	7.6	12.2		163.2
3	10.6	9.2		36.2	19	22.7	-	3	160.3
4	12.4	7.3		43.6	20	12.4	7.3		167.6
5	22.7	-	3	40.6	21	10.6	9.2		176.8
6	30.9	-	11.1	29.5	22	39.1	-	19.3	157.5
7	10.6	9.2		38.6	23	6.1	13.7		171.2
8	26	-	6.3	32.4	24	1.5	18.2		189.4
9	0	19.8		52.1	25	12.4	7.3		196.7
10	0	19.8		71.9	26	7.6	12.2		208.9
11	1.5	18.2		90.1	27	10.6	9.2		218.1
12	16	3.7		93.8	28	0	19.8		237.8
13	4.5	15.2		109	29	0	19.8		257.6
14	10.6	9.2		118.2	30	0	19.8		277.3
15	9.4	10.4		128.5	31	0	19.8		297.1
16	12.4	7.3		135.9					

In this study, comparison of LCOEs was made between different sources of energy; wind-driven pump, electricity from the grid, PV photovoltaic pump, and diesel pump for irrigation. Table 8 shows the initial costs of different technologies and other variables used for calculation of LCOE. There is no absolute standard as to which costs are included in O&M cost, O&M cost frequently recurring labour and material cost. These costs were estimated according to the suggestion of the cited manual [27]. Table 9 shows the maintenance cost of each technology for financial assessment; maintenance cost is expressed in fraction of the capital cost. Equation (9) demonstrates the relationship used to calculate the LCOE of above mentioned energy technologies.

$$\mathrm{LCOE} = \frac{\mathrm{I} \cdot \mathrm{FCR}}{\mathrm{Q}} + \frac{\mathrm{O\&M}}{\mathrm{Q}} \tag{9}$$

FCR is the fixed charge rate, I is the initial investment, O&M is the annual operation and management cost, Q is the annual output.

$$\mathrm{FCR} = \frac{\mathrm{d} \cdot (1+\mathrm{d})^{\mathrm{n}}}{(1+\mathrm{d})^{\mathrm{n}}-1} \tag{10}$$

Where n is the period of analysis, d is the annual discount rate, the value used for discount rate was 0.05.

2.9. Internal rate of return

The intention to perform this financial analysis was to check the project's worth in terms of the profit. The total cost of technology is the sum of initial capital cost, maintenance, and operational cost. The life cycle of wind-driven pumps is 20 years [27]. The internal rate of return was determined by the following expression [8]:

$$\mathrm{B_A} \cdot \left[\frac{(1+\mathrm{IRR})^{\mathrm{n}}-1}{\mathrm{IRR} \cdot (1+\mathrm{IRR})^{\mathrm{n}}}\right] = \mathrm{C_I} + \mathrm{OM} \cdot \left[\frac{(1+\mathrm{IRR})^{\mathrm{n}}-1}{\mathrm{IRR} \cdot (1+\mathrm{IRR})^{\mathrm{n}}}\right] \tag{11}$$

Where IRR is the internal rate of return, C_I is initial cost, B_A is annual benefit, OM is annual operational and maintenance cost, n is no. of years.

The annual benefit is the cost of total volume of water pumped by the wind pumping system equivalent to that of electricity.

3. Results and Discussion

The initial results showed that the LCOEs associated with electricity from the grid and diesel pumping is lower than that is associated with the renewable energy systems (wind pumps and PV pumping), as initial cost associated with the renewable energies was high. Fig. 5 indicates the LCOE associated with each technology for all the selected locations.

Buan and shouguang are the locations situated near the ocean and is an area reclaimed for agriculture, but currently there is no grid connection. Pakistan has been experiencing energy shortage for the past decade, although grid connections are well distributed over a maximum area, but some rural areas still do not have access to electrical power. For these areas, renewable energy could therefore be the best option. So further analyses were done to verify the feasibility of adopting wind technology at these locations.

The wind resources found in Shouguang are very strong throughout the year and Buan average wind situation is good enough to meet the feasibility requirement for the use of wind pumping.

