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. AlS, 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. 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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The earth and its atmosphere continuously receive $1.7 \times 10^{17}$ 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.

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.

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            |

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:

\[ E_{(kWh)} = \frac{V \times g \times h}{3.62 \times 10^6 \times \text{Efficiency}} \]

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 (1.2\( H + 3 \)) (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 district.

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.

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

| Power (hp) | Total cost (Rs) | Central Government’s share (30%) | State Government’s share (30%) | Farmer’s share (40%) |
|------------|----------------|---------------------------------|-------------------------------|----------------------|
| 3.0        | 165,558        | 49,666                          | 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, m³) 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 | 2,384,590 |
| 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  | 14,140 | 5,700      | 378,700   | 14,140      | 378,700      | 3,587,800| 62,014,242 |
| 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 | 2,384,590 |
| Jalandhar    | 3,048,520 | 0      | 100,500| 163,600    | 13,160    | 100,500     | 13,160       | 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 | 3,285,350 |
| Pathankot    | 504,750   | 3,590  | 0      | 39,920     | 2,200     | 32,480      | 39,920       | 32,480 | 555,340   |
| 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   |
| Sangur       | 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     | 960         | 14,864       | 201    | 220,888 |
| Fatehgarh Sahib | 387,920 | 16     | 8,716  | 1,409      | 425       | 13,843      | 624          | 642    | 412,953 |
| Fazilka      | 177,306 | 0      | 28,940 | 1,043      | 421       | 27,930      | 6,007        | 6,458  | 248,105 |
| Ferozpur     | 501,641 | 141    | 0      | 3,019      | 96        | 14,864      | 201          | 519    | 519,962 |
| Gurdaspur    | 292,253 | 83     | 19,615 | 3,155      | 534       | 13,077      | 763          | 329    | 329,480 |
| Hoshiarpur   | 249,666 | 125    | 30,511 | 6,076      | 7,064     | 26,062      | 3,309        | 333    | 333,146 |
| Jalandhar    | 703,015 | 0      | 23,176 | 37,728     | 3,035     | 36,842      | 0            | 803    | 796,796 |
| Kapurthala   | 357,440 | 16     | 6,836  | 20,392     | 12,813    | 23,822      | 3,135        | 377    | 377,695 |
| 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      | 146,440 | 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     | 3,407  | 641        | 421       | 9,498       | 371          | 125    | 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       | 24,814      | 540          | 676    | 765,561 |
| Total        | 10,781,885| 8,895 | 212,976| 141,315    | 152,205   | 84,215      | 521,702      | 34,011 | 11,937,204 |

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 the lowest energy requirement was for 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 whilst 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.
Table 8. Cost (Rs million) of installing SPV pumps with and without subsidy in Punjab

| District     | Cost without subsidy (Rs million) | Farmer’s share 40% (Rs million) | State Government’s share (Rs million) | Central Government’s share (Rs million) | Total Government share (Rs million) |
|--------------|----------------------------------|---------------------------------|---------------------------------------|----------------------------------------|-------------------------------------|
| Amritsar     | 22,617.9                         | 9,296.5                         | 8,295.8                               | 8,295.8                                | 16,591.6                            |
| Barnala      | 489.0                            | 260.1                           | 82.4                                  | 117.2                                  | 234.5                               |
| Bathinda     | 14,601.7                         | 7,218.3                         | 4,084.2                               | 1,691.9                                | 8,168.5                             |
| Faridkot     | 5,077.8                          | 2,128.2                         | 1,691.9                               | 8,295.8                                | 6,338.3                             |
| 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                         | 5,741.2                               | 5,741.2                                | 15,082.5                            |
| Hoshiarpur   | 9,308.3                          | 3,807.7                         | 3,266.3                               | 3,266.3                                | 6,532.7                             |
| Jalandhar    | 19,911.3                         | 9,785.0                         | 5,599.3                               | 5,599.3                                | 11,188.6                            |
| 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                               | 3,158.7                                | 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                               | 3,286.8                                | 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 m³.
- 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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