Techno-Economic Analysis of Sustainable Energy Management Techniques – A Case Study

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Abstract

Rapid population growth rate and urbanization will have a dramatic effect on the increased demand for residences. India needs to increase its electricity generation by five to six times to meet the lifeline per capita consumption needs. Using renewable energy can play an important role in the generation of energy. An integrated tool having energy conservation modules is developed for generating design sizes, estimates of capital, life cycle costs, saving in energy, carbon emission prevented for the identified technically efficient and economically viable sustainable technologies. A case study of a residential township in Nagpur, India has been presented. Unit costs of energy per Kilowatt-hour using a solar water heater, solar photovoltaic are found INR11.21 (1USD = INR63 in 2015) and INR2.36 respectively. Cost of installation and life cycle cost of solar water heater, are INR24, 16,295, INR40, 14,238.75 respectively. Solar photovoltaic panels required initial capital of INR5, 84,254 and the life cycle cost was found INR 36,13,325.07. Carbon emission prevented using SWH and Solar photovoltaic was 101.84 MT and 13.58 MT respectively. This paper also addresses module of wind turbine and hybrid energy (solar photovoltaic + wind turbine). This study created a choice of technologies for integration in residential townships for conservation of energy.

Keywords — *Energy, Energy conservation, Sustainable technology*

I. INTRODUCTION

India suffers from shortage of electricity and continually requires additional power to meet the demands and to support its growing economy. The overall power deficit has risen from 8.4% in 2006 to 11% in 2009. There is no electricity in about 1,00000 villages in India. Per capita consumption (639 kWh) of India is one of the lowest in the world. India needs to increase its primary energy supply by three to four times and electricity generation by five to six times to meet the lifeline per capita consumption needs and to sustain 8% growth rate. There is a need to improve operation and efficiency as well as the introduction of new generation methods. Renewable energy can play an important role in the generation of energy. India's electricity production mainly depends on coal and natural gas. The current usage level of coal suggests that coal reserves may run out in 45 years. India used to import about 10% coal for electricity generation [1]. 2010). It is expected to further increase every year. Variations in the price of oil and gas have been experienced in recent years.

Renewable energy technologies are urgently required for preventing depletion of fossil fuels and emission of greenhouse gases. Solar power can be used in India as it has a high solar insolation. Large projects have been proposed in the solar energy sector. The daily average solar energy incident over India varies from 4-7 kWh/m² and has 1500-2000 sunshine hours per year [2]. Tamil Nadu, Maharashtra, Karnataka, Rajasthan, Gujarat, Andhra Pradesh, Madhya Pradesh, Kerala and West Bengal are the major states having wind energy potential [3].

Despite the obvious advantages of renewable energy, an initial investment for the said technology presents a challenge for research. It is therefore found essential to evaluate these technologies based on life cycle cost (LCC) analysis. Choice of sustainable technology depends upon natural and local availability of resources, commercial availability of components and availability of space for the sustainable technology depending upon the location of residential apartment buildings.

Although various software tools such as Hybrid Optimization by Genetic Algorithms (HOGA), Premium Solver, RETSCREEN, and Hybrid Optimization Model for Electric Renewables (HOMER) are mentioned in literature for determining the techno-economic sizes of renewable energy sources [4, 5]. An indigenous tool for Indian climatic conditions, integrating sustainable technologies using a solar water heater, solar photovoltaic panels and rooftop wind turbines for generating electricity was found essential.

The present paper discusses the developed Sustainable Renewable Resource Management (SRRM) tool for modelling locally available renewable sources of energy (solar and wind), using identified techno-economically sustainable technologies in stand-alone and hybrid system to meet electrical requirements for lighting in common areas of a residential township in Nagpur, Maharashtra, and in Chikkodi, Belgaon, India. Parametric study of sizing and life cycle costing of solar water heater (SWH), solar photovoltaic (SPV) panels and rooftop wind turbine was carried out. Flow diagrams were developed for carving out interfaces of Sustainable Renewable Resource Management **(**SRRM) in Power Builder from SAP technology. The database used for storing the data was also from SAP technology i.e. SQL Anywhere. Economics and environmental aspects of integrating sustainable technologies for generating electricity in residential township conserving natural resource of coal are also discussed.

Graphical views of LCC and results of sensitivity analysis on the parameters of the rates of components of sustainable technologies are also reported.

II. MATERIALS & METHODS

A detailed literature survey, extensive market survey as well as web survey was carried out in order to identify techno-economically sustainable technologies.

