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ELECTRICITY GENERATION POTENTIAL OF ROOFTOP PHOTOVOLTAICS IN PUNJAB

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ABSTRACT: Solar energy is pollution free and is available in Punjab for around 300 days in a year. Installing photovoltaics on rooftops can solve the need for open land required for solar photovoltaics. An estimate of the potential of solar electricity generation in the state by installing rooftop photovoltaics on residential houses was carried out in this study and it was estimated that around 2475 GWh/year can be generated from rooftop solar photovoltaics installed on 90% of the residential houses in Punjab. The electricity produced by solar photovoltaics installed on rooftops of 90% of the houses can supply upto 25% of the total domestic electricity needs in the state. Money savings are also realizable in case of rooftop photovoltaics. The total money savings for rooftop photovoltaics mounted on 90% of the houses would be about 14850 Million/year. Reduction in greenhouse gases emission is also possible by using rooftop photovoltaics. The reduction in emission of greenhouse gases like carbon dioxide, methane and nitrous oxide would be about 806.67 kT/year, 92.9 kT/year and 13.51 kT/year respectively. So rooftop photovoltaics can be used to reduce the emission and are economical over their full life span.

KEYWORDS

Renewable energy, solar energy, photovoltaic cell, solar electricity

Introduction

Urbanization is expected to continue at a faster rate in the near future (UN, 2014), as a result of which expenditure on energy is anticipated to increase rapidly (Pal, 2015). At present, the main source of energy supply is from fossil fuels. However, combustion of fossil fuels produces a lot of greenhouse gases with undesirable consequences (Peng & Lu, 2013). Electricity is the most convenient source of energy used and among the user categories, domestic sector is one of the major consumers of electricity. Coal based thermal power plants generate a major share of total power in Punjab. The high percentage of the total power generation from coal produces a lot of greenhouse gases. On the other hand Punjab has vast potential of solar energy with over 300 days of sunshine in a year (Anon., 2012). Annual average global insolation in Punjab is nearly 5.25 kWh/m2 in a day (Ramachandra et al, 2011). Therefore the problem of greenhouse gas emission can be reduced by using solar energy for generating electricity. Photovoltaics can be used to generate power from solar energy. These are environment friendly and have a huge potential for sustainable source of electricity generation (Hosenuzzaman et al, 2015). Photovoltaic manufacturing cost is decreasing due to increase in production (Lang et al, 2016). The payback time period is around 3 years only for the photovoltaic systems (Hosenuzzaman et al, 2015). Electricity generated from photovoltaics will be competitive with traditional systems very soon and will be an ideal source of renewable energy (Peng & Lu, 2013). The cost of photovoltaic modules in India is around Rs. 4.95 crores/MW (Anon., 2017). The problem, however, is that Photovoltaic plants require around 2.13 ha of land per MW of electricity generated (Chandel et al, 2014). Acquiring this large land area is not an easy job in any state (Sukhatme, 2011). So, the real obstacle is accessibility of open land and not the setup costs in the near future or in the long run (Sukhatme, 2011). Therefore, the potential for generating electrical power through solar photovoltaic power plants may

be limited, if we depend upon availability of open land. However, the problem of open land availability is not insurmountable and can be solved by installing solar photovoltaics on rooftops (Pal, 2012 and Peng & Lu, 2013). Therefore the use of rooftop photovoltaic cells is the viable option to utilize the available solar energy. Around 30% of the annual electricity can be generated by rooftop photovoltaics (Byrne et al, 2015). Further the greenhouse gas emission can be reduced by utilizing rooftop photovoltaics (Peng & Lu, 2013). Also there are no transmission and distribution losses because the electricity is produced on-site (Ruther et al, 2008).

Keeping in mind that the domestic sector is one of the major consumers of electricity and rooftop photovoltaics can be used to generate electricity from solar energy in an environment friendly way, an attempt is made here to estimate the potential of solar electricity generation by installing photovoltaic cells on the rooftops of the houses in Punjab.