Table 10 shows the LCOE associated with wind resources expressed in total number of hours per year, by increasing the number of hours the levelized cost of energy would therefore decrease. Fig. 6 shows that the water elevation has significant influence on pumping water output as well as LCOE, water elevation is a crucial factor needs to be considered while taking decision to adopt wind pumps.

Fig. 7 shows the LCOE of wind energy relevant to the greenhouse size, which is another significant factor to be looked at, as LCOE for the small size greenhouse is high, the economic evaluation between input and output of wind pumping does not satisfy the feasibility recruitments to use small size 1,000 m^2 greenhouses.

Table 8. Capital cost of different technologies and variables for each country

Technology	Symbol	Unit	China	South Korea	Pakistan
Wind pump	P_w	$/pump	2,300	3,000	2,675
PV pump	P_s	$/pump	2,250	2,700	2,500
Diesel pump	P_{dp}	$/W	1.28	1.63	1.20
Price of diesel	P_d	$/L	1.2	1.1	0.92
Price of electricity	P_e	$/kWh	0.12	0.62	0.18

Table 9. Maintenance cost of each technology

Annual Maintenance cost	Unit	China	South Korea	Pakistan
Wind pump	Fraction	0.02	0.03	0.02
PV pump	Fraction	0.02	0.03	0.01
Diesel pump	Fraction	0.08	0.06	0.09
Grid connection	Fraction	0.02	0.02	0.02

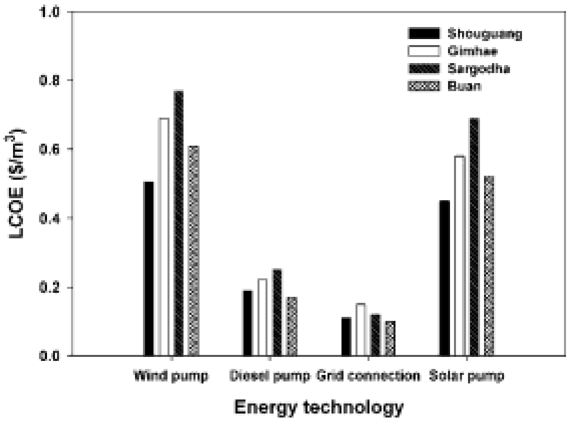

Fig. 5. LCOE ($/m^3) associated with all technologies for all locations to meet the annual crop water requirements

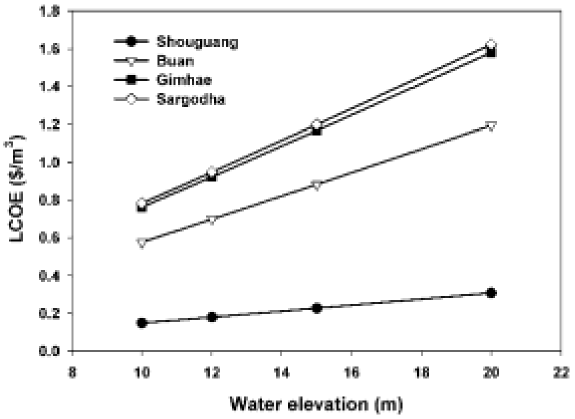

Fig. 6. LCOE ($/m^3) of wind pumping relevant to the water elevation for all selected locations

In Sargodha and Gimhae wind resources are scarce, and as the price of diesel and electricity is low in this situation conventional source would be the preferred options if available on the site level. Nevertheless, in view of the scarcity of electricity in Pakistan, employing wind pumping for crop irrigation in medium-size greenhouse could be an option relevant to the volume of water that needs to be supplied. Moreover, this option would be economically feasible because of the high price of tomatoes in Pakistan, and after the payback period using a renewable source can provide energy for the greenhouse irrigation system at a minimum levelized cost of energy than that of others conventional systems [29] . The outcomes of the analysis indicate that electricity from the grid, if available, would be the best option for Gimhae (South Korea) according to the current scenarios.

