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Solar photovoltaic pump sets as a substitute for conventional pump sets

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The growing energy demand for feeding the ever-increasing population has triggered the issue of energy security. This has made it essential to utilize the untapped potential of renewable resources. Punjab, India, has great potential of generating solar energy. In the present study, the cost of running electrical and diesel tube wells has been estimated along with the cost of replacement of the conventional pump sets with solar photovoltaic (SPV) pump sets. It was found that the cost of running the electric and diesel-operated pump sets for shallow and medium tube wells was almost Rs 73.9 million per year. If these are replaced by SPV pump sets, then installation cost of the latter is Rs 212.71 billion without subsidy. According to the Government scheme, the farmer's share is Rs 96.18 billion and the Government share is Rs 132.71 billion. Further, with replacements using the solar pumping system, green energy will be available and additional energy can be released into the grid system. This might be especially true for a state like Punjab, where 30–35% electricity is consumed in the agricultural sector for irrigating about 72% of the total irrigated area (99%) through groundwater pumping. The cost of SPV pump sets is expected to reduce as it is gaining popularity. Also, with the advancement of technology, electronic goods are becoming cheaper and compact.

Keywords: Energy demand, renewable resources, solar photovoltaic pumps, tube wells.

IRRIGATION has played a major role in the agricultural growth of Punjab, India, and a substantial share of irrigation is contributed by minor irrigation schemes across the state. As stated in the Fifth Minor Irrigation (MI) Census Report of India, there are 1,120,963 MI schemes in Punjab, accounting for 5% of the total MI schemes in the country[1]. Also, Punjab is a leading state in the use of shallow, medium and deep tube wells. The number of shallow (0–35 m), medium (35–70 m) and deep (70–150 m) tube wells in Punjab is 248,655, 384,707 and 485,378 respectively, with a total of 1,118,740 MI schemes in the state that use groundwater as a source[1]. Among these schemes, 1,068,914 are electric pumps, 48,052 diesel pumps, 192 wind mill pumps, 106 solar pumps and 1503 use other sources of energy for lifting groundwater.

Electricity in Punjab is generated in various plants with the burning of coal. A large amount of electricity is used for running pumps. So a large quantity of coal is being burnt on a daily basis to meet the energy demands, which further leads to a huge amount of carbon emissions in the state. The number of diesel pumps in Punjab is also high and therefore, a large amount of carbon emissions comes from diesel being burnt to run pumps on a daily basis. The oil stock of the world is being depleted at a fast pace and we will run out of oil in the next four decades. Coal will be exhausted in about 140 years. Switching to solar energy can help slow down the depletion of coal and oil stock. Further, these resources will be available for use for a longer period and for critical needs, when other alternatives are not viable. So, there is a need of replacing the power generated by electricity and diesel with solar photovoltaic (SPV) energy. The Ministry of New and Renewable Energy (MNRE), Government of India (GoI) is promoting the use of solar energy for irrigation in the agriculture sector. It has launched the Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan (PM-KUSUM) scheme with the aim of providing energy security to the farmers, increase their income, and conserve fossil fuels and protect the environment. The Government of Punjab decided to implement the scheme by providing 30% subsidy to the general category farmers and 50% to farmers from the scheduled caste over and above the 30% GoI subsidy under the funding pattern CS (centre scheme) : SS (state scheme) : Benf (beneficiary) = 30 : 30 : 40 and

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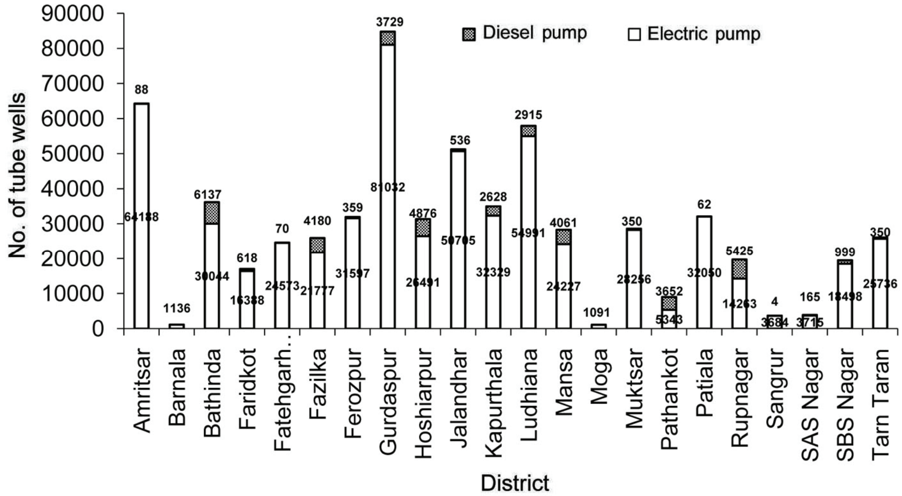

Figure 1. Distribution of shallow and medium tube wells (no.) based on energy source.

Table 1. Distribution of shallow and medium tube wells (no.) according to horsepower (hp), in Punjab, India

District	No. of tube wells based on hp						
	0–2	2–4	4–6	6–8	8–10	>10	Total
Amritsar	147	165	6,371	48,345	203	9,045	64,276
Barnala	0	3	13	83	0	1,037	1,136
Bathinda	260	102	940	10,638	1,035	23,206	36,181
Faridkot	50	122	8,696	3,420	2,783	1,935	17,006
Fatehgarh Sahib	35	63	393	3,698	1	20,453	24,643
Fazilka	164	1,781	11,746	3,929	2,614	5,723	25,957
Ferozpur	28	1,543	15,016	8,184	262	6,923	31,956
Gurdaspur	150	28,840	24,857	26,377	3,705	832	84,761
Hoshiarpur	104	5,179	8,239	6,123	9,005	2,717	31,367
Jalandhar	41	984	5,136	14,233	398	30,449	51,241
Kapurthala	136	5,753	6,590	10,765	4,306	7,407	34,957
Ludhiana	110	4,813	16,276	16,778	4,052	15,877	57,906
Mansa	249	74	1,140	5,540	3,116	18,169	28,288
Moga	1	2	18	127	0	943	1,091
Muktsar	27	1,032	24,018	1,823	950	756	28,606
Pathankot	20	3,053	1,514	1,433	2,917	58	8,995
Patiala	48	65	1,182	2,057	274	28,486	32,112
Rupnagar	266	2,038	3,115	7,262	2,443	4,564	19,688
Sangrur	2	2	7	396	7	3,274	3,688
SAS Nagar	38	101	1,197	1,053	112	1,379	3,880
SBS Nagar	39	348	3,337	10,926	974	3,873	19,497
Tarn Taran	28	32	533	13,862	648	10,983	26,086
State total	1,943	56,095	140,334	197,052	39,805	198,089	633,318

Source: refs 4, 9.

30 : 50 : 20 respectively. The scheme is applicable in safe groundwater blocks for pumping groundwater, while in dark groundwater blocks this scheme is applicable for lifting water from village ponds, tanks and canals[1].

The earth and its atmosphere continuously receive 1.7×10^{17} W of radiation from the sun. The mean extraterrestrial radiation normal to the solar beam on the outer fringes of the earth's surface is called the solar constant. The average value of solar constant is 1.366 kW m^2 (ref. 2). So, if a SPV cell is installed in 1 m^2 area with 15% efficiency, it will produce 0.20 kW of energy. If the area is 5 m^2, then it will produce about 1.0 kW of energy which is equivalent to about 1.3 horsepower (hp) and the electricity generated will be 1.0 kWh. India has tremendous scope for generating solar energy. The reason being its geographical location and also it receives solar radiation almost throughout the year, which amounts to 3000 h of sunshine. This is equal to more than 5000 trillion kWh. Almost all parts of India receive 4–7 kWh of solar radiation per m^2 (ref. 3).

The solar energy is a renewable source and requires negligible cost for the operations of solar pump sets. Solar energy can be considered as the most feasible, cheap and the best form of energy which can be used to run pumps. Further it will be a relief for Punjab Government as it provides 100% subsidized electricity for pumping the irrigation water. Therefore, a study was undertaken for estimating potential energy and cost-saving by replacing diesel and electric operated irrigation pump sets with SPV pump sets.

Data on shallow and medium tube wells were collected from various State and Central agencies. The tube well depth of 0–35 was considered as shallow and 35–70 m as medium[4].

Various energy sources are being used for the operation of pumps in Punjab and the hp of these pump sets is also different. Figure 1 shows the distribution of pump sets based on energy use. Table 1 gives district-wise information of shallow and medium tube wells based on hp[4].

Table 2. Proportion of electric and diesel pump sets in Punjab

District	Electric pump (%)	Diesel pump (%)
Amritsar	99.86	0.14
Barnala	100.00	0.00
Bathinda	83.04	16.96
Faridkot	96.37	3.63
Fatehgarh Sahib	99.72	0.28
Fazilka	83.90	16.10
Ferozpur	98.88	1.12
Gurdaspur	95.60	4.40
Hoshiarpur	84.46	15.54
Jalandhar	98.95	1.05
Kapurthala	92.48	7.52
Ludhiana	94.97	5.03
Mansa	85.64	14.36
Moga	100.00	0.00
Muktsar	98.78	1.22
Pathankot	59.40	40.60
Patiala	99.81	0.19
Rupnagar	72.45	27.55
Sangrur	99.89	0.11
SAS Nagar	95.75	4.25
SBS Nagar	94.88	5.12

Table 3. Water requirement for various crops

Crop	Water requirement (mm)
Wheat	400
Rice	1400
Maize	400
Fruit crops	800
Pulses	300
Fodder crops	600
Cotton	400
Vegetables	500
Oilseeds	300
Sugarcane	1600
Others	400

Source: ref. 9.

The farmers use electrical as well as diesel pump sets for irrigating their crops. Table 2 shows the proportion of electric and diesel pump sets used for determining the energy consumption. Table 3 gives the crop-wise water requirement of major *kharif* and *rabi* crops in Punjab. The water requirement of each crop was taken from the district irrigation plan of the state. The crop water requirement on volume basis was determined by multiplying area and water requirement of each crop.

The district-wise energy requirement for a particular crop was calculated using the following formula[5]

$$E\ (\text{kWh}) = \frac{V \times g \times h}{3.62 \times 10^6 \times \text{Efficiency}},$$

where E is the energy consumption of a particular crop, V the water requirement of the crop (m^3), g the acceleration due to gravity (9.81 m^2/sec), h the head ($1.2H + 3$) (m) (ref. 6), H the water table depth (m) and efficiency = 35% (assumed).

Table 4 gives the average water table depth (m) of each district in Punjab.

The average fuel consumption of diesel engines in Punjab is 240 g for generating 1 kWh of energy. The density of diesel is 0.832 kg/l (ref. 7). So, diesel of 240 g weight has a volume of 0.289 l. Therefore, the fuel consumption of a diesel engine is 0.289 l for generating 1 kWh of energy. Thus, by multiplying the values of energy consumption of diesel pump sets in each district and each category of pump set with 0.289, we can obtain the total consumption of diesel per year in each

Table 4. Average water table depth

District	Water table depth (m)
Amritsar	14.78
Barnala	29.01
Bathinda	17.01
Faridkot	8.16
Fatehgarh Sahib	21.84
Fazilka	5.44
Ferozpur	12.09
Gurdaspur	8.67
Hoshiarpur	12.91
Jalandhar	22.32
Kapurthala	16.06
Ludhiana	19.17
Mansa	14.10
Moga	25.04
Muktsar	3.65
Pathankot	8.20
Patiala	28.05
Rupnagar	13.28
Sangrur	32.10
SAS Nagar	21.06
SBS Nagar	16.96
Tarn Taran	18.73

Source: ref. 10.

Table 5. Solar photovoltaic submersible AC pump sets rate

		Subsidy distribution (Rs)		
Power (hp)	Total cost (Rs)	Central Government's share (30%)	State Government's share (30%)	Farmer's share (40%)
3.0	165,558	49,667	49,666	66,225
5.0	231,305	69,390	69,390	92,525
7.5	352,500	142,705	142,705	134,180
10.0	439,956	100,631	100,630	238,695

Source: refs 1, 8.

Table 6. District-wise water requirement (000, m^3) of *kharif* and *rabi* crops in Punjab

District	Cereals	Pulses	Cotton	Vegetables	Sugarcane	Fruit crops	Fodder crops	Others	Total
Amritsar	2,691,400	3,680	0	29,900	23,030	31,000	29,900	31,000	2,839,910
Barnala	2,217,090	180	0	18,610	14,900	650	18,610	650	2,270,690
Bathinda	2,932,200	22,070	552,970	0	0	33,480	0	33,480	3,574,200
Faridkot	2,154,800	300	24,000	0	28,410	11,400	0	11,400	2,230,310
Fatehgarh Sahib	1,715,330	70	0	38,540	6,230	1,880	38,540	1,880	1,802,470
Fazilka	2,404,030	0	392,390	14,140	5,700	378,700	14,140	378,700	3,587,800
Ferozpur	3,700,530	1,040	0	0	22,270	710	0	710	3,725,260
Gurdaspur	2,816,000	800	0	189,000	30,400	5,140	189,000	5,140	3,235,480
Hoshiarpur	1,743,740	870	0	213,100	114,600	49,340	213,100	49,340	2,384,090
Jalandhar	3,048,520	0	0	100,500	163,600	13,160	100,500	13,160	3,439,440
Kapurthala	2,072,770	90	0	39,640	118,250	3,090	39,640	3,090	2,276,570
Ludhiana	4,614,780	3,600	1,920	23,000	51,310	53,840	23,000	53,840	4,825,290
Mansa	1,993,640	460	336,720	460	7,580	6,700	460	6,700	2,352,720
Moga	3,116,422	1,400	4,790	560	39,060	9,700	560	9,700	3,182,192
Muktsar	2,912,780	670	256,000	1,410	8,200	13,940	1,410	13,940	3,208,350
Pathankot	504,750	3,590	0	39,920	2,200	32,480	39,920	32,480	655,340
Patiala	4,612,550	1,010	1,680	32,280	41,140	18,030	32,280	18,030	4,757,000
Rupnagar	752,860	100	0	23,240	4,370	2,870	23,240	2,870	809,550
Sangrur	4,990,110	1,890	39,430	25,950	21,790	6,810	25,950	6,810	5,118,740
SAS Nagar	640,560	2,400	0	9,000	36,950	19,240	9,000	19,240	736,390
SBS Nagar	1,228,900	160	0	48,650	49,990	10,570	48,650	10,570	1,397,490
Tarn Taran	3,591,740	5,300	390	3,300	930	0	3,300	0	3,604,960
Total	56,455,502	49,680	1,610,290	851,200	790,910	702,730	851,200	702,730	62,014,242

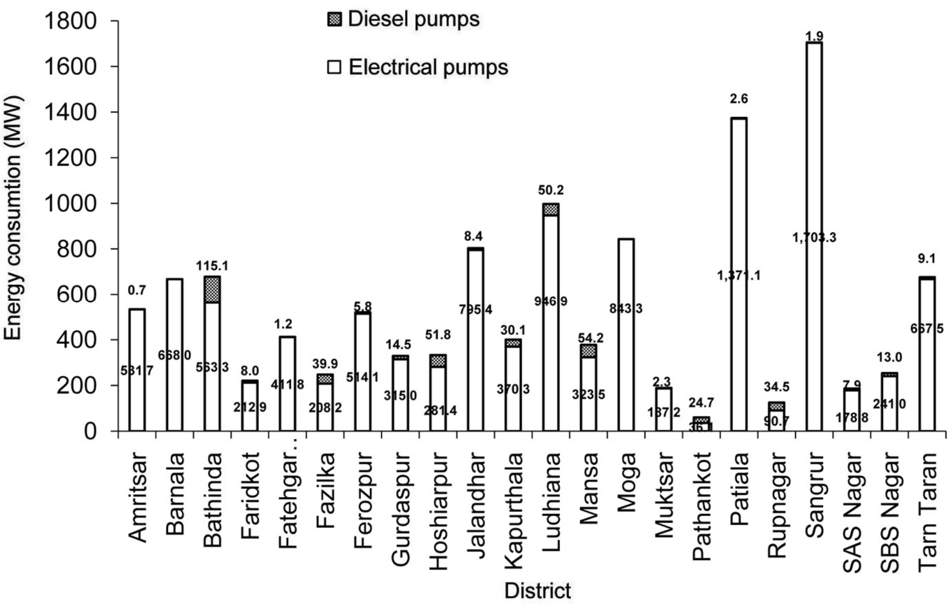

Figure 2. Energy consumption by electrical and diesel pumps (MWh).

Table 7. Total energy requirement (kWh) for irrigating *kharif* and *rabi* crops in Punjab

District	Cereals	Pulses	Cotton	Vegetables	Sugarcane	Fruit crops	Fodder crops	Others	Total
Amritsar	432,001	591	0	4,799	3,697	4,976	84,373	2,048	532,485
Barnala	649,159	53	0	5,449	4,363	190	8,210	539	667,963
Bathinda	531,647	4,002	100,261	0	0	6,070	34,692	1,736	678,408
Faridkot	213,421	30	2,377	0	2,814	1,129	990	127	220,888
Fatehgarh Sahib	387,920	16	0	8,716	1,409	425	13,843	624	412,953
Fazilka	177,306	0	28,940	1,043	421	27,930	6,007	6,458	248,105
Ferozpur	501,641	141	0	0	3,019	96	14,864	201	519,962
Gurdaspur	292,253	83	0	19,615	3,155	534	13,077	763	329,480
Hoshiarpur	249,666	125	0	30,511	16,409	7,064	26,062	3,309	333,146
Jalandhar	703,015	0	0	23,176	37,728	3,035	36,842	0	803,796
Kapurthala	357,440	16	0	6,836	20,392	533	12,813	2,382	400,412
Ludhiana	929,145	725	387	4,631	10,330	10,840	39,326	1,675	997,059
Mansa	307,489	71	51,934	71	1,169	1,033	14,613	1,315	377,695
Moga	797,490	359	1,226	143	9,995	2,482	30,792	791	843,278
Muktsar	166,440	38	14,628	81	469	797	6,047	1,002	189,502
Pathankot	50,180	357	0	3,969	219	3,229	2,427	436	60,817
Patiala	1,309,260	287	477	9,163	11,678	5,118	35,875	1,885	1,373,743
Rupnagar	110,382	15	0	3,407	641	421	9,948	371	125,185
Sangrur	1,604,205	608	12,676	8,342	7,004	2,189	67,060	3,134	1,705,218
SAS Nagar	140,219	525	0	1,970	8,088	4,212	31,167	519	186,700
SBS Nagar	222,195	28	0	8,796	9,038	1,911	7,859	4,159	253,986
Tarn Taran	649,413	958	71	597	168	0	24,814	540	676,561
Total	10,781,885	8,895	212,976	141,315	152,205	84,215	521,702	34,011	11,937,204

district and in each hp category of the pump set. The market rate of the diesel was considered as Rs 70/l.

In Punjab, electricity to the farmers is subsidized, but according to the Punjab State Power Corporation Limited, the electricity charge for agricultural pump sets is Rs 5.57/kWh (ref. 8).

Table 5 gives the total cost of solar-powered pump set with respect to wattage along with subsidy distribution.

Table 6 presents the district-wise crop water requirement calculated on volume basis. It shows that the highest water-consuming districts are Sangrur, Ludhiana and Patiala. The highest water consumption was due to more area under paddy cultivation. The lowest water-consuming districts are Pathankot, SAS Nagar and SBS Nagar, because these districts grow less water-consuming crops such as maize, orchards and vegetables.

Table 7 presents the district-wise and crop-wise energy requirements for irrigating *kharif* and *rabi* crops. The highest energy requirement was for the districts of Sangrur, Patiala and Ludhiana, and lowest for Pathankot, Rupnagar and SAS Nagar. The highest energy consumption was for cereals, followed by fodder crops and cotton. The total energy requirement for all districts of Punjab was calculated to be about 1.2 billion kWh. Figure 2 shows the district-wise energy consumption by electrical and diesel pump sets. The highest energy consumption through electrical pump sets was from Sangrur, Patiala and Ludhiana, and for diesel pump sets from Bathinda. The lowest energy consumption was from Pathankot.

Figure 3 shows the district-wise cost of diesel and electricity. The highest energy cost was in the districts of Sangrur, Patiala and Ludhiana, and the lowest cost in Pathankot, Rupnagar and Muktsar. The total cost for running an electrical pump sets was found to be Rs 638.4 lakhs and for diesel pump sets it was Rs 101.64 lakhs.

The cost of employing SPV pump sets in place of electric and diesel tube wells up to 10 hp in the category of shallow and medium tube wells in each district of Punjab, with and without subsidy according to the Government scheme was determined (Table 8).

The cost of electrical energy and diesel for operating shallow and medium tube wells was almost Rs 73.9 million per year. If these pumps are replaced by SPV pump sets, then the installation cost would be Rs 212,711 million, which is without subsidy. According to the Punjab Government scheme, the farmer's share is Rs 96,183 million while the Government's share is Rs 132,709 million. The cost of installation of SPV is high compared to the cost of operating electrical and diesel pump sets. However, considering the possible carbon-emissions and degradation of the environment, the replacement of these pump sets with SPV could be a viable option. During the non-pumping hours, additional electricity generated through SPV can be supplied to the main grid. Table 8 gives the district-wise cost of replacement of electrical and diesel pump sets with SPV.

The cost of electricity is high and the Punjab Government provides subsidy to the farmers, which is a big burden on the state Government. The cost of diesel is also high and farmers do not get any subsidy for diesel. So it is difficult for them to make sufficient profits from their crops, as a large share of the profit is being spent on diesel.

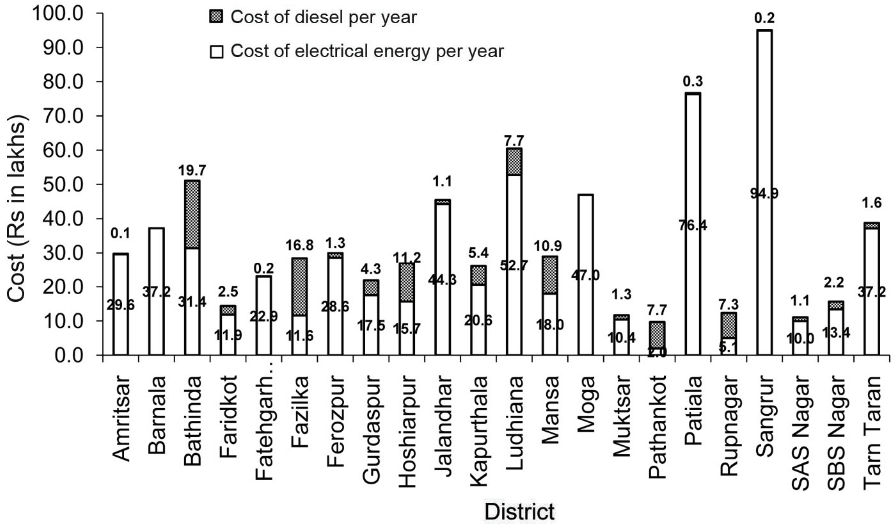

Figure 3. Cost of operating by electrical and diesel pumps sets.

Table 8. Cost (Rs million) of installing SPV pumps with and without subsidy in Punjab

		Cost with subsidy			
District	Cost without subsidy	Farmer's share 40%	State Government's share	Central Government's share	Total Government share
Amritsar	22,617.9	9,296.5	8,295.8	8,295.8	16,591.6
Barnala	489.0	260.1	117.2	117.2	234.5
Bathinda	14,601.7	7,218.3	4,084.2	4,084.2	8,168.5
Faridkot	5,077.8	2,128.2	1,691.9	1,691.9	3,383.8
Fatehgarh Sahib	10,409.4	5,422.0	2,618.2	2,618.2	5,236.4
Fazilka	7,863.2	3,484.0	2,421.3	2,421.3	4,842.6
Ferozpur	9,756.4	4,310.3	3,021.9	3,021.9	6,043.9
Gurdaspur	21,519.0	8,506.3	7,541.2	7,541.3	15,082.5
Hoshiarpur	9,308.3	3,807.7	3,266.3	3,266.4	6,532.7
Jalandhar	19,911.3	9,785.0	5,559.3	5,559.3	11,118.6
Kapurthala	11,070.6	4,803.7	3,645.8	3,645.8	7,291.7
Ludhiana	18,907.5	8,450.5	5,944.1	5,944.2	11,888.3
Mansa	11,362.0	5,627.5	3,158.7	3,158.8	6,317.5
Moga	464.3	244.0	114.4	114.4	228.8
Muktsar	7,040.9	2,894.8	2,191.0	2,191.0	4,382.0
Pathankot	2,417.8	944.3	884.3	884.3	1,768.6
Patiala	13,646.4	7,231.5	3,286.8	3,286.9	6,573.7
Rupnagar	6,530.9	2,838.9	2,174.8	2,174.8	4,349.6
Sangrur	1,584.8	836.5	387.7	387.7	775.3
SAS Nagar	1,317.2	607.9	395.0	395.0	790.0
SBS Nagar	6,734.6	2,862.5	2,338.7	2,338.7	4,677.4
Tarn Taran	10,080.0	4,622.9	3,215.8	3,215.8	6,431.7
State total	212,711.1	96,183.5	66,354.7	66,354.9	132,709.6

A big part of the carbon emission in Punjab is attributed to the electric and diesel tube wells. Therefore, it is necessary to replace the electric and diesel tube wells with SPV pumps, which require only one-time installation cost. The following conclusions can be drawn from the present study:

- The total irrigation requirement for various *kharif* and *rabi* crops in Punjab was found to be 62,014 million m^3.
- Total energy requirement for the conventional method of irrigation for *kharif* and *rabi* crop was 11.94 M kWh.
- The cost of electrical energy and diesel for operating shallow and medium tube wells was almost Rs 73.9 million per year. If these pumps are replaced by SPV pump sets, then the required cost for installation of the SPV pumps is Rs 212.71 billion, without subsidy. According to the Government scheme, the farmer's share is Rs 96.18 billion and the state Government's share is Rs 132.71 billion.

- With the replacement of conventional pump sets by the solar pumping system, green energy will be available. This will help reduce the burden on the environment as electric and diesel-operated pumps directly or indirectly emit carbon.

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