Materials and Methods

Various materials and methods used for the present work to compute the parameters like electricity generated, monetary savings, and greenhosue gases emission reduction are presented in the following sections.

Materials

Solar thermal or solar photovoltaic power plants can be utilized to generate electricity from solar energy. In solar thermal power plants, high pressure steam is produced by focusing the sun's energy. The steam produced can be utilized for generation of electricity. The main hurdle in this is requirement of open land. The open land requirement for solar thermal power generation is around 3 ha/MW of electric energy produced (Sharma et al, 2015). Conversion via photovoltaic method is another way of generating electricity from solar energy. Solar photovoltaics cells can give 25 to 30 years of functional life (Granata et al, 2014). The problem of acquiring open land exists in case of solar photovoltaics power plant also. The problem of availability of open land can be solved by using rooftops photovoltaic cells on the residential buildings (Pal, 2012 and Peng & Lu, 2013). The photovoltaic cells based on the photovoltaic effect can generate electric current or voltage in a material on exposure to light. In photovoltaic effect the electrons gets transferred between different bands within the material thereby developing potential difference between the two electrodes. The schematic sketch of a p-n junction photovoltaic cell is shown in Fig. 1(Pal, 2012).

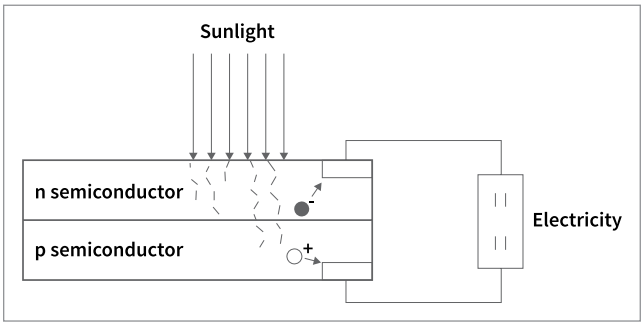

FIGURE 1. Schematics of a photovoltaic cell

The ground area to rooftop area factor can be used to find out the total available roof area (Defaix et al, 2012). The rooftop area suitable for photovoltaics installation is around 0.4 times the ground area for residential buildings (Peng & Lu, 2013). So, the available rooftop area was worked out from the roof area factor and the ground area. The electricity generation potential using rooftop photovoltaics was computed from the rooftop area available. The annual money savings are

calculated from electricity generated and cost of electric energy after the payback period of the photovoltaics. The emission of greenhouse gases was computed from the electricity generated and emission factor for various greenhouse gases like carbon dioxide, methane and nitrous oxide for coal based thermal power plants.

Methods

Various methods utilized to compute the parameters like the amount of electricity generated, money savings and greenhouse gases emission reduction are presented in the following sections.

Electricity Generation

The estimation of solar electricity produced by mounting solar photovoltaic cells on rooftops of houses in Punjab is based on Eq. (1) (Pal, 2012) given below: -

$$P = L^* p * n * N_{pv} * h \quad (1)$$

Where P is total power generated (in GWh/year), p is power generated by rooftop photovoltaic per house (0.4 kW), L is load factor of cell/year (0.2) (Sukhatme, 2011), N_{pv} is photovoltaics installed houses (%age), n is number of residential houses in Punjab (3922108) (Anon., 2011) and h is number of hours/year (8760).

Maximum 90% of residential houses are considered fit for installation of photovoltaic cells due to constraints like monetary condition of the possessor of house and strength of the house etc.

Money Savings

Money savings are obtainable by using rooftop photovoltaics after the payback period. Money savings can be computed from the total electricity generation by Eq. (2).

$$M = P * R \quad (2)$$

Where M is total money savings (Rs/year) and R is cost of electric energy (Rs/kWh).

Emission Reduction

The methods to calculate the reduction in emission of greenhouse gases like carbon dioxide, methane and nitrous oxide are given in the subsequent sections.