The storage tank is required for the storage of water to make sure the water supply throughout the year to fulfil the water demand of crops in less water-pumping periods. Table 11 shows storage tank capacity under four different scenarios; scenario 1 is for maximum pumping of water under available wind resources, scenario 2 is if the pumping water decrease of 30%, scenario 3 is if pumping water decrease to 50%, scenario 4 is if pumping water decrease to 70 %. Table 11 shows the effect of decreasing volume of water pumped on storage tank capacity. In Shouguang as volume of water is excess thorough out the year, according to our need, so we can fulfil our water demand even with no storage tank, but we can save water in the storage tank to irrigate more land.

Fig. 8 shows the monthly excessive and less volume of water to meet the annual water requirement. Results show that Shouguang and buan have excessive water after fulfilling of water demand of 6,500 m^2 of greenhouse. Gimhae and Sargodha have less water to satisfy the crop water demand in some months.

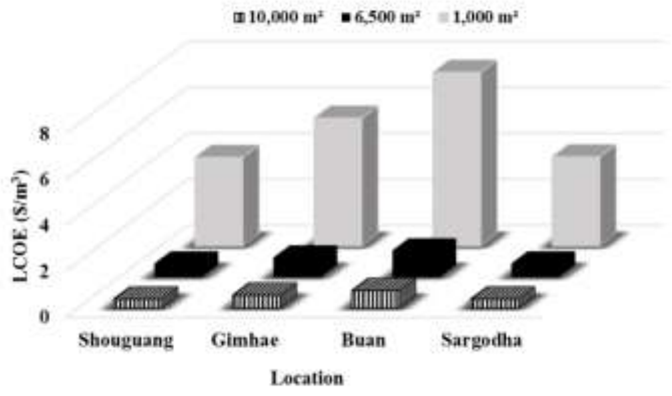

Fig. 7. Levelized cost of energy ($/m3) of wind pumping associated with different greenhouse sizes for all selected locations

Table 11. Storage tank capacity, m^3

Location	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Sargodha	2,372	2,996	3,413	3,829
Buan	-	-	-	935
Gimhae	-		1,533	2,321
Shouguang	-	-	-	-

Table 10. LCOE ($/m^3) of wind pumps relevant to the different wind resources at fixed elevation for 6,500 m^2 of greenhouse size

Height (m)	Country	Location	Wind resources (hr)					
			1,695	1,950	2,580	3,096	3,405	5,502
15	China	Shouguang	1.01	0.87	0.66	0.55	0.5	0.22
15	Korea	Gimhae,Buan	1.34	1.16	0.88	0.73	0.66	-
15	Pakistan	Sargodha	1.19	1.04	0.78	0.66	0.59	-

Therefore, we need a storage tank to save excessive water and to utilize it in low pumping period or more area can be irrigated with the excessive stored water at Shouguang and Buan. Fig. 9 shows the maximum irrigable area which can be irrigated with the available water at each location. Moreover, shows the trend of decreasing irrigable area with the increase in water elevation.

Although the LCOE is low for the other technologies, e.g., diesel pumping and electricity from the grid, this advantage is offset by the high operational and maintenance costs required for the entire operating period. In contrast, the renewable energy sources, wind and sunlight, required an initial high capital outlay but, thereafter, the maintenance cost was minimal and there were no operational costs [30].

Table 12 exhibits the internal rate of return of the wind pumping system at each location depending on input (total investment) and output (volume of water pumped). Financial analysis (section 2.9) shows IRR of wind-driven pumping system at Buan was highest among others, which means that this location is financially most profitable. Shouguang and Gimhae have similar values, and Pakistan has the lowest value of internal rate of return. The initial cost, operating & maintenance cost and electricity price at Buan and Gimhae were same, but high difference between IRR at both locations were because of the high volume of water pumped due to high wind speed at Buan comparing with Gimhae. Volume of water pumped at Shouguang was very high, but due to low electricity price internal rate of return is less than Buan. Pakistan is least in merit due to the low value of IRR because of low wind speed and electricity price.