Current situation, sizing, life cycle costing parameters, local availability, specifications and prices of sustainable technologies were found out for conservation of energy in residential buildings.

A. Swh system

SWH system having simple mechanism, operating without a pump, on thermocyphonic action requiring less control, instrumentation, economical was identified. Components of a SWH system consisted of the water tank, collector and balance of system. SWH with heat exchanger was found suitable for extremely cold ambient temperature. The suitability of evacuated tube / flat plate SWH collector was identified depending upon the quality of water like hard, acidic and alkaline at the site. SWH suitable for areas having hailstorms was identified. Calculation of water heating load for the winter season was found essential parameter for sizing of SWH system. The normal temperature of the hot water requirement is between 30^{o} to 40^{o} C in residences The ratio of cold water to the hot water mix was given by the equation (1.0).

$$\frac{Quantity\ \ of\ cold\ \ water}{Quantity\ \ of\ hot\ \ water} = \frac{Hot\ \ water\ \ temperatur\ \ e - Use\ \ water\ \ temperatur\ \ e}{Mean\ \ water\ \ temperatur\ \ e - Cold\ \ water\ \ temperatur\ \ e} \quad (1.0)$$

Size of storage tank was then decided depending upon the quantity of hot water required limited to 3000 lit for thermosyphonic action to take place. India is located in the northern hemisphere of the earth. The collector for all locations in India should be oriented in a direction facing south at an angle of latitude plus 10 to15 degrees from the horizontal. The hot water storage tank is normally located higher, behind the collector and size of collector area was provided at the rate of 1 m^2 for obtaining 100 liters of hot water at 60 ^{0}c. The approximate costs and specifications of ETC and FPC systems with different capacities for providing hot water of 60^{o} to 70^{o} C were obtained from web survey [6].

B. Spv panels for lighting

Techno-economic SPVs were identified for generation of electricity for lighting in the common spaces of residential buildings based on efficiency, economics, and terrace area required for SPV modules. Local and commercial availability of SPV modules was also checked. Crystalline solar panels were found most efficient. Monocrystalline photovoltaic panels are found efficient in high temperature areas and were the costliest. Polycrystalline photovoltaic panels were found technically efficient and economically viable for Indian climatic condition. The SPV system was designed for the demand lighting load. The number of batteries and modules were calculated on the basis of demand loads. The SPV system was designed for the worst month of the year [7]. Determination of wattage, units, running hours of lights was required to determine the demand load complying with Energy Conservation Building Code *(*ECBC*)* 2007 norms of lighting. Number of PV modules was calculated by determining the demand load and PV array size. Parameters of the wattage of PV module and mean daily solar radiation were required. The efficiency of the battery and charge controller was assumed 80% and 90% respectively. The mismatch factor of SPV was assumed as 0.85. The area required for SPV panels was calculated at the rate of 12 m^2 per kWp of array size. Battery bank was determined from the data given by the manufacturer of the battery for voltage, ampere hour, and the watt hours. One or two day's backup is generally provided in all parts of India except North-Eastern states and Himalayas where three day backup is provided. The required battery capacity was calculated using equation (2.0).

Required battery capacity (Ah)

$$= \frac{(Daily\ \ lighting\ \ demand\ \ * No\ .of\ \ back\ \ up\ \ days}{(No\ \ min\ \ al\ voltage\ \ \ of\ \ battery\ \ * 0.65\ )} \quad (2.0)$$

The cost of polycrystalline monocrystalline solar panels were found INR 45/Wp and INR 60/Wp respectively [8, 9].

C. Rooftop wind turbine

Most vertical axis wind turbines (VAWTs) have an average decreased efficiency from a common horizontal axis wind turbines (HAWTs), mainly because of the additional drag that they have as their blades rotate into the wind. Versions that reduce drag produce more energy, especially those that funnel wind into the collector area. It is less cost effective

[10]. Generally, average annual wind speed of at least 4.0- 4.5 m/s is needed for a small wind turbine to produce enough electricity [11]. Vertical axis wind turbine is an immature technology, whereas, horizontal axis technology is proven, tested and constantly refined technology. Vertical axis wind turbines require twice the swept area and four times the material compared to HAWT, for generating the same electricity [12]. A wind energy conversion system can operate at its maximum efficiency only if it is designed for a particular site because the rated power and cut-in and cut-off wind speeds must be defined based on the site wind characteristics. The performance of a wind turbine installed in a given site was examined by the amount of mean power output over a period of time ($P_{e,ave}$) and the conversion efficiency or capacity factor of the turbine. The mean power output ($P_{e,ave}$) of a wind turbine was estimated using the following expressions based on Weibull distribution function [13].