1. Reduction In Carbon Dioxide

The formula for computing carbon dioxide emission reduction is presented in Eq. (3). The emission reduction is worked out from product of carbon dioxide emission factor and electric energy generated.

$$M_{co2} = C_{co2} * P \quad (3)$$

Where C_{co2} is emission factor of carbon dioxide (kg/kWh), and M_{co2} is reduction in carbon dioxide (kg).

2. Reduction in Methane

The method for calculating methane emission reduction is given by Eq. (4). The methane emission reduction is figured out from the product of methane emission factor and electric energy generated.

$$M_{ch4} = C_{ch4} * P \quad (4)$$

Where C_{ch4} is emission factor of methane (kg/kWh) and M_{ch4} is reduction in methane emission (g).

3. Reduction in Nitrous Oxide

The formula for working out nitrous oxide emission reduction is given by Eq. (5). The nitrous oxide emission reduction is computed by the product of nitrous oxide emission factor and electric energy generated.

$$M_{N2O} = C_{N2O} * P \quad (4)$$

Where C_{N2O} is emission factor of nitrous oxide (kg/kWh) and M_{N2O} is reduction in nitrous oxide emission (g).

Results and Discussion

The various results like electricity generation, money savings and reduction in emission of greenhouse gases computed from Eqs. (1) – (5) are presented in the following sections.

Electricity Generation

The potential of electricity generated by installing rooftop solar photovoltaics on houses is given in Fig. 2 and Table 1. Electricity generation capacity due to rooftop solar photovoltaics installed on 10% of houses is 275 GWh/year. The electricity generation potential increases linearly with increase in percentage of houses installed with rooftop photovoltaics.

Electricity generation capacity by installing rooftop solar photovoltaics on 90% of houses in Punjab can be of the order of 2475 GWh/year. This electric energy generated can meet about 25% of total electric energy needed for domestic sector. This is a big amount considering that Punjab is a wealthy state of India and per capita energy consumption is very high as compared to some of the other states in the country. The energy consumption in Punjab on per capita basis was 1858 kWh as compared to national average of 1010 kWh in 2014-15 (Swain, 2017).

Houses with Photovoltaics	Electricity generation (GWh/year)	Money savings (Million Rs/year)	Carbon dioxide reduction (kT/year)	Methane reduction (kT/year)	Nitrous oxide reduction (kT/year)
10%	275	1650	89.63	10.32	1.5
20%	550	3300	179.26	20.64	3.0
30%	825	4950	268.89	30.97	4.5
40%	1100	6600	358.52	41.29	6.01
50%	1375	8250	448.15	51.61	7.51
60%	1650	9900	537.78	61.93	9.01
70%	1925	11550	627.41	72.25	10.51
80%	2200	13200	717.04	82.57	12.01
90%	2475	14850	806.67	92.9	13.51

TABLE 1. Electricity generation, money savings and emission reduction by rooftop photovoltaics