Table 12. Internal rate of return, %

Location	Internal rate of return (IRR)
Gimhae	4.4
Buan	10
Shouguang	5.2
Pakistan	Below 1.0

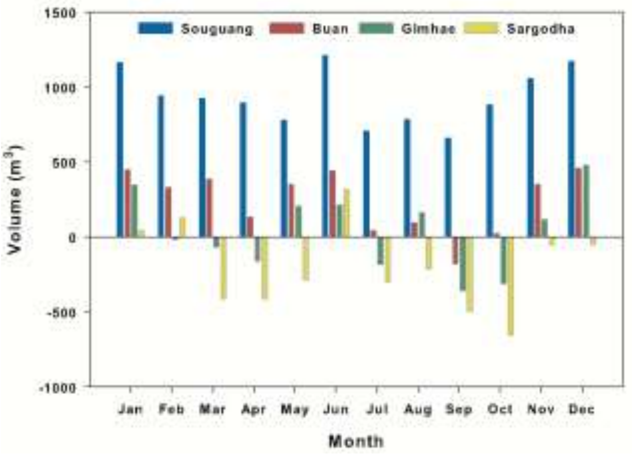

Fig. 8. Variation between supply and demand

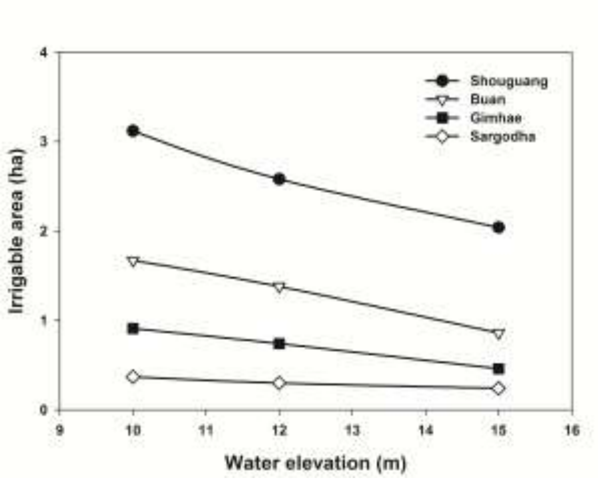

Fig. 9. Irrigable area by using wind pump under available wind resource

4. Conclusion

A simple methodology was used to assess the wind energy potential and economic feasibility of wind-driven pump as a long-term source of energy for the greenhouse irrigation system. This evaluation was made out by considering several factors such as, available wind resources at all selected sites, cost of technology, greenhouse size, crop water requirements, water storage-tank capacity, water elevation, price of tomato in the market, and growing season and duration of the tomato crop. The outcomes exhibits that the while taking decisions, the size of the greenhouse and the elevation of the water are the important factors be considered, along with the available wind resources. The conditions related to the wind in Shouguang (China) and Buan (South Korea) were suitable, i.e., wind resources were high enough for the use of a wind pump. Taking into account all the factors that influence the use of wind pumps, it could be a smart choice, as after the payback period, no costs were incurred to receive the water required for the crops.

In Sargodha (Pakistan) and Gimhae (South Korea), the average wind resources are inadequate. However, for the medium-size greenhouses, the wind-driven pumps are able to attain the required output to meet the annual water demand for the crops. In addition, it is a suitable option to face electricity shortage in rural areas. We determined storage tank capacity under different risk levels of water pumping, to guarantee the continuous water supply when there is no pumping because of low wind speed. We determined the internal rate return of the wind pumping system at each location.

References

[1] R. C. D. M. Pires, P. R. Furlani, R. V. Ribeiro, D. Bodine Junior, E. Sakai, A. L. Lourenção, et al., "Irrigation frequency and substrate volume effects in the growth and yield of tomato plants under greenhouse conditions", Scientia Agricola, vol. 68, pp. 400-5, 2011. (Article)

[2] G. C. Rodrigues, L. S. Pereira, "Assessing economic impacts of deficit irrigation as related to water

productivity and water costs", Biosystems Engineering, vol. 103, pp. 536-51, 2009. (Article)

[3] M. Loura, Study: Plastic greenhouse in china, 2013, pp. (Electronic Article)