$$P_{e,ave} = P_{eR} * \left\{ \frac{e^{-\left(\frac{v_c}{c}\right)^k} - e^{-\left(\frac{v_r}{c}\right)^k}}{\left(\frac{v_r}{c}\right)^k - \left(\frac{v_c}{c}\right)^k} - e^{-\left(\frac{v_f}{c}\right)^k} \right\} \quad (3)$$

Where,

v_c, v_r, v_f are the cut-in wind speed, rated wind speed and cut-off wind speed, respectively. 'k' and 'c' are Weibull distribution shape and scale parameters [14].

The monthly and annual values of Weibull parameters were calculated using the standard deviation method. This method was found useful where only the mean wind speed and standard deviation are available. In addition, it gives better results than graphical method and has relatively simple expressions when compared with other methods. The shape and scale factors were computed from equations (4) and (5) [15].

$$k = (\sigma / V_m)^{-1.086} \quad (4)$$

$$c = \frac{V_m\, k^{2.6674}}{0.184 + 0.816 k^{2.6674}} \quad (5)$$

Where,

'v_m' is the mean wind speed. 'σ' is the standard deviation of wind speed.

The available wind speeds were adjusted to the wind turbine hub height using the following power law equation (6) [16].

$$\frac{V}{V_0} = \left(\frac{h}{h_0}\right)^{\propto} \quad (6)$$

Where,

v = wind speed at hub height 'h'

v_0 = wind speed at the original height 'h_0'

h = hub height

h_0 = original height

α = the surface roughness coefficient, assumed to be 0.143 in most cases.

The surface roughness coefficient was determined from the equation (7).

$$\propto = [0.37 - 0.088 \ln(V_0)]/[1.0.088\, ln\left(\frac{h_0}{10}\right)] \quad (7)$$

Alternatively, the Weibull probability density function was also used to obtain the extrapolated values of wind speed at different heights, since the boundary layer development and the effect of the ground are nonlinear with respect to wind speed, the scale factor 'c' and shape factor 'k' change as a function of height given by the following equations (8, 9) [17].

$$c(h) = c_0\,(h/h_0)^n \quad (8)$$

$$k(h) = k_0\,[1 - 0.088 \ln(h_0/10)]\,/\,[1 - 0.088 \ln\left(\frac{h}{10}\right)] \quad (9)$$

Where,

c_0, k_0 are scale factor and shape factor, respectively, at height 'h_0'

ch, k(h) are scale factor and shape factor, respectively, at height 'h'

The exponent 'n' is given by equation (10)

$$n = [0.37 - 0.088 \ln(c_0)]/\left[1 - 0.088 \ln\left(\frac{h}{10}\right)\right] \quad (10)$$

Small wind turbines with capacity ranging from 300 W to 25 kW are now available in Indian market and gaining popularity. Costs of various wind turbine models, available in India, along with start-up, cut in and design wind velocity were obtained from the manufacturers and through a web survey, [18- 20].

D. Hybrid energy (spv + wt)

The Input parameters required for this module were the parameters required module of solar PV as well as module of wind turbine. Parameter of mean wind speed (V_m) decided the percentage penetration of the total demand load using solar PV and the wind turbine. For values of mean speed (V_m) less than 4 m/sec, stand-alone solar PV system was recommended for lighting. For values of mean wind speed (A_m) greater than 8 m/sec, use of wind turbine and for the mean wind speed (V_m) values ranging from 5 m/sec to 7 m/sec use of hybrid energy was suggested [21, 22].

E. Life cycle cost analysis approach

Life cycle cost (LCC) analysis was found an economic evaluation technique that determined the total cost of owning and operating a facility over a period of time. LCC analysis facilitated an ability to compare the cost of sustainable technology alternatives and determine which alternative provides the best value of INR spent. The economic model (11) of LCC used was as under [23].

$$LCC = I + Repl. - Res. + E + W + OM \& R \quad (11)$$

Where,

LCC = Present-value of total life cycle cost
I = Present value investment costs
Repl = Present value of replacement costs
Res = Present value of residual cost
E = Present value of energy cost
W = Present value of water cost
OM & R = Present value of operation, maintenance & repair costs