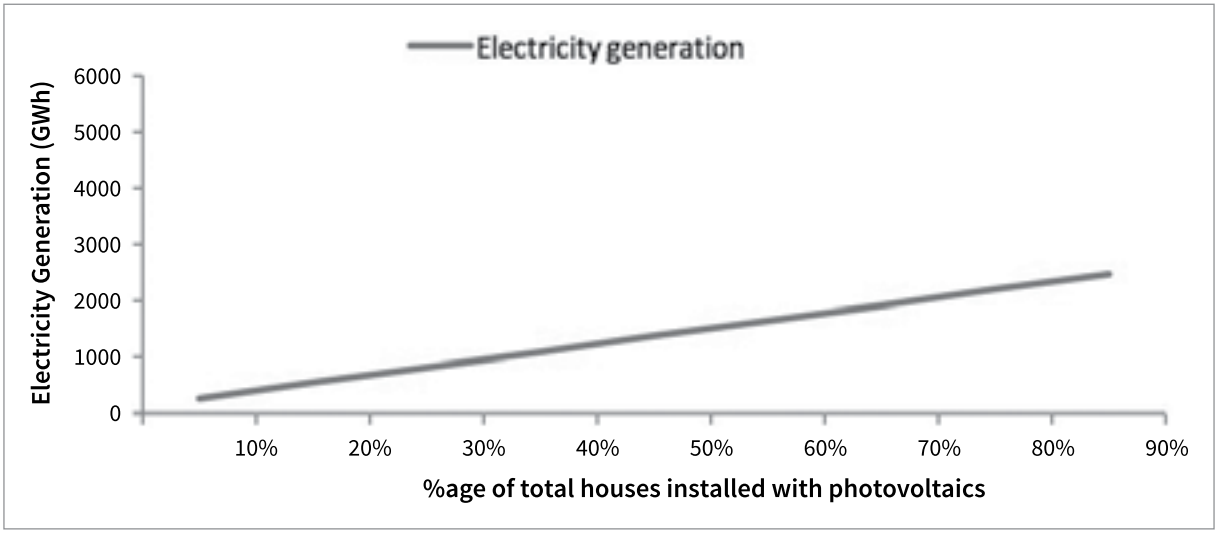

FIGURE 2. Electricity generation by using rooftop photovoltaics

Money Savings

Money savings are attainable by using rooftop photovoltaics after the payback period as there is no running cost for the photovoltaic system. The money savings obtained are presented in Fig. 3 and Table 1. The money savings obtainable by mounting rooftop photovoltaics on 10% of the houses are Rs 1650 Million/ year. The money savings potential increases linearly with increase in percentage of houses installed with rooftop photovoltaics. The potential amount of money savings achievable by installing rooftop photovoltaics on 90% of the houses are Rs 14850 Million/year.

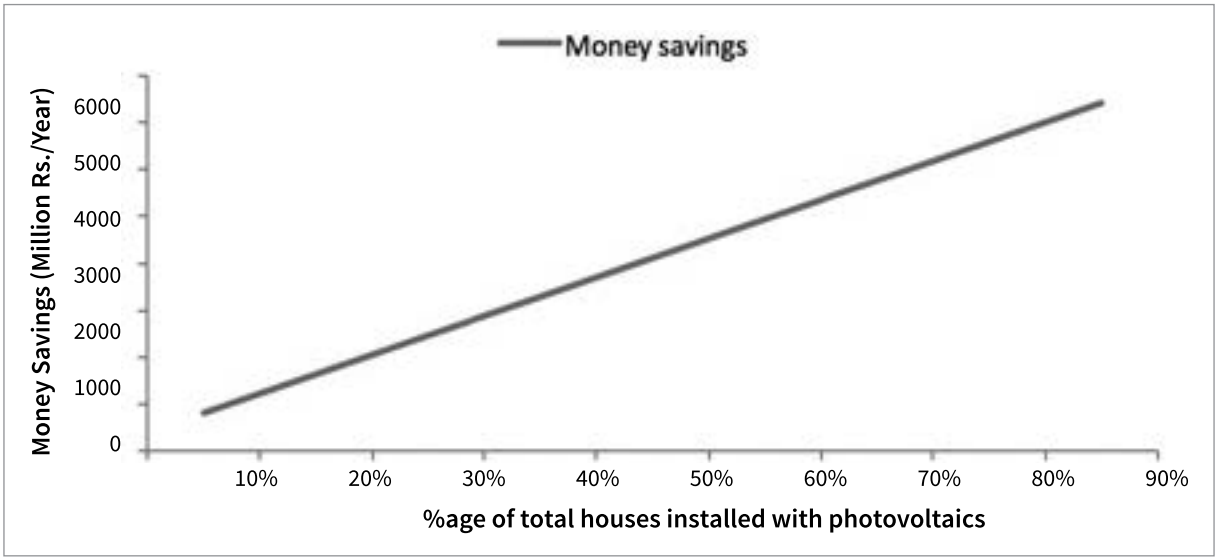

FIGURE 3. Money savings by using rooftop photovoltaics

Emission Reduction

The greenhouse gases emission reduction by installing rooftop photovoltaics on the houses in Punjab is presented in Table 1 and Fig. 4-5. The emission of these gases will get reduced due to the fact that lesser amount of electricity needs to be generated from coal based thermal power plants.