[4] R. V. U. Marcel Stallen, Greenhouse sector study South Korea, 2006, pp. 52. (Electronic Article)

[5] S. Ali, M. Q. Mustafa, I. A. Shahbazi, "Agriculture value added and income inequality in Pakistan: a time series analysis", Ali, S, Mustafa, MQ, & Shahbazi, IA (2013) Agriculture Value Added and Income Inequality in Pakistan: A Time Series Analysis Research Journal of Economics, Business and ICT, vol. 8, pp. 25-33, 2013. (Article)

[6] M. Amer, T. U. Daim, "Selection of renewable energy technologies for a developing county: A case of Pakistan", Energy for Sustainable Development, vol. 15, pp. 420-35, 2011. (Article)

[7] A. Vardar, O. Taşkin, "Technical and economic evaluation of energy production from wind in Istanbul and surrounds", Journal of Energy in Southern Africa, vol. 26, pp. 64-9, 2015. (Article)

[8] M. Sathyajith, Wind Energy Fundamentals, Resource Analysis and economics, New york: Springer, 2006. (Book)

[9] R. Allen, L. Peirera, D. Raes, M. Smith. Crop evapotranspiration. FAO irrigation and drainage paper no. 56, FAO, Rome. 2015.

[10] L. M. Kamp, L. F. Vanheule, "Review of the small wind turbine sector in Kenya: Status and bottlenecks for growth", Renewable and Sustainable Energy Reviews, vol. 49, pp. 470-80, 2015. (Article)

[11] Z. Guo, "A simple method to downscale daily wind statistics to hourly wind data", arXiv preprint arXiv:13053367, vol., pp., 2013. (Article)

[12] M. Peillón, R. Sánchez, A. M. Tarquis, J. L. García-Fernández, "The use of wind pumps for greenhouse microirrigation: A case study for tomato in Cuba", Agricultural Water Management, vol. 120, pp. 107-14, 2013. (Article)

[13] K. H. Han, Y. S. Jang, D. B. Lee, "Development of agriculture facility or greenhouse farmland ", Korean national Committe of irrigation and dranige vol., pp. 34-42, 2013. (Article)

[14] N. M. Abdalla, X. Zhang, A. Ishag, H. Gamareldawla, "Estimating reference evapotranspiration using CROPWAT model at Guixi Jiangxi Province", State Key Laboratory of Hydrology and Water Resources and Hydraulic Engineering, Hohai University, China, vol., pp., 2010. (Article)

[15] Z. Feng, D. Liu, Y. Zhang, "Water requirements and irrigation scheduling of spring maize using GIS and CropWat model in Beijing-Tianjin-Hebei region", Chinese Geographical Science, vol. 17, pp. 56-63, 2007. (Article)

[16] P. Najafi, "Assessment of CropWat model accuracy for estimating potential evapotranspiration in arid and semi-arid region of Iran", Pakistan journal of biological sciences : PJBS, vol. 10, pp. 2665-9, 2007. (Article)

[17] G. Stancalie, A. Marica, L. Toulios, "Using earth observation data and CROPWAT model to estimate the actual crop evapotranspiration", Physics and Chemistry of the Earth, Parts A/B/C, vol. 35, pp. 25-30, 2010. (Article)

[18] A.-K. Bouraima, Z. Weihua, W. Chaofu, "Irrigation water requirements of rice using Cropwat model in Northern Benin", International Journal of Agricultural and Biological Engineering, vol. 8, pp. 58-64, 2015. (Article)

[19] N. Katerji, G. Rana, "FAO-56 methodology for determining water requirement of irrigated crops: critical examination of the concepts, alternative proposals and validation in Mediterranean region", Theoretical and applied climatology, vol. 116, pp. 515-36, 2014. (Article)

[20] Harmanto, V. M. Salokhe, M. S. Babel, H. J. Tantau, "Water requirement of drip irrigated tomatoes grown in greenhouse in tropical environment", Agricultural Water Management, vol. 71, pp. 225-42, 2005. (Article)

[21] R. Díaz-Méndez, A. Rasheed, M. Peillón, A. Perdigones, R. Sánchez, A. M. Tarquis, et al., "Wind pumps for irrigating greenhouse crops: Comparison in different socio-economical frameworks", Biosystems Engineering, vol. 128, pp. 21-8, 2014. (Article)

[22] S.-E. Gryning, E. Batchvarova, R. Floors, A. Peña, B. Brümmer, A. N. Hahmann, et al., "Long-term profiles of wind and Weibull distribution parameters up to 600 m in a rural coastal and an inland suburban area", Boundary-layer meteorology, vol. 150, pp. 167-84, 2014. (Article)

[23] M. Raju, A. Kumar, D. Bisht, D. Rao, "Stochastic Analysis of Wind Energy for Wind Pump Irrigation in Coastal Andhra Pradesh, India", Journal of The Institution of Engineers (India): Series A, vol. 95, pp. 157-68, 2014. (Article)

[24] M. M. Alam, A. K. Azad, "Unusual wind speed pattern of Sitakunda, a windy coastal location of Bangladesh", International Journal of Advanced Renewable Energy Research, vol. 1, pp. 89-94, 2012. (Article)

[25] J. Hernández-Moro, J. Martínez-Duart, "Analytical model for solar PV and CSP electricity costs: Present LCOE values and their future evolution", Renewable and Sustainable Energy Reviews, vol. 20, pp. 119-32, 2013. (Article)

[26] K. Branker, M. J. M. Pathak, J. M. Pearce, "A review of solar photovoltaic levelized cost of electricity", Renewable and Sustainable Energy Reviews, vol. 15, pp. 4470-82, 2011. (Article)

[27] W. Short, D. J. Packey, T. Holt. A manual for the economic evaluation of energy efficiency and renewable energy technologies: University Press of the Pacific; 2005. (Book)

[28] D. Watts, D. Jara, "Statistical analysis of wind energy in Chile", Renewable Energy, vol. 36, pp. 1603-13, 2011. (Article)

[29] M. A. Hossain, M. S. Hassan, M. A. Mottalib, M. Hossain, "Feasibility of solar pump for sustainable irrigation in Bangladesh", International Journal of Energy and Environmental Engineering, vol. 6, pp. 147-55, 2015. (Article)

[30] K. Meah, S. Ula, S. Barrett, "Solar photovoltaic water pumping—opportunities and challenges", Renewable and Sustainable Energy Reviews, vol. 12, pp. 1162-75, 2008. (Article)

Nomenclature

The following symbols are used in this study

W_h	wind velocity at h hour, m/s
W_{avg}	average wind velocity, m/s
h	number of hours
$	US dollar
ET	evapotranspiration
ET_c	ET of Crop, mm/day
ET_o	ET of reference crop, mm/day
K_c	crop factor, dimensionless
$ET_c[g]$	ET of crop under greenhouse, mm/day
LCOE	levelized cost of energy, $/m^3 of water
H	height, m
WN	total irrigation requirement, mm/year
EC	energy demand in kWh/year
EP	minimum power in kW
D	number of days
t	time
I	initial investment, $
FCR	fixed charged rate
O&M	operation and maintenance cost, $
Q	annual output, m^3
L	liter
n	period of analysis, no. of years
PV	photovoltaic
CMA	China Meteorological Administration
PMD	Punjab Meteorological Department
KMA	Korean Meteorological Administration
d	annual discount rate
W	wind velocity, m/s
η	pump efficiency, dimensionless
ηw	wind pump efficiency, 0.25
ηPV	photovoltaic solar-pump efficiency, 0.39
ηd	diesel pump efficiency, 0.75
ρ	water density, kg/m3
K	shape parameter of Weibull distribution
C	scale parameter of Weibull distribution
P_w	price of wind pump, $/pump
P_s	price of solar pump, $/pump
P_d	price of diesel pump, $/W
P_d	price of diesel, $/Liter
P_e	price of electricity, $/kWh
C_I	initial cost, $
B	annual benefit, $
IRR	internal rate of return, %