F. Sustainable, Renewable, Resource Management (SRRM) tool

A generalized tool - SRRM has been developed in Power Builder from SAP technology for integrating energy conservation techniques for calculation of sizes of components of techno-efficient, economically viable SWH, SPV, wind turbine and hybrid (SPV + WT) systems for residential townships. Input interfaces of the module of SWH requires the data location, latitude, longitude, minimum temperature of the place, number of operational days, shadow free area, daily hot water requirement, average temperature of hot water and cold water in summer and winter, the number of days of summer season, the number of days of the winter season, total length of G.I. pipe, rate of G.I. pipe, rate of PVC pipe, project life, electricity tariff and quality of water. Input interfaces of the module of SPV requires data for latitude and longitude of the place, average annual solar radiation, available rooftop area, daily lighting demand, rates of solar panel, battery, inverter, a number of clear sunny days, wattage of lights, number of hours of lighting, battery, inverter, wattage of PV panel, selected battery capacity. The input parameters of this module were identified as anemometer height (h_0, meters) , mean wind speed at anemometer height (Vo, m/s), demand load per day (kWh), hub height (h_m, meters), standard deviation of wind velocity (**σ**), rated power of selected wind turbine (Pr,Watt-hr/day), cut in speed (V_c, m/s), rated velocity(V_r, m/s), cut out velocity (V_f, m/s), capacity of selected battery (amp-hour), voltage of selected battery (volts), wattage of inverter (Watt), number of back up days, cost of wind turbine with all accessories. Hybrid system required the inputs of both modules of SPV and WT. The 'Help' menu and 'Alerts!' are provided in SRRM tool which guides the user for input values and keeps the user on the right path during and the execution. The output of each module consists of designing sizes, installation, operation, maintenance, replacement and LCCs for each apartment building of a residential township. The summary sheet is generated giving ready values of LCCs for all the energy conservation techniques implemented in the residential township. It also evaluates the unit cost of energy and carbon emission prevented using these technologies. Abstract of results for cluster of apartment buildings can also be generated.

III. A CASE STUDY

A case study of housing scheme consisting of a cluster of residential apartment buildings of types, 'A', 'B', 'C' and 'D' at Bhamti in Nagpur was selected for integration of identified sustainable technologies, for conservation of energy using SRRM tool. Nagpur is located in the state of Maharashtra, India at latitude of 21^0 06' N and longitude $79^0$03' E, at an elevation of 310 m above MSL in the composite climate zone of India. Total plot area of the cluster is 9909.665 m^2. The apartment buildings are G+5 structures, 'D' with 60 apartments (1 BHK) and 'C' with 70 apartments (2 BHK) 'B' with 20 apartments (3 BHK) and building 'A' with 50 apartments (3 BHK) The total number of apartments in a cluster of selected housing is 200. Figure 1 shows the input values of module of SWH. SRRM tool computed values for sizes, installation, operation, replacement, LCCs, energy and carbon emission saved using modules of SWH and SPV for daily lighting demand of 4150 Wh in common areas of 'D' type of building. The results of the cluster of apartment buildings were also generated.

The wind velocity at Nagpur is less than 4 m/s hence modules of WT and hybrid energy (SPV + WT) for lighting in common areas of 'D' type of building are demonstrated considering in Chikkodi in Belgaon, Karnataka, India. The mean wind speed at Chikkodi is 6.54 m/sec with a standard deviation of 0.63 [24].

IV. RESULTS & DISCUSSION

A. Application of module of swh

Snapshot in Figure 1 shows the input values and computed value of hot water demand at 40^0c for 'D' type of building as 4500 liters. Total installation cost of SWH system, including plumbing was INR 4,90,697.60. Operation, maintenance cost for the lifetime and LCC was found INR 3,24,507.62, INR 8,15,205.22 respectively. The total saving of energy in a lifetime was found 299541.8 kWh. Unit cost of energy (per kWh) saved was found INR 2.72. The total amount of carbon emission prevented during the lifetime of SWH was 101.84MT.

B. Application of module of spv

Snapshot of computed values' window in Figure 2 shows that the array size of 1352.15 Wp was required for 'D' type of building. 19 panels of 74 Wp were required with a tilt angle of 36 ^{0} facing South. The total area of panels required was 16.23 m^2. Battery capacity of 1064 Ah was essential. Inverter of 500 watts was found sufficient. The total installation cost of the SPV system along with the balance of the system was found INR1, 81,247. Total maintenance, replacement costs were INR 1,73,007.87 and INR 7,69,180.53 respectively. The total LCC of this system was found INR 11, 01,934.73. The total amount of energy saving in the life time of 25 years was 98701.2 kWh. Unit cost of energy (per kWh) saved was found INR11.16. The total amount of carbon emission prevented was 4.13 MT.

C. Abstract of results for a cluster of buildings

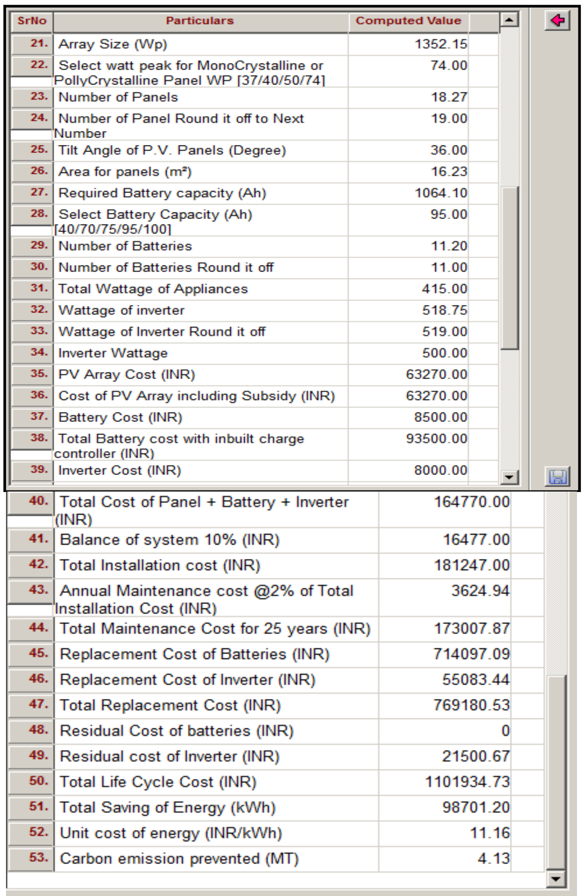
The result in the form of an abstract for a cluster of 'A', 'B', 'C' and 'D' type of buildings was obtained as shown in Table I. The total installation cost of SWH system and SPV system was INR 24,16,295.97 and INR 5,84,254 respectively. LCCs of SWH systems and SPV systems was INR 40,14,238.75 and INR 36,13,325.07 respectively. The unit costs of energy saved per kWh, using SPV and SWH were found as INR 11.21 and INR 2.36. The total energy saved using SWH, SPV was 16,97,576.27 kWh and 322077.6 kWh respectively. The amount of carbon emission prevented using SWHs and SPVs was found 577.17 MT and 13.58 MT respectively. Graphical results were also generated using SRRM tool for LCC of SWH, SPV and unit cost of energy for cluster of housing scheme as shown in Figures 3, 4 and 5.

SrNo	Particulars	Computed Value
1.	Number of clear sunny days per year	117.00
2.	Available terrace area (m²)	378.80
3.	Daily hot water use litre per day per capita for bath	40.00
4.	Temperature of hot water achieved in solar water heater (°C)	60.00
5.	Cold water temperature in Winter (°C)	16.00
6.	Number of days of winter	107.00
7.	Cold water temperature in summer (°C)	30.00
8.	Number of days of summer	167.00
9.	Quality of water (1=Hard 2=Soft 3=Saline 4=Alkaline 5=Acidic 6=Hail Storm)	1.00
10.	Total length of pipe 50 mm dia from SWH to the tap (m)	297.04
11.	Type of pipe (1=PVC 2=GI)	2.00
12.	Subsidy percentage on Capital Cost[%] (INR)	0
13.	Subsidy considering area [INR/m	0
14.	Rate of GI pipe with insulation (INR/m)	440.00
15.	Project life (Yrs.)	20.00
16.	Power Tarrif (INR/kWh)	7.12
17.	Hot water demand for bathing at 40 °C (@ 25 Litre per day per person) (lit)	4500.00

SrNo	Particulars	Computed Value
18.	Add for 20% heat losses in piping & mixing of hot water & cold water (Lit)	900.00
19.	Total Hot water requirement at 40 C (lit)	5400.00
20.	Temperature difference of water (°C)	24.00
21.	Amount of hot water required at 60°C (Lit)	2945.00
22.	Tilt angle of Panel (degrees)	31.00
23.	Collector area m²	30.00
24.	Total Installation cost without subsidy	360000.00
25.	Total subsidy (INR)	0
26.	Subsidy considering m² area	0
27.	Minimum subsidy	0
28.	Installation cost deducting subsidy (INR)	360000.00
29.	Cost of plumbing (INR)	130697.60
30.	Total cost of Installation (INR)	490697.60
31.	Operation & maintenance cost (2 % of installation cost per annum) (INR)	9813.95
32.	Total operation & maintenance cost (INR)	324507.62
33.	Life cycle cost (INR)	815205.22
34.	Electricity saved during summer (kWh/annum)	5901.78
35.	Electricity saved during winter (kWh/annum)	9075.31
36.	Electricity saved per annum (kWh)	14977.09
37.	Total Saving of Energy (kWh)	299541.80
38.	Unit cost of energy (INR/kWh)	2.72
39.	Carbon emisssion prevented (MT)	101.84

Fig 1: Module of SWH: Computed values

SrNo	Particulars	Computed Value
1.	Average annual solar radiation (kWh/m²)	5.31
2.	Available rooftop area (m²)	348.81
3.	Daily lighting demand load (Wh)	4150.00
4.	Rate of solar panel (INR/Wp)	45.00
5.	Rate of 40 (Ah) Battery (INR)	4100.00
6.	Rate of 70 (Ah) Battery (INR)	5000.00
7.	Rate of 75 (Ah) Battery (INR)	6900.00
8.	Rate of 95 (Ah) Battery (INR)	8500.00
9.	Rate of 100 (Ah) Battery (INR)	11600.00
10.	Rate of 500 Watt Inverter (INR)	8000.00
11.	Rate of 800 Watt Inverter (INR)	14940.00
12.	Rate of 1000 Watt Inverter (INR)	16000.00
13.	Rate of 1500 Watt Inverter (INR)	21000.00
14.	Subsidy on Solar Panels(% of Capital Cost of Solar Panels)[INR]	0
15.	Clear sunny days	117.00
16.	Project life (Yrs.)	25.00
17.	Battery life (Yrs.)	5.00
18.	Battery eficiency	0.80
19.	Inverter Life (Yrs.)	8.00
20.	Array Load (Wh)	6102.94



SrNo	Particulars	Computed Value
21.	Array Size (Wp)	1352.15
22.	Select watt peak for MonoCrystalline or PollyCrystalline Panel WP [37/40/50/74]	74.00
23.	Number of Panels	18.27
24.	Number of Panel Round it off to Next Number	19.00
25.	Tilt Angle of P.V. Panels (Degree)	36.00
26.	Area for panels (m²)	16.23
27.	Required Battery capacity (Ah)	1064.10
28.	Select Battery Capacity (Ah) [40/70/75/95/100]	95.00
29.	Number of Batteries	11.20
30.	Number of Batteries Round it off	11.00
31.	Total Wattage of Appliances	415.00
32.	Wattage of inverter	518.75
33.	Wattage of Inverter Round it off	519.00
34.	Inverter Wattage	500.00
35.	PV Array Cost (INR)	63270.00
36.	Cost of PV Array including Subsidy (INR)	63270.00
37.	Battery Cost (INR)	8500.00
38.	Total Battery cost with inbuilt charge controller (INR)	93500.00
39.	Inverter Cost (INR)	8000.00
40.	Total Cost of Panel + Battery + Inverter (INR)	164770.00
41.	Balance of system 10% (INR)	16477.00
42.	Total Installation cost (INR)	181247.00
43.	Annual Maintenance cost @2% of Total Installation Cost (INR)	3624.94
44.	Total Maintenance Cost for 25 years (INR)	173007.87
45.	Replacement Cost of Batteries (INR)	714097.09
46.	Replacement Cost of Inverter (INR)	55083.44
47.	Total Replacement Cost (INR)	769180.53
48.	Residual Cost of batteries (INR)	0
49.	Residual cost of Inverter (INR)	21500.67
50.	Total Life Cycle Cost (INR)	1101934.73
51.	Total Saving of Energy (kWh)	98701.20
52.	Unit cost of energy (INR/kWh)	11.16
53.	Carbon emission prevented (MT)	4.13

Fig. 2: Module of solar PV: Computed values

TABLE I
ABSTRACT OF RESULTS FOR CLUSTER OF BUILDINGS, 'A', 'B', 'C', 'D'

Sr. No.	Particulars	Conservation of energy		Grand total
		P.V. Generating electricity	Solar water heater	
1.	Total cost of installation (INR)	584254	2416295	3000549.9
2.	Total maintenance cost (INR)	557694.9	1597942	2155637.6
3.	Total replacement cost (INR)	2557378	Nil	2557378.7
4.	Life cycle cost (INR)	3613325.	4014238	7,627,563
5.	Total saving of energy (kWh)	322077.6	1697573	2019650.8
6.	Carbon emission prevented (MT)	13.58	577.17	590.75
7.	Unit cost of energy (INR/kWh)	11.21	2.36	----

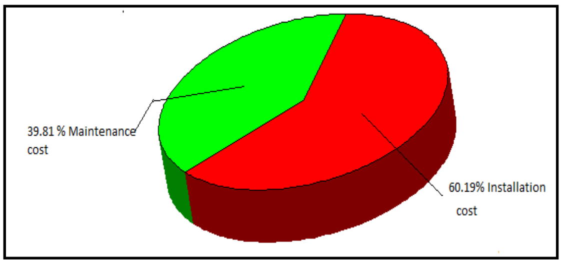


Fig. 3: LCC of SWH for a cluster of buildings (A, B, C, D)

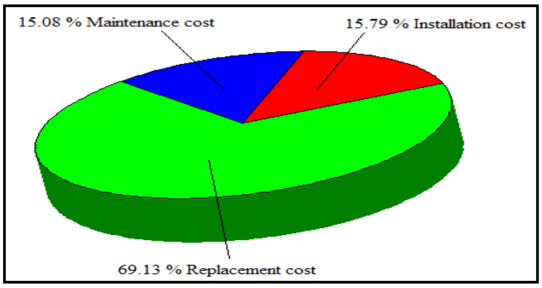


Fig. 4: LCC of solar PV for a cluster of buildings (A, B, C, D)

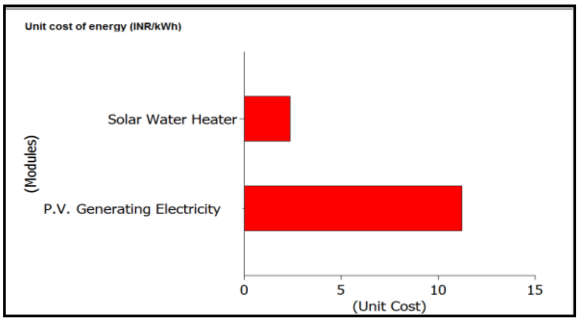


Fig. 5: Unit cost of energy

D. Application of module of wind turbine

For the selected case study of residential apartment buildings in the city of Nagpur annual mean wind velocity is 1.7 m/sec, less than 4m/sec, which is the minimum wind speed requirement for the economic feasibility of electricity generation using rooftop wind turbines [25, 26].

Snapshot in Figure 6 shows the computed values of Weibull parameters for the selected WT model of rated output power of 4800 Watt-hr /day. 11 batteries of 95 Ah and one inverter of 500 Watt were required. The total installation cost of this system was INR 1,98,500. Total operational, replacement costs were INR 1,42,107.44, INR 10,63,220.51 respectively. The total LCC was found INR 13,42,627.28. The amount of energy and carbon emission saved during the lifetime was found as 42047 kWh and 12.88 MT. Unit cost of energy saved using WT was found INR 31.93.

Similar computed values were obtained for the module of hybrid energy (SPV + WT). The total installation cost and LCC of the hybrid system (SPV + WT) was INR 1,97,291.60 and INR 11,11,582.02 respectively. Saving in energy was 56675.86 kWh. Unit cost of energy saved using wind energy was computed as INR 19.61. This system saved carbon emission of 19.27 MT.

The unit cost of energy using SWH and solar PVs for lighting, common spaces of housing scheme was found INR 2.36/ kWh, 11.22 INR/ kWh respectively. The area of terrace required for SPV panels and SWH collectors was only 13.52% of the available terrace area. With the increase in prices of natural gas, oil and electricity, the future of using sustainable technologies looks brighter. In future due to the increased demand of sustainable technologies more industries will get set up decreasing the cost of these technologies. Cost reduction on the installation side will come primarily from scale benefits.

SrNo	Particulars	Computed Value
1.	Anemometer height (ho) (m)	10.00
2.	Mean wind speed at anemometer height Vo(m/s) (If mean Wind Speed < 4 m/s then use of Wind Turbine not feasible)	6.54
3.	Standard deviation of wind velocity for the Place/city	0.63
4.	Demand Load [Watts-Hr / Day]	4150.00
5.	Select a wind turbine having o/p (Watts.hr/day)	4800.00
6.	Cut in speed (Vc) (m/s)	1.20
7.	Rated velocity (Vr) (m/s)	3.90
8.	Cut out speed (Vf) (m/s)	25.00
9.	Rated electrical power Pr (Watt-H)	4800.00
10.	Height of Hub (hm) (m)	20.00
11.	Wind Turbine Cost (INR)	48000.00
12.	Cost of Pole (INR)	2500.00
13.	Life of wind Turbine (Yrs.)	25.00
14.	Battery Life (Yrs.)	5.00
15.	Cost of Battery (INR)	12000.00
16.	Inverter Life (Yrs.)	8.00
17.	Cost of Inverter (INR)	8000.00
18.	Roughness coefficient	0.22
19.	Velocity At hub ht(Vm) (m/s)	7.62
20.	Weibull parameters-Shape factor (k)	14.99
21.	Weibull parameters-Scale factor(c o)m/s	7.71
22.	Weibull parameters-Exponent (n)	0.19
23.	Weibull parameters-Scale factor (Ch) m/s	8.80
24.	Weibull parameters-Shape factor (kh)	15.96
25.	Average Power o/p of wind turbine (Pav)	4799.99
26.	Check	4799.99
27.	Select battery voltage (Volt)(12/24/48)	12.00
28.	Backup days	1.00
29.	Storage capacity (Amp.-Hr)	1064.10
30.	Select battery (Ah)	95.00
31.	No. of batteries	11.20
32.	Batteries-Round it off	11.00
33.	Select Inverter (Wattage)(500/1000/2000)	500.00
34.	Wind turbine cost (INR)	56000.00
35.	Cost of pole (INR)	2500.00
36.	Battery cost (INR)	132000.00
37.	Inverter cost (INR)	8000.00
38.	Total Installation Cost (INR)	198500.00
39.	Operation and Maintenance cost/annum(1.5% of Installation Cost)	2977.50
40.	Total operational & Maintenance cost during lifetime (INR)	142107.44
41.	Replacement Cost-Batteries (INR)	1008137.07
42.	Replacement Cost-Inverter (INR)	55083.44
43.	Total replacement cost (INR)	1063220.51
44.	Residual Costs- Wind Turbine (20% of Inst.n Cost)(INR)	39700.00
45.	Residual Costs-Batteries (INR)	0
46.	Residual Costs-Inverter (INR)	21500.67
47.	Total Residual Cost (INR)	61200.67
48.	Total Life Cycle Cost (INR)	1342627.28
49.	Total Electricity Saved (kWh)	37868.00
50.	Wind turbine Pr (Watt-H/day)	4150.00
51.	Battery voltage (V)	12.00
52.	Inverter Wttage	500.00
53.	Installation cost (INR)	198500.00
54.	LCC (INR)	1342627.28
55.	Total Saving of Energy (kWh)	42047.91
56.	Unit cost of energy (INR/kWh)	31.93
57.	Carbon emisssion prevented (MT)	12.88

Fig. 6: Module of wind turbine for lighting

V. CONCLUSION

This study showed that in composite climatic zones of India with locations having daily average solar radiation of 5.135 kWh/m^2, use of thermosyphonic solar water heater was technically efficient, which do not require electricity. Choice of evacuated/flat plate collector for solar water heater depended upon the climatic conditions of a place and the quality of water. For hard water ETC and for soft water FPC was found suitable. In cold regions SWH with heat exchanger was found useful. Solar water heater shows a great potential of saving carbon emission.

Use of crystalline solar photovoltaic solar panels is efficient and polycrystalline panels are economically viable. Rooftop horizontal axis wind turbine was found a matured technology for generating electricity. Rooftop wind turbines were found economically beneficial for wind speeds more than 4 m/sec. Use of a combination of solar photovoltaic panels and wind turbines was found possible only when the intensity of wind is more than 4 m/sec.

Total estimated cost of Bhamti housing scheme was 29 crores. The amount required towards energy conservation techniques was found only 10% of the construction cost. The developed SRRM tool is indigenous, does not require complex input data and simulation time. The LCC analysis approach of the tool gave insight into the economics of the designed sustainable technologies throughout the lifetime. SRRM tool is useful for stakeholders to plan and take decisions for the integration of sustainable technologies into residential apartment buildings.

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