1. Carbon Dioxide Reduction

The reduction in carbon dioxide emission is possible because of electricity generation using rooftop photovoltaics. This is due to the fact that electricity generation from rooftop photovoltaics is pollution free. The reduction in carbon dioxide emission (Table 1 and Fig. 4) for Punjab is 806.67 kT/year when 90% of the houses are installed with roof top photovoltaics.

2. Methane Reduction

Reduction in methane emission is also achievable due to electricity generation using rooftop photovoltaics. This is because of the fact that electricity generated from rooftop photovoltaics is free from pollution. Total reduction in methane emission (Table 1 and Fig. 5) for Punjab is 92.9 kT/year when rooftops photovoltaics are fitted on 90% of the houses. This is significant as the global warming potential is higher for methane as compared to carbon dioxide.

3. Nitrous Oxide Reduction

Reduction in nitrous oxide emission is also attainable as a result of electricity generation from rooftop photovoltaics due to the fact already explained. Reduction in methane emission (Table 1 and Fig. 5) is 13.51 kT/year when rooftops photovoltaics are mounted on 90% of the houses. This is also significant as the global warming potential is even higher for the nitrous oxide as compared to methane.

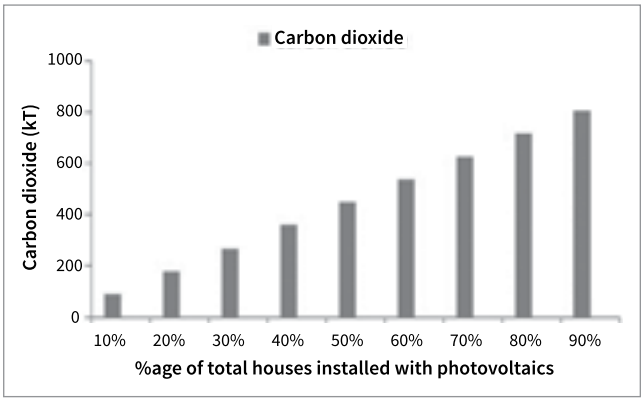

FIGURE 4. Carbon dioxide reduction by rooftop photovoltaics

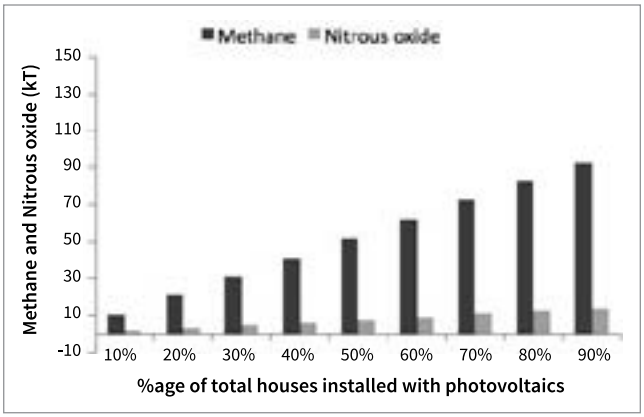

FIGURE 5. Methane & nitrous oxide reduction by rooftop photovoltaics

Conclusion

Electricity generation capacity due to rooftop solar photovoltaic cells installed on 90% of houses in Punjab can be as high as 2475 GWh/year. Rooftop solar photovoltaic cells can supply around 25% of total energy needed in the domestic sector. Money savings are also achievable after the payback period in case of rooftop photovoltaics. The total money savings for rooftop photovoltaics installed on 90% of the houses is Rs 14850 Million/year. Greenhouse gases emission reduction is also possible by using rooftop photovoltaics. The reduction in emission of carbon dioxide, methane and nitrous oxide is 806.67 kT/year, 92.9 kT/year and 13.51 kT/year respectively. Therefore, rooftop photovoltaics can reduce the emission and are more economical over the life span of the photovoltaics